METROLOGY SYMPOSIUM

DIGITALIZATION AND AUTOMATION IN MASS METROLOGY

Third Edition: Future and New Solutions

RADWAG

ČESKÝ METROLOGICKÝ INSTITUT

The influence of ambient conditions on calibration of mass standards

METROLOGY SYMPOSIUM

DIGITALIZATION AND AUTOMATION IN MASS METROLOGY

Third Edition: Future and New Solutions

Presenter

Michał Solecki PhD Eng.

A mass comparator manager for technical issues

RADWAG ČMI ČESKÝ METROLOGICKÝ INSTITUT **16-18.04.2024**, Radom, Poland

Introduction

The following presentation focuses on the **study of mass comparators and the possibility to reduce the influence of environmental factors**, including temperature, humidity, vibrations, air flow as well as the magnetism, on the procedure of mass standard calibration.

By analysing the mentioned variables, we strive to increase the precision and stability of the measurement results under laboratory conditions.

The ambient conditions affecting the performance of mass comparator and correctness of the obtained results

Requirements according to OIML R111

Temperature

Weight class	Temperature change during calibration (2)
E_1	± 0.3 °C per hour with a maximum of ± 0.5 °C per 12 hours
E_2	± 0.7 °C per hour with a maximum of ± 1 °C per 12 hours
F_1	± 1.5 °C per hour with a maximum of ± 2 °C per 12 hours
F_2	± 2 °C per hour with a maximum of ± 3.5 °C per 12 hours
M_1	± 3 °C per hour with a maximum of ± 5 °C per 12 hours

Humidity

Weight class	Range of relative humidity (*hr*) of the air (3)
E_1	40 % to 60 % with a maximum of ± 5 % per 4 hours
E_2	40 % to 60 % with a maximum of ± 10 % per 4 hours
F	40 % to 60 % with a maximum of ± 15 % per 4 hours

Magnetism

Weight class	E_1	E_2	F_1	F_2	M_1	M_{1-2}	M_2	M_{2-3}	M_3
Maximum polarization, $\mu_0 M$, (μT)	2.5	8	25	80	250	500	800	1 600	2 500

Weight class	E_1	E_2	F_1	F_2
$m \leq 1$ g	0.25	0.9	10	-
2 g $\leq m \leq$ 10 g	0.06	0.18	0.7	4
20 g $\leq m$	0.02	0.07	0.2	0.8

Air flow

No requirements in OIML R111

Vibrations

No requirements in OIML R111

Devices subject to evaluation

Manual comparator

Resolution: 50 million units

Maximum capacity [Max]:	6,1 g
Readability [d]:	0,1 ug

Robotic comparator

Resolution: 1 billion units

Maximum capacity [Max]:	1020 g
Readability [d]:	1 ug

Vacuum comparator

Resolution: 10 billion units

Maximum capacity [Max]:	1002 g
Readability [d]:	0,1 ug

Ambient conditions measuring instruments. The measurement of temperature, humidity and pressure

The THB sensor is intended for measuring such parameters as temperature, humidity, pressure and air density calculation.

Temperature reading [d]	0.001 °C
Range of the measured pressure	+/- 0.1 °C
Range of the measured pressure	850 -1050 hPa
Pressure reading [d]	0.001 hPa
Pressure measurement accuracy	1 hPa
Rande of the humidity measured	0-100 %
Working temperature	+5 – +45 °C
Humidity reading [d]	0.01 %
Humidity measurement accuracy	+/- 1.8 %
Interface	USB 2.0
Vibrations detection	YES
Air density measurement	YES
Temperature measurement range	+5 – +45 °C

Ambient conditions measuring instruments. Air flow measurement

The air flow indicator informs the user about the permissible air flow level in m/s.

The more precise the scale or comparator, the smaller range of allowable air flow.

Parameters measurement

- Measurement range – **0,01 m/s do 1,5 m/s**
- Measurement range – **0-100%**
- Measurement resolution – **0,01 m/s / 1%**
- Temperatures range – **15 do 35°C**

Software specification

Results presentation

- diagram in PC application
- digital value on the small display on the sensor module

Communication interface – USB 2.0

Ambient conditions measuring instruments. Vibrations measurement

This is much more difficult than measuring other environmental conditions because vibrations are characterized by amplitude and frequency. We cannot describe them with one value. They can be represented as displacement, velocity or acceleration. Using the acceleration value, it is easy to calculate the disturbing force that directly affects the weighing pan. Vibration is usually measured as the average RMS value, in mm/s^2 over a specific frequency range.

Accelerometer - 393B04 model of PCB Piezotronics company	
Sensitivity	102mV/(m/s^2)
Measurement range	+/-49m/s^2 pk
Frequency range (+/-5%)	0.06 to 450Hz
Frequency range (+/-10%)	0.05 to 750Hz
Frequency range (+/- 3dB)	0.02 to 1700Hz
Wideband resolution (1 to 10000Hz)	0.03mm/s^2 rms
Signal conditioner - 485B39 model of PCB Piezotronics company	
Frequency range (+/-5%)	0.8 to 20700Hz
Frequency range (+/- 3dB)	0.25 to 22900Hz
Internal transducer A/C	24bit
Parameters measurement	
Measurement range	1.5mm/s^2 to 10000mm/s^2
Measurement resolution	0.1mm/s^2 rms
Frequency range (+/-5%)	0.25Hz to 495Hz

Ambient conditions measuring instruments. Measurement of mass standards magnetism

The magnetism of the standards tested is also a parameter that impacts the correctness of the obtained results. When the standards are magnetic, it will affect the comparator and the results will be incorrect, therefore the magnetic susceptibility and polarization (residual magnetism) of the standards tested should be verified.

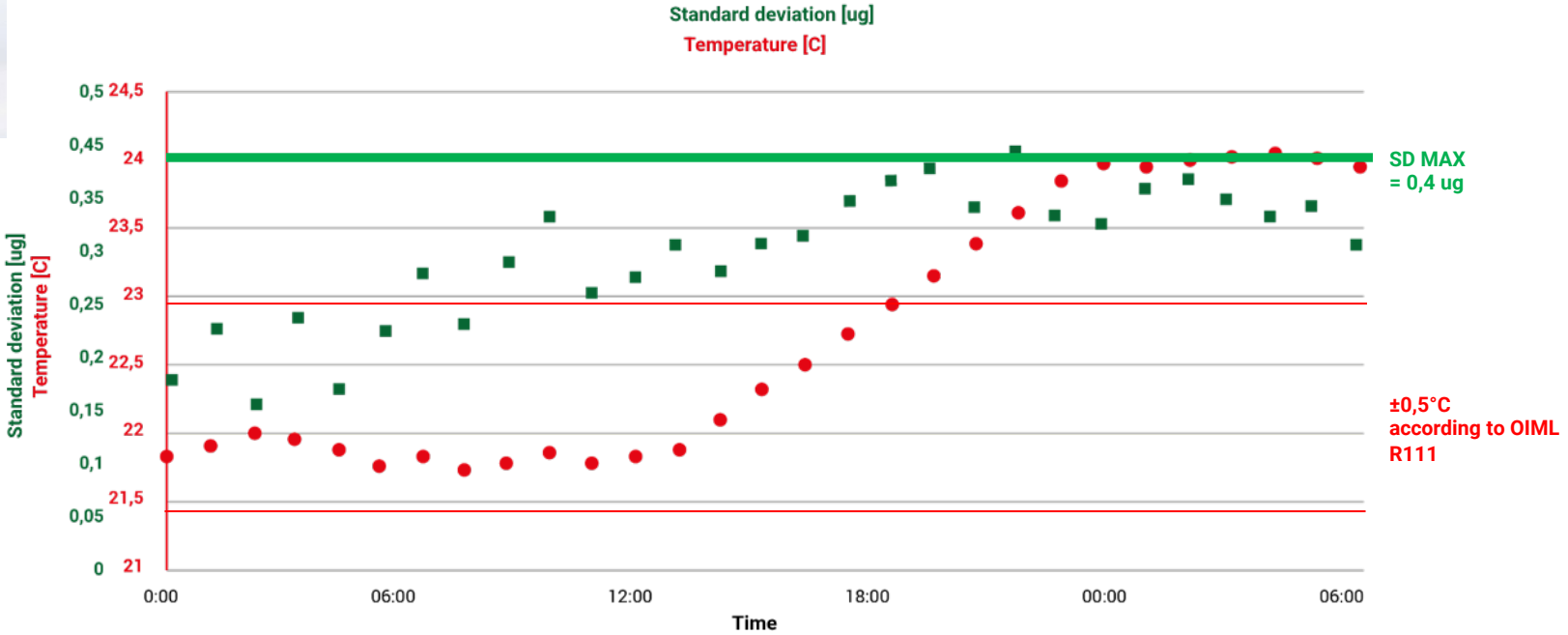
E1 Calibration Range	1 g- 50 kg
E2 Calibration Range	1 g- 50 kg
F1 Calibration Range	1 g- 50 kg
F2 Calibration Range	1 g- 50 kg
Maximum capacity [Max]	50 kg
Readability [d]	1 ug
Stabilization time	10 s
Calibration Range	1 g- 50 kg
Distance platform Z0	20; 27; 43 mm
Magnetizing field strenght	2000; 800; 200 A/m
Weighing pan dimensions	ø300 mm

Temperature

Temperature stability is one of the key factors influencing the operation of mass comparators, mainly due to the material expansion of the elements of which the weighing modules of mass comparators are made. The best solution would be to build a measuring instrument made of uniform material, but this is practically impossible. The higher the resolution of the device, the greater the errors resulting from the dynamic temperature changes.

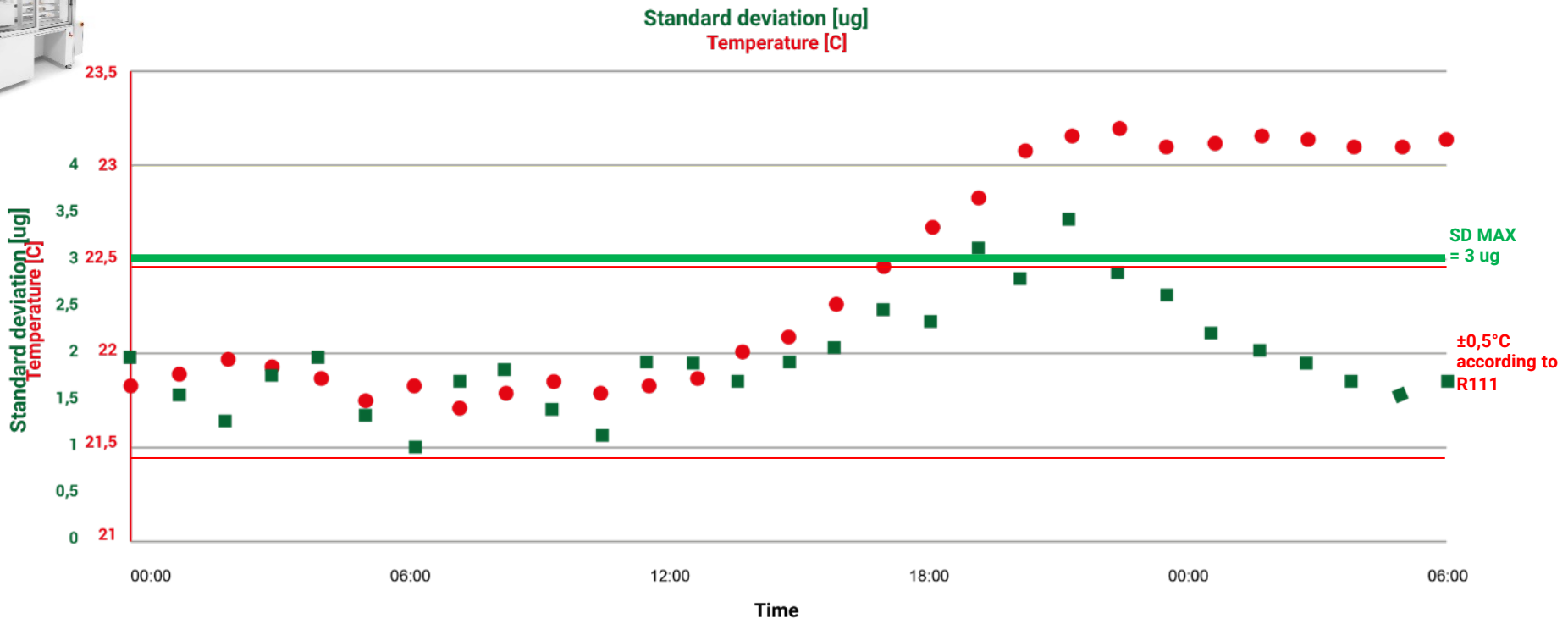
Weight class	Temperature change during calibration (2)
E_1	± 0.3 °C per hour with a maximum of ± 0.5 °C per 12 hours
E_2	± 0.7 °C per hour with a maximum of ± 1 °C per 12 hours
F_1	± 1.5 °C per hour with a maximum of ± 2 °C per 12 hours
F_2	± 2 °C per hour with a maximum of ± 3.5 °C per 12 hours
M_1	± 3 °C per hour with a maximum of ± 5 °C per 12 hours

The influence of dynamic temperature change on the operation of the manual comparator with the resolution of 50 million reading units and a maximum capacity of 6 g



The comparator tested by using an internal adjustment standard during weekend without the presence of people and with a programmed temperature change, showed a slight increase in repeatability by the dynamic temperature change. Due to its structure and lower resolution (50 million units), the comparator is quite resistant to sudden temperature changes.

The influence of dynamic temperature change on the operation of the robotic comparator with the resolution of 1 billion reading units and a maximum capacity of 1000 g



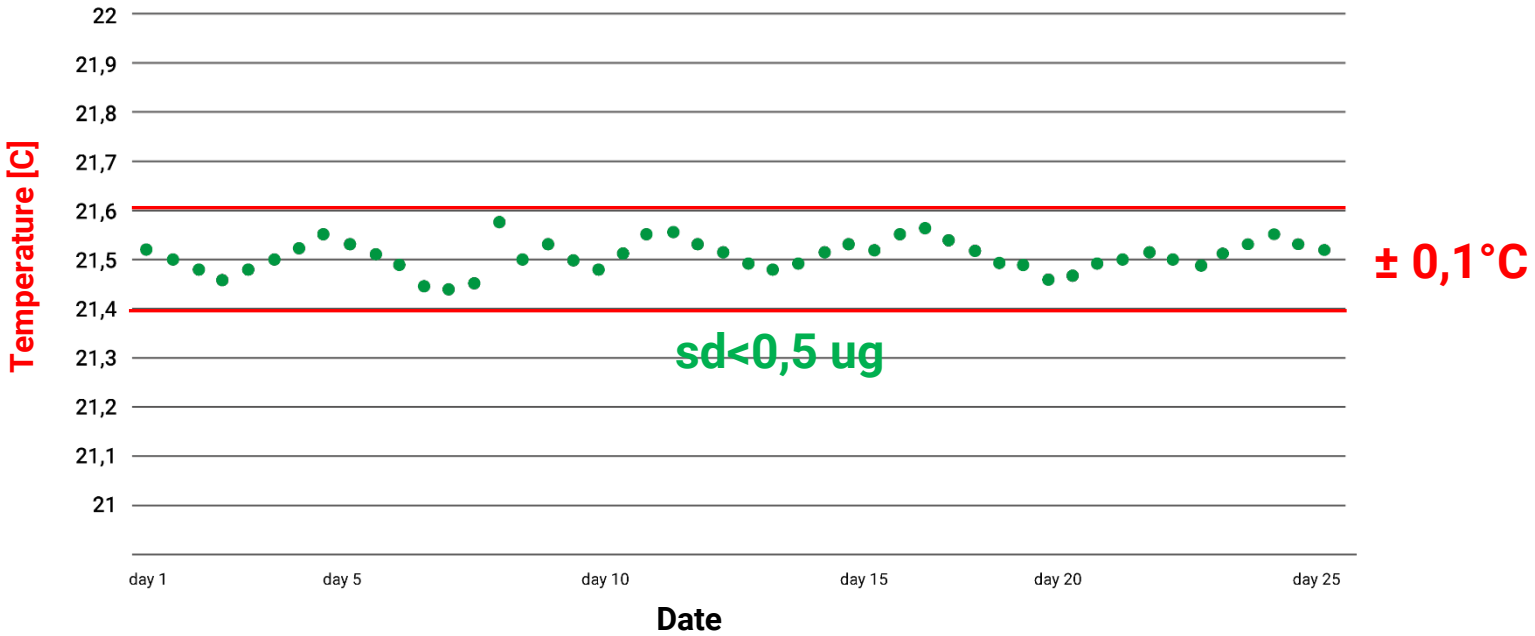
The influence of dynamic temperature change on the operation of the robotic comparator with the resolution of 1 billion reading units and a maximum capacity of 1000 g

CONCLUSIONS:

- Analyzing the obtained results, it can be noticed that when the temperature remained within the range consistent with the requirements for E1 class according to OIML R111, the repeatability of the comparator was much lower than declared by the manufacturer (about 1.5 ug).
- After a significant dynamic increase in temperature by approximately 1.2 C, the repeatability temporarily deteriorated to approximately 3.3 ug.
- After stabilizing the temperature at a new level, the repeatability dropped dramatically to values identical to those before the dynamic increase.

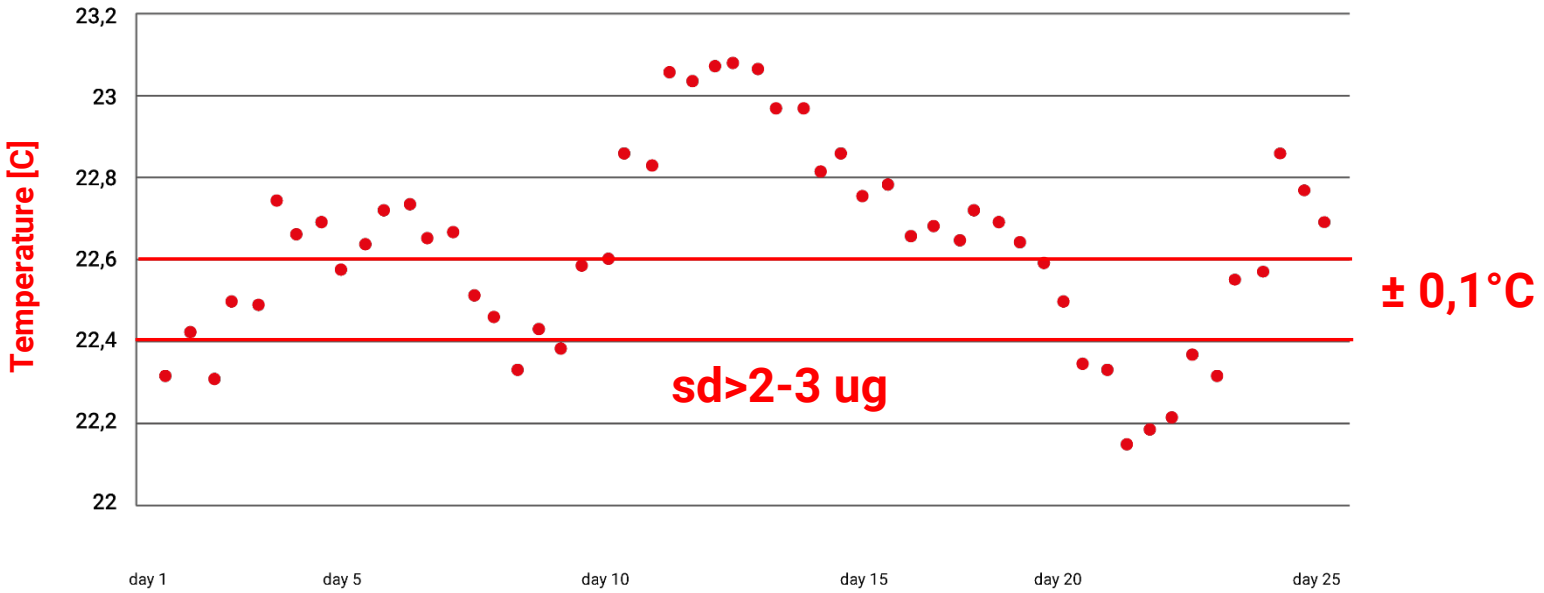
The influence of dynamic temperature change on the operation of the comparator with a resolution of 10 billion units and a maximum capacity of 1000 g (vacuum comparator)

Correct temperature distribution



The influence of dynamic temperature change on the operation of the automatic comparator with a resolution of 10 billion units and a maximum capacity of 1000 g (vacuum comparator)

Incorrect temperature distribution

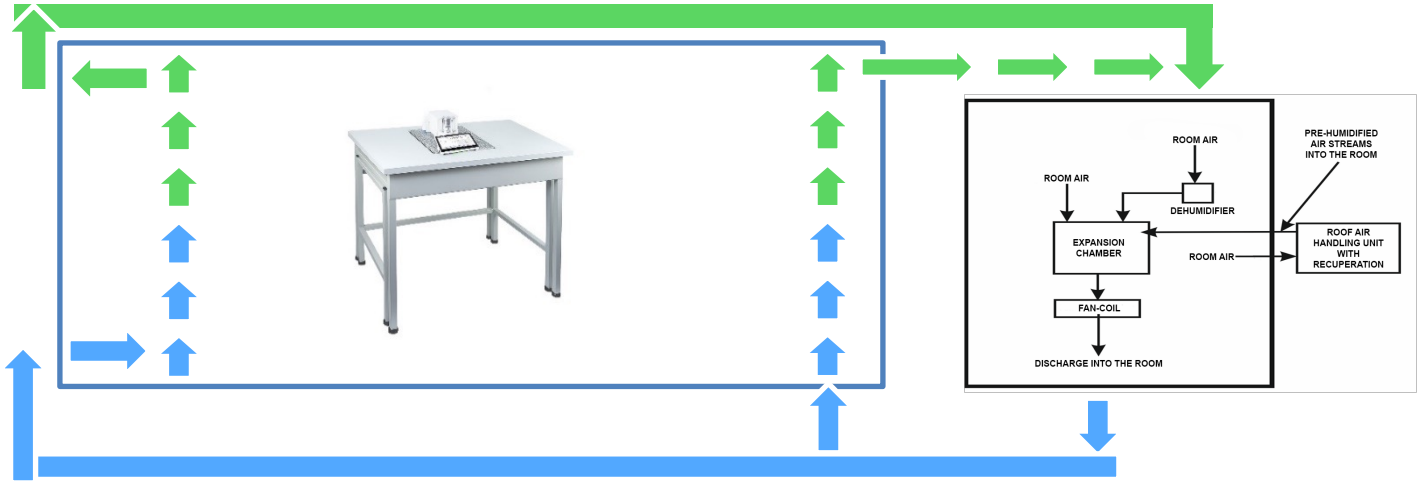


The influence of dynamic temperature change on the operation of the automatic comparator with a resolution of 10 billion units and a maximum capacity of 1000 g (vacuum comparator)

For a vacuum comparator, the temperature range must be constant throughout the entire operation time of the comparator. Temperature changes greater than the +/- 0.1 C range cause significant increase in the zero drift as well as the repeatability of the comparator, as can be seen from the graph even 5-6 times.

Recommendations to improve the impact of the temperature changes on measurements

- Purchase of a dedicated device to continuously monitoring environmental conditions
- Providing a better temperature control system such as laminar air conditioning



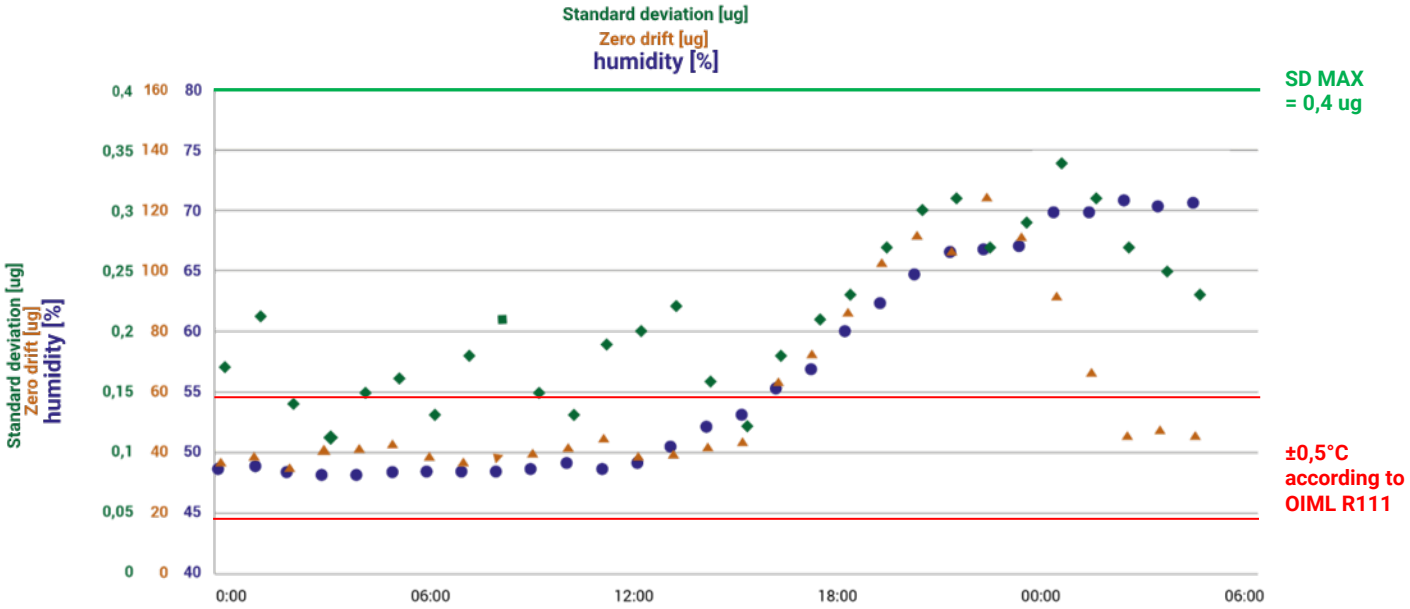
- Limiting the number of personnel in the laboratory room during measurements, each person is 200-300 W

Humidity

Dynamic changes in humidity are another very important factor affecting the accuracy of measurements. Due to a sudden large change in humidity, mechanical elements absorb moisture (sorption), changing their mass. The comparator begins to show this in the form of a zero drift, the higher the resolution of the measuring device, the greater the drift.

Weight class	Range of relative humidity (*hr*) of the air (3)
E_1	40 % to 60 % with a maximum of ± 5 % per 4 hours
E_2	40 % to 60 % with a maximum of ± 10 % per 4 hours
F	40 % to 60 % with a maximum of ± 15 % per 4 hours

The influence of dynamic humidity change on the operation of the manual comparator with a resolution of 50 million reading units and a maximum capacity of 6 g



The influence of dynamic humidity change on the operation of the manual comparator with a resolution of 50 million reading units and a maximum capacity of 6 g

The comparator tested by using an internal adjustment standard during a weekend without the presence of people and with a programmed change in relative air humidity, showed a slight increase in repeatability by a dynamic change of humidity. Similarly to temperature change, the comparator showed quite high resistance to sudden changes in relative humidity.

The influence of dynamic humidity change on the operation of the robotic comparator with a resolution of 1 billion units and a maximum capacity of 1000 g

The influence of dynamic humidity change on the operation of the robotic comparator with a resolution of 1 billion units and a maximum capacity of 1000 g

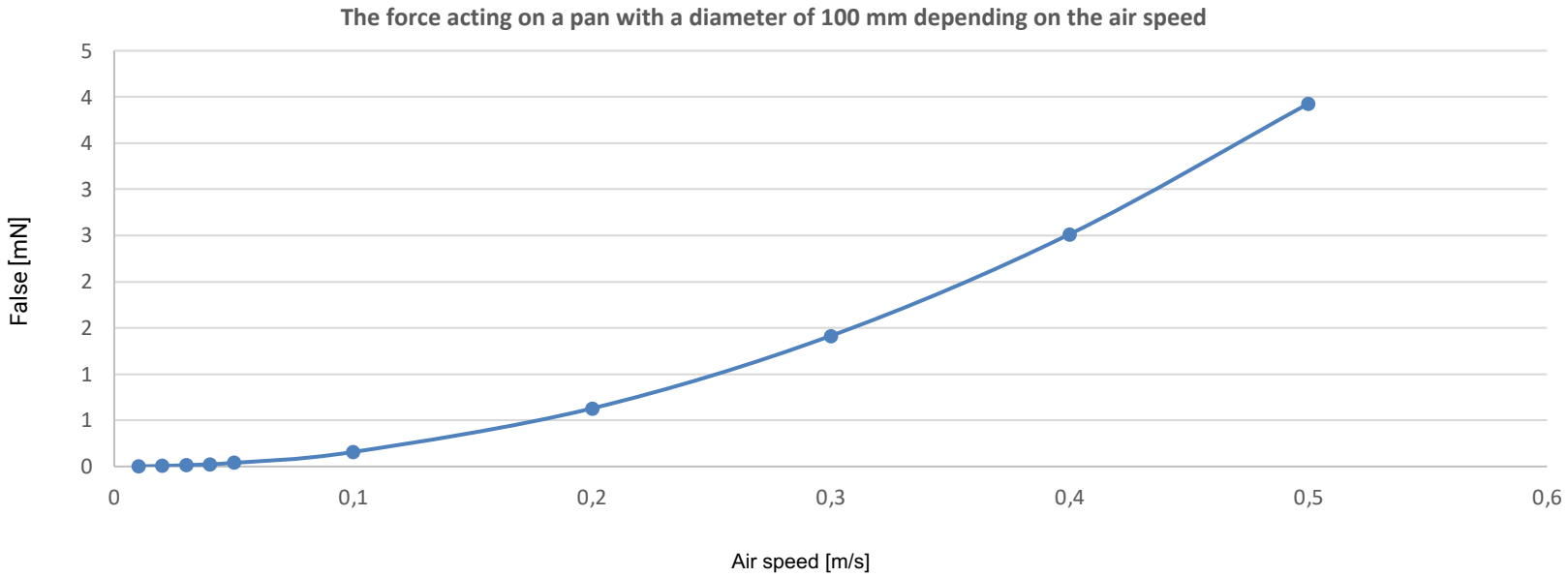
At the relative humidity increase in the weighing chamber, a correlated increase in the zero drift of the comparator can be observed, obviously shifted of the time constant needed for the mechanism to respond. When the increase in humidity is constant, there is no significant increase in the repeatability of the results, but when the humidity suddenly changes the trend and the zero drift also changes the value, then the repeatability increases slightly.

Recommendations to improve the impact of the humidity changes on measurements

- Purchase of a dedicated device to continuously monitoring environmental conditions
- **Humidity control in the laboratory by using dehumidifiers or air humidifiers, depending on needs.**
- The use of automatic comparators which are located under covers during measurements, where moisture sorption is limited and slower due to the weighing chambers not being opened.

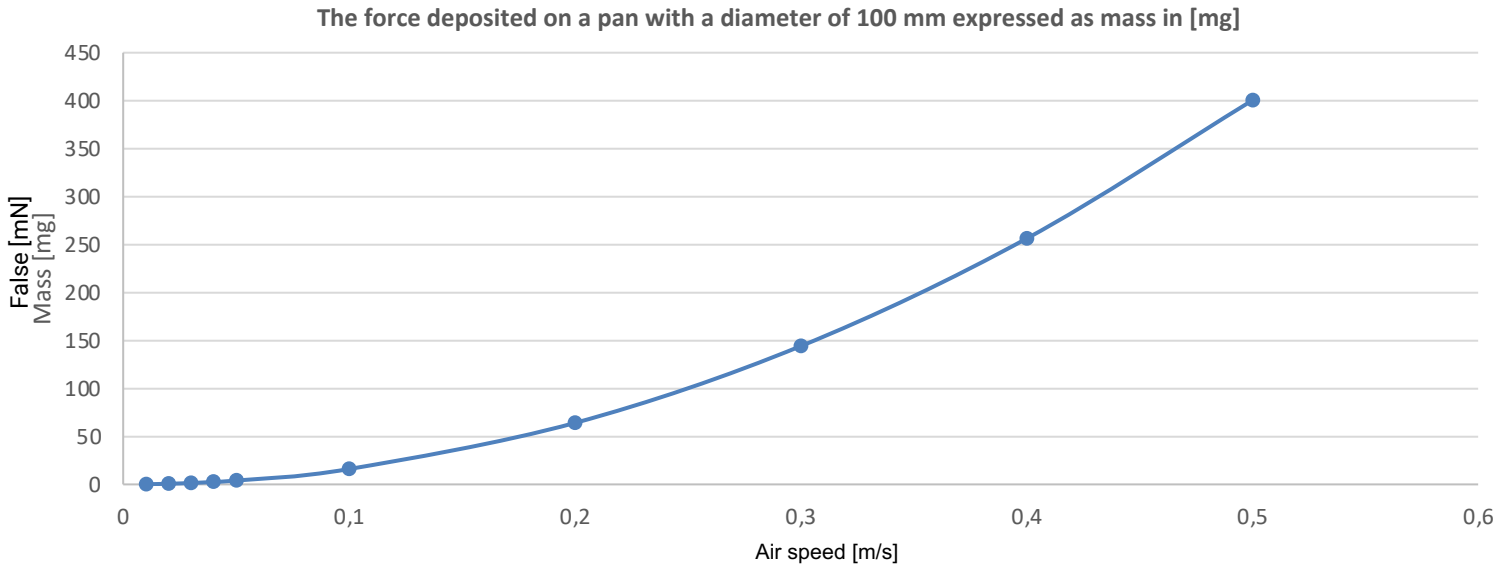
Air flow

Air drifts during a series of measurements are the reason of the lack of repeatability and large dispersion of the results obtained. They also cause the extension of the measurement process due to difficulties in obtaining the measurement stability.



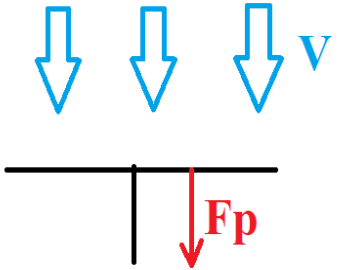
Air flow

Air drifts during a series of measurements are the reason of the lack of repeatability and large dispersion of the results obtained. They also cause the extension of the measurement process due to difficulties in obtaining the measurement stability.



Air flow

Air drifts during a series of measurements are the reason of the lack of repeatability and large dispersion of the results obtained. They also cause the extension of the measurement process due to difficulties in obtaining the measurement stability.



$$F_p = 2 \cdot \rho_p \cdot v^2 \cdot S$$

ρ_p – air density

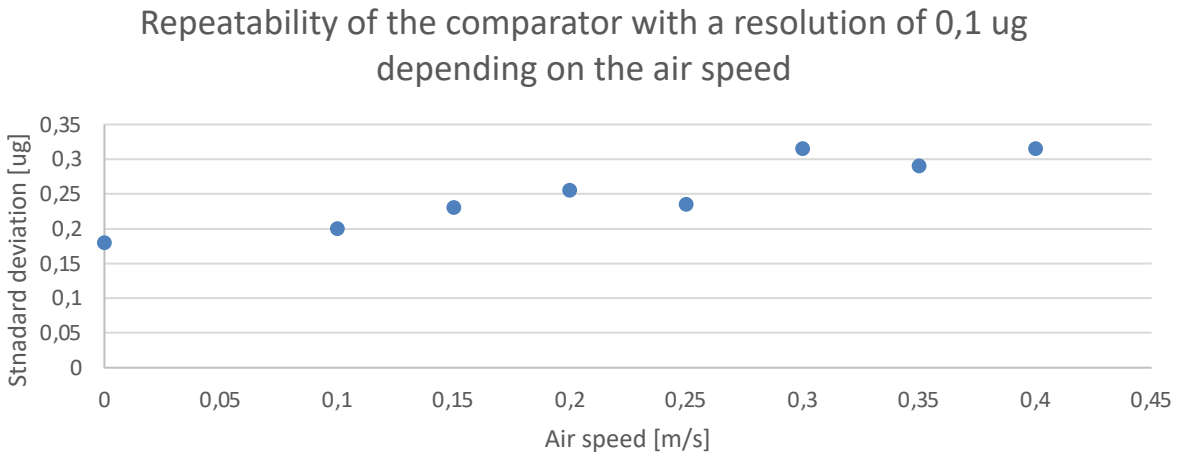
v – air speed

S – pan surface

Air speed [m/s]

The influence of air drift on the operation of a manual comparator with the resolution of 50 million units and maximum capacity of 6 g

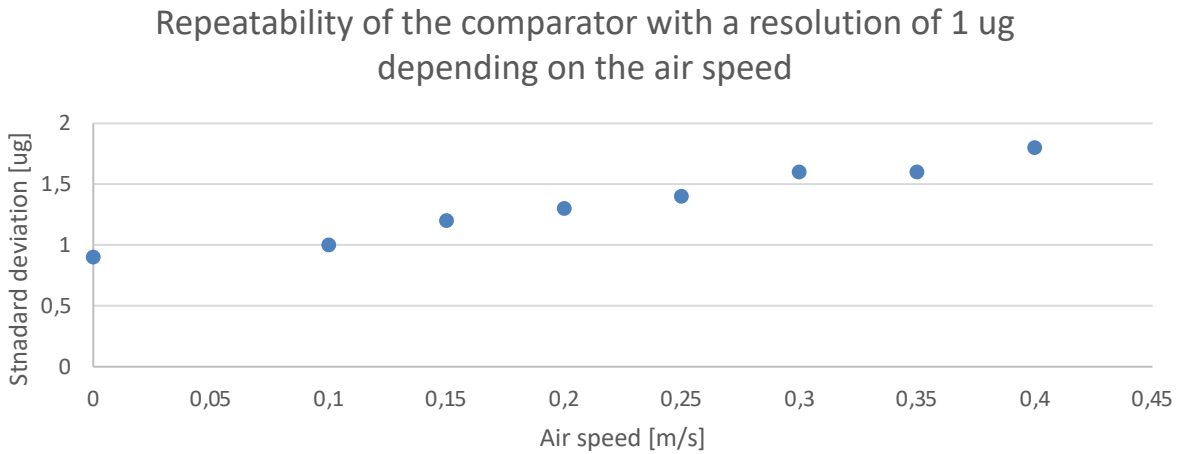
The test was carried out on a special measurement station where the air movement was forced at a specific speed V.
The test carried out on two models of scales, one with a resolution of **1 ug**, the other with a resolution of **0.1 ug**.
As you can see, the repeatability of the comparator increases almost linearly to the increase of air movement.



As you can see, the repeatability of the comparator increases almost linearly with the increase in air movement.

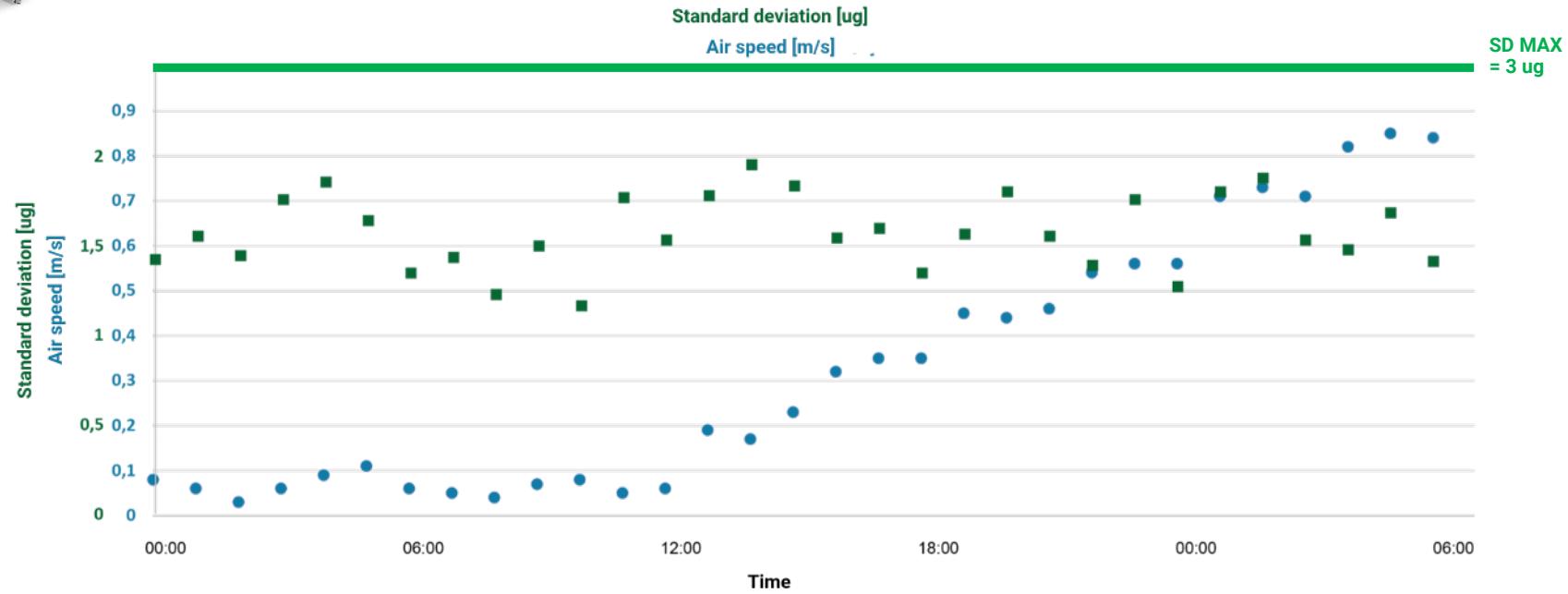
The influence of air drift on the operation of a manual comparator with the resolution of 50 million units and maximum capacity of 6 g

The test was carried out on a special measurement station where the air movement was forced at a specific speed V. The test carried out on two models of scales, one with a resolution of **1 ug**, the other with a resolution of **0.1 ug**. As you can see, the repeatability of the comparator increases almost linearly to the increase of air movement.



As you can see, the repeatability of the comparator increases almost linearly with the increase in air movement.

The influence of air flow on the operation of a robotic comparator with the resolution of 1 billion units and maximum capacity of 1000 g

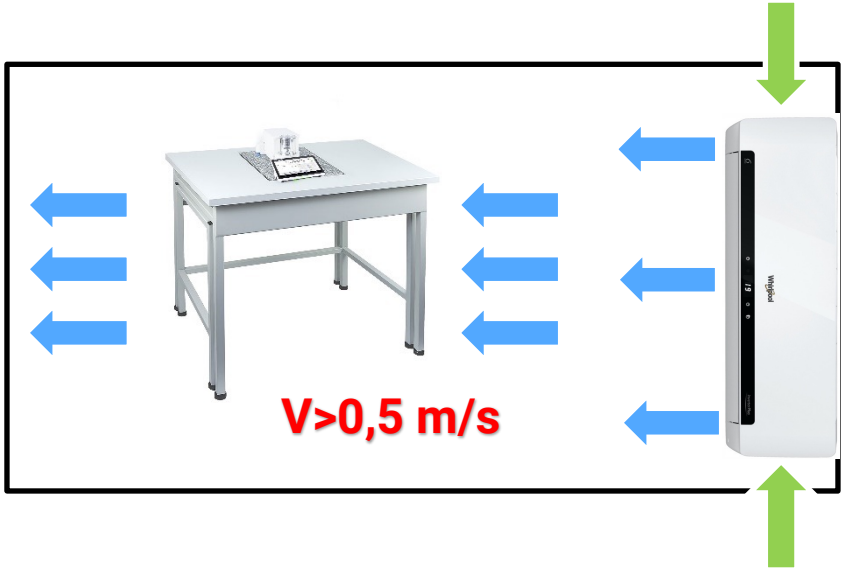


The influence of air flow on the operation of a robotic comparator with the resolution of 1 billion units and maximum capacity of 1000 g

There is no visible influence of air movement on the repeatability of the comparator. This is caused by the double cover (weighing chamber and main cover of the robot), and mainly by not opening the weighing chamber during measurement due to the connectionof the automatic comparator with the robotic system.

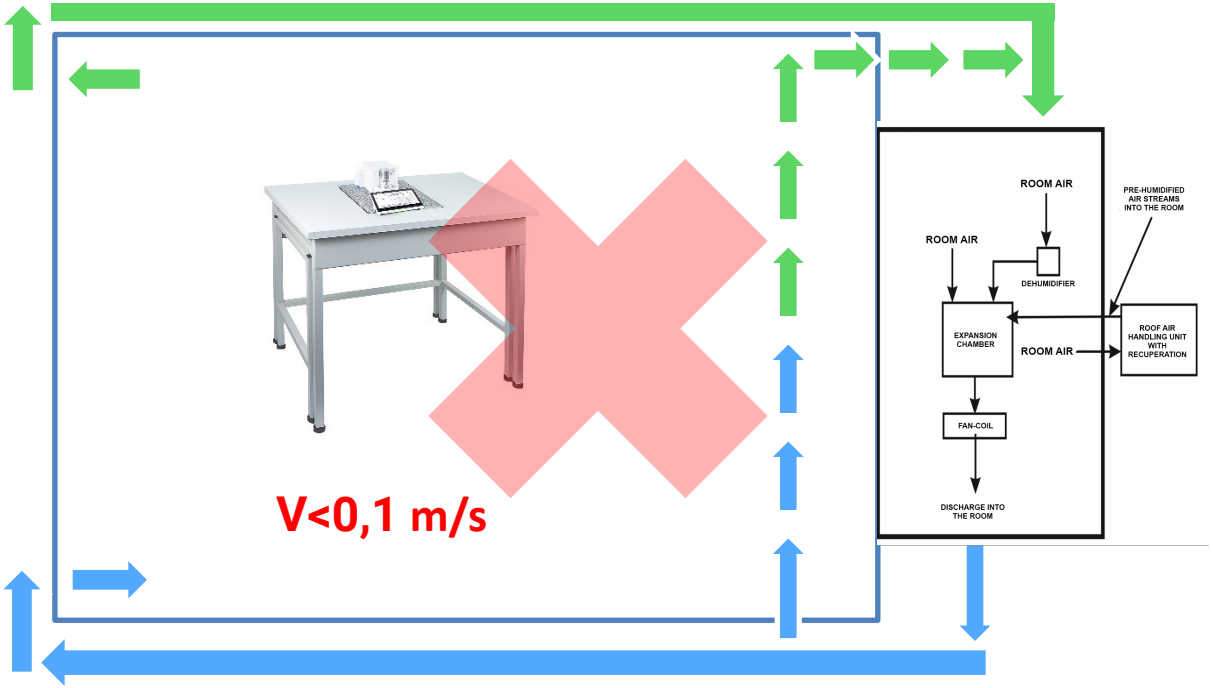
Recommendations to improve the impact of air movement on measurements

In order to reduce the air movement the best solution is to use a laminar air conditioning or other of similar design.



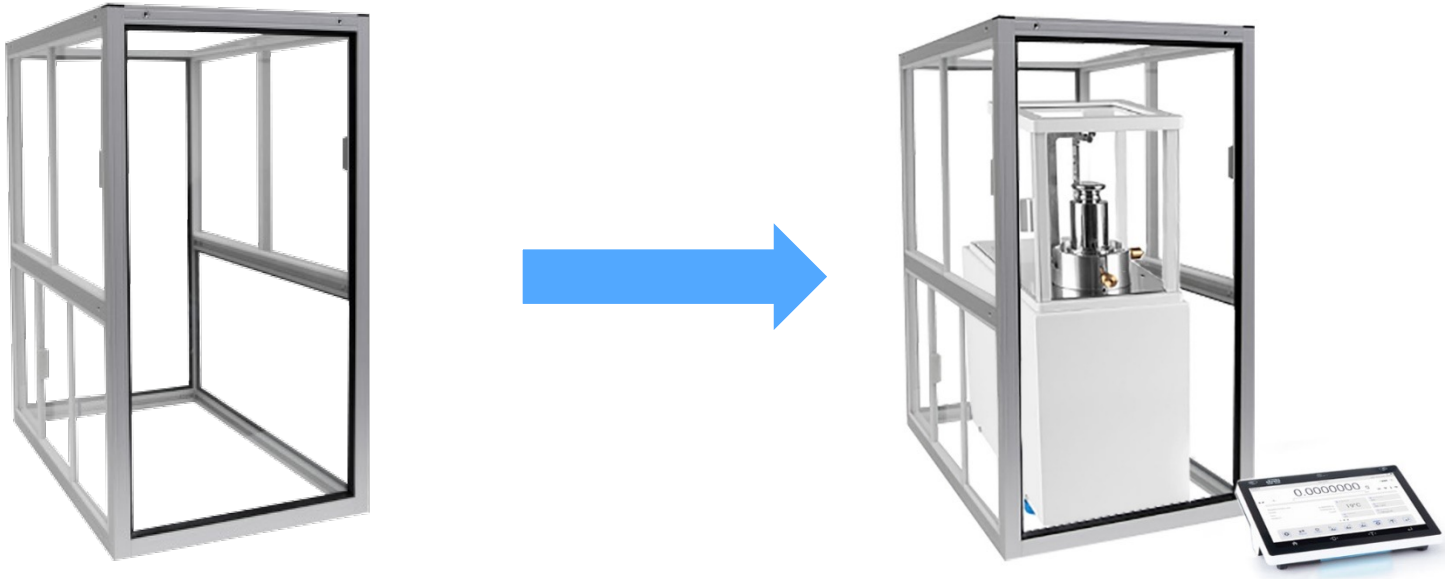
Recommendations to improve the impact of air movement on measurements

In order to reduce the air movement the best solution is to use a laminar air conditioning or other of similar design.



Recommendations to improve the impact of air movement on measurements

- Use of anti-draft shields on used measuring devices



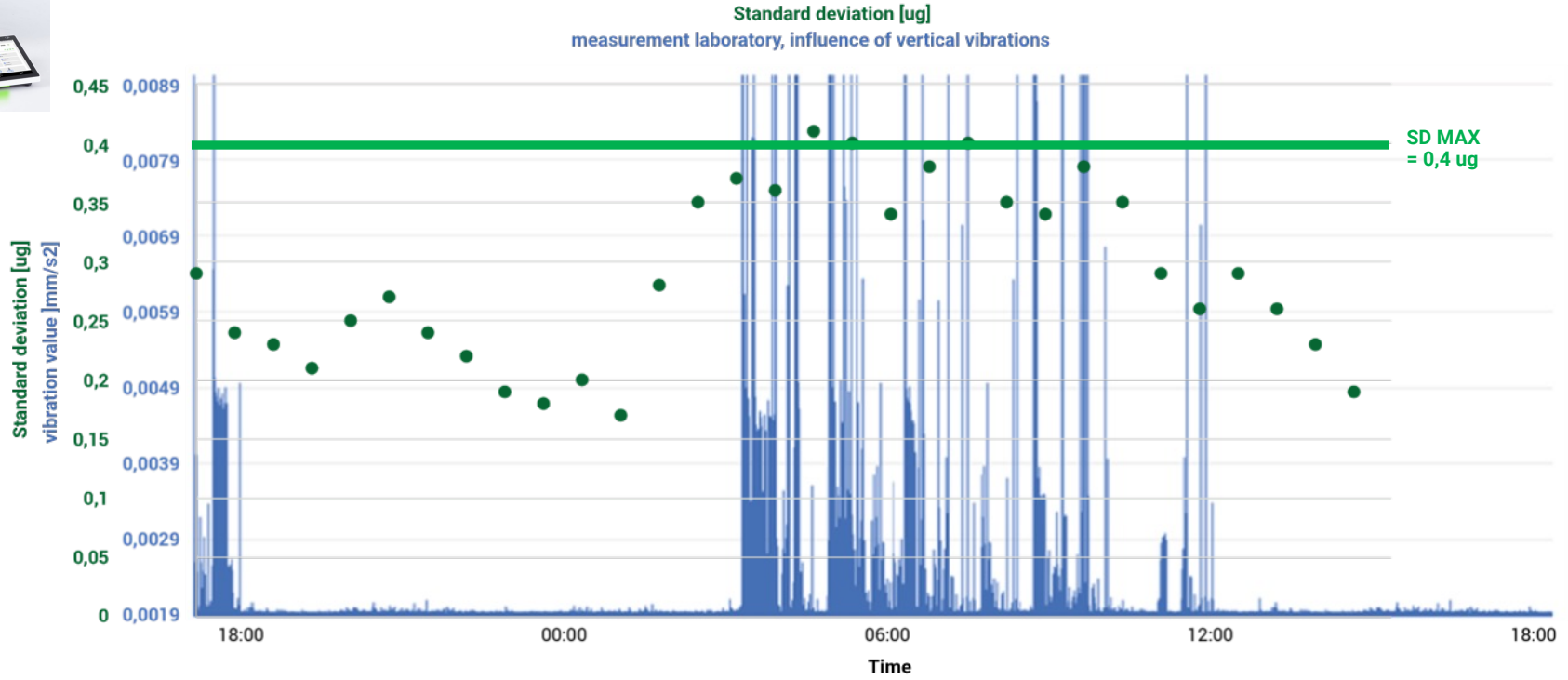
- Elimination of employees movement during work because a walking person may cause a temporary dynamic air turbulence >1 m/s

Vibrations

Vibrations, even of a very low amplitude, can introduce significant disturbances in the process of mass measurement or calibration, which is particularly visible on the devices with a very high measurement resolution. The transmission of vibrations from the surroundings, such as city traffic, the operation of heavy equipment or even the movement of people, can lead to false and unstable readings and measurement errors. The analysis of the impact of vibrations on the precision of measurements showed that the key aspect is the effective isolation of measuring devices from all sources of vibrations, both external and internal.

METROLOGY SYMPOSIUM
Third Edition: Future and New Solutions

The impact of vibrations on the operation of the robotic comparator with the resolution of 50 million units and maximum capacity of 6 g

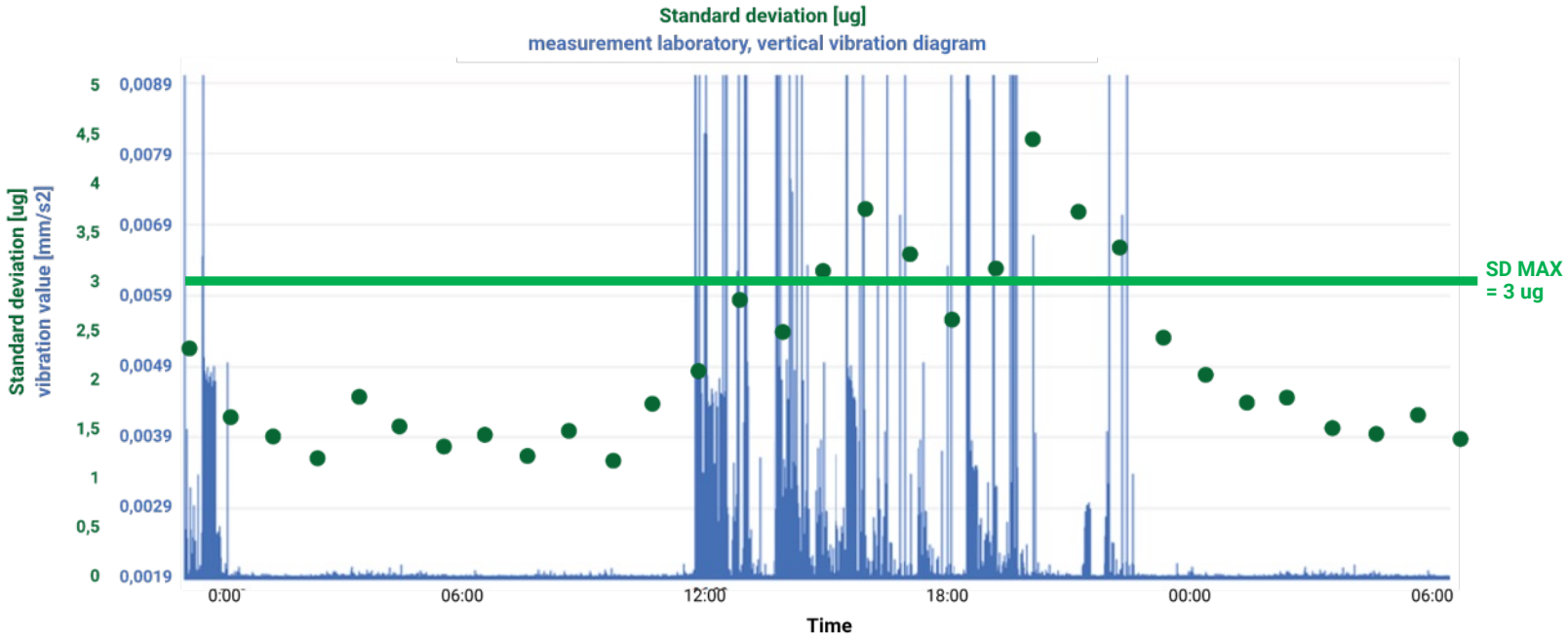


The impact of vibrations on the operation of the robotic comparator with the resolution of 50 million units and maximum capacity of 6 g

The comparator tested by using an internal adjustment standard during the day, when people are working and at night without people presence.

The study showed that **sd is about 80% greater during the day** and averaged **about 0.4 ug,** however, **at night the sd dropped to approximately 0.23 ug**.

The impact of the vibrations on the operation of the robotic comparator with the resolution of 1 billion units and the maximum capacity of 1000 g



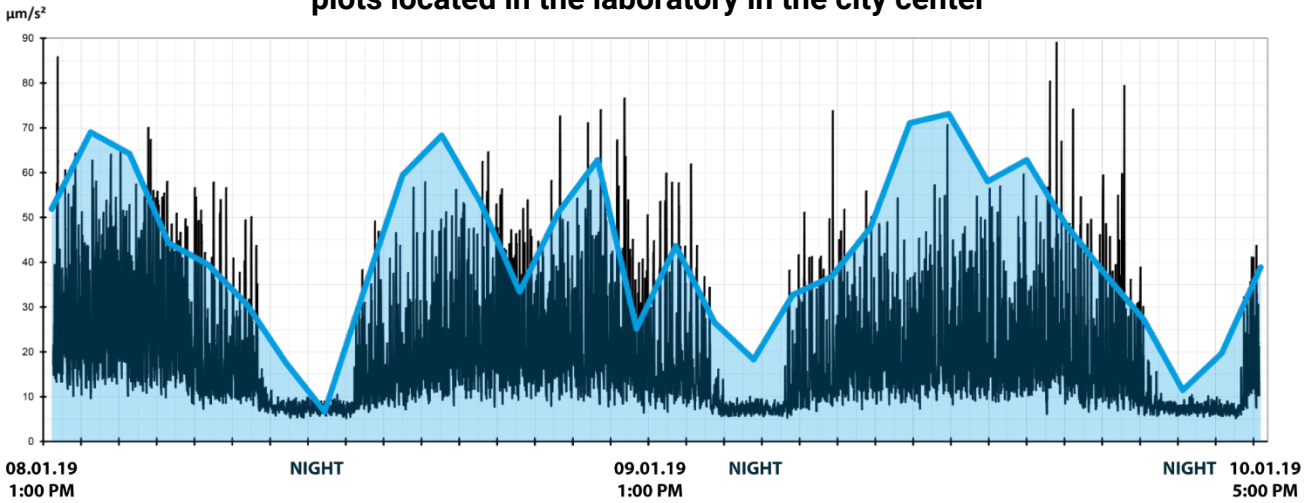
The impact of the vibrations on the operation of the robotic comparator with the resolution of 1 billion units and the maximum capacity of 1000 g

The device was tested in a laboratory located on the first floor, where during the daytime operation of the device, when people are in the building and the **vibrations in the laboratory are much greater than at night, sd is on average 3.8 ug**, while **at night sd is 2.5 times lower and is on average 1.6 µg.**

The impact of the vibrations on the operation of the automatic comparator with the resolution of 10 billion units and the maximum capacity of 1000 g (vacuum comparator)

Hour	1:13 PM	3:18 PM	5:24 PM	7:30 PM	9:36 PM	11:40 PM	1:46 AM	3:52 AM	5:59 AM	8:05 AM	10:12 AM	12:18 PM	3:25 PM	4:32 PM	6:37 PM	8:43 PM	10:50 PM	12:57 AM	3:04 AM	5:11 AM	7:17 AM	9:23 AM	11:30 AM	1:37 PM	3:43 PM	5:49 PM	7:56 PM	10:02 PM	12:08 AM	2:15 AM	4:22 AM	6:30 AM
s [µg]	1.23	1.48	1.41	1.12	1.05	0.92	0.73	0.57	0.96	1.34	1.47	1.25	0.96	1.22	1.39	0.84	1.11	0.86	0.74	0.95	1.01	1.17	1.51	1.54	1.32	1.39	1.18	1.02	0.87	0.64	0.76	1.04

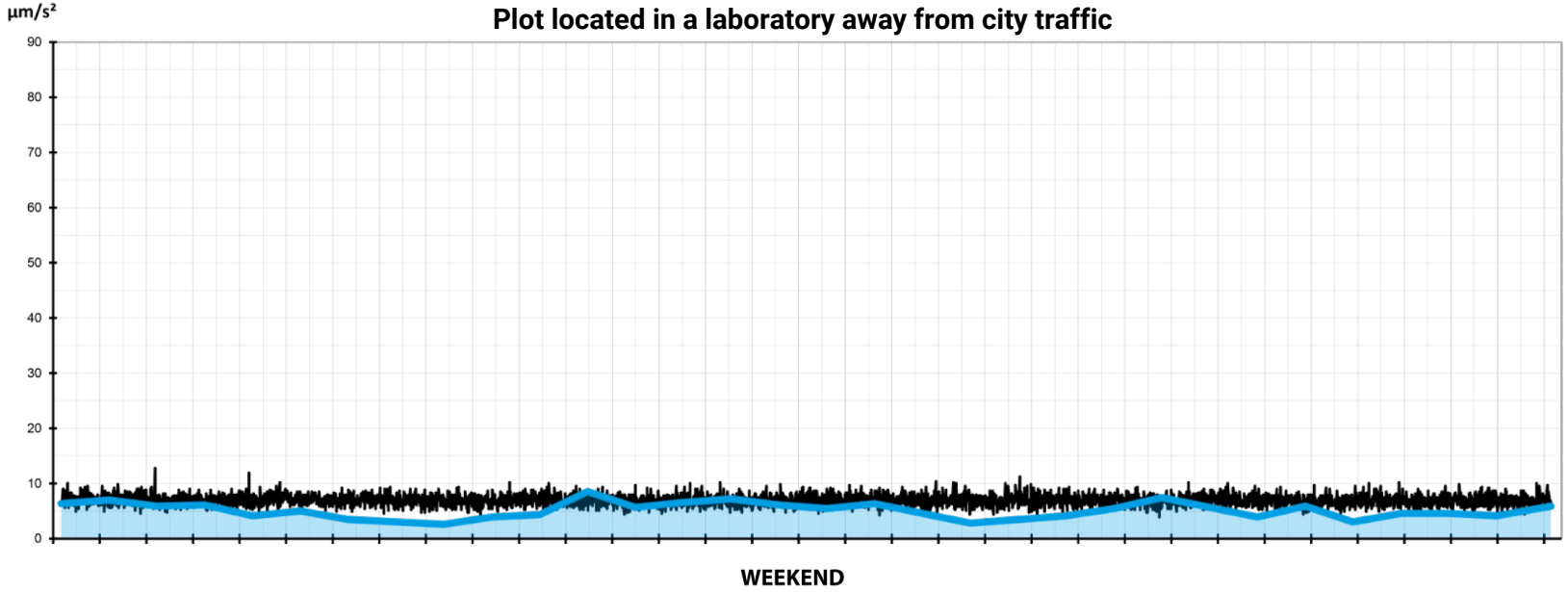
The influence of vibrations on the operation of an automatic comparator with a resolution of 10 billion plots located in the laboratory in the city center



The impact of the vibrations on the operation of the automatic comparator with the resolution of 10 billion units and the maximum capacity of 1000 g (vacuum comparator)

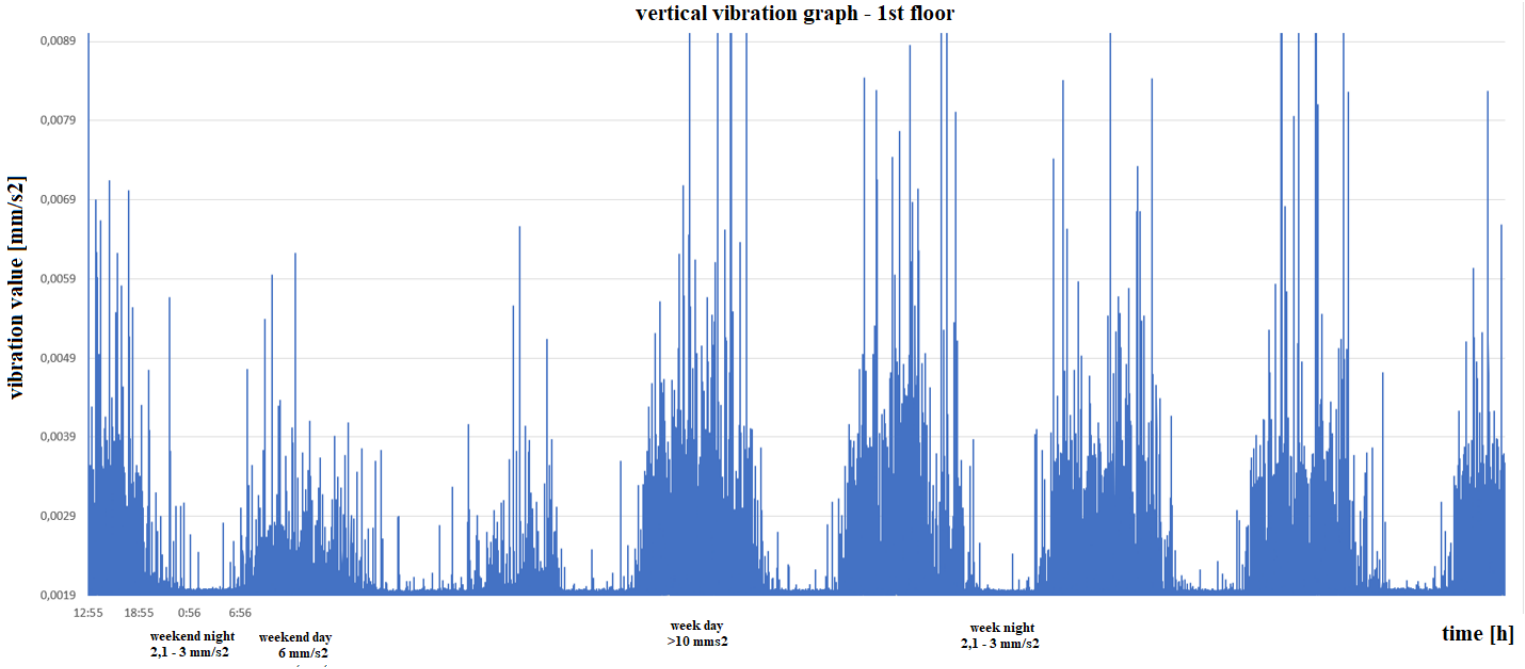
Hour	10:02 AM	12:25 PM	2:29 PM	4:32 PM	6:36 PM	8:40 PM	10:44 PM	12:47 AM	2:51 AM	4:55 AM	6:58 AM	9:02 AM	11:06 AM	1:09 PM	3:13 PM	5:17 PM	7:20 PM	9:23 PM	11:28 PM	1:31 AM	3:35 AM	5:39 AM	7:42 AM	9:46 AM	11:49 AM	1:52 PM	3:56 PM	5:59 PM	8:03 PM	10:06 PM	12:09 AM	2:13 AM
s [µg]	0.48	0.51	0.46	0.47	0.38	0.42	0.35	0.33	0.31	0.37	0.39	0.58	0.45	0.49	0.52	0.47	0.44	0.48	0.40	0.32	0.35	0.38	0.44	0.53	0.45	0.37	0.46	0.33	0.40	0.40	0.38	0.44

The influence of vibrations on the operation of an automatic comparator with a resolution of 10 billion
Plot located in a laboratory away from city traffic



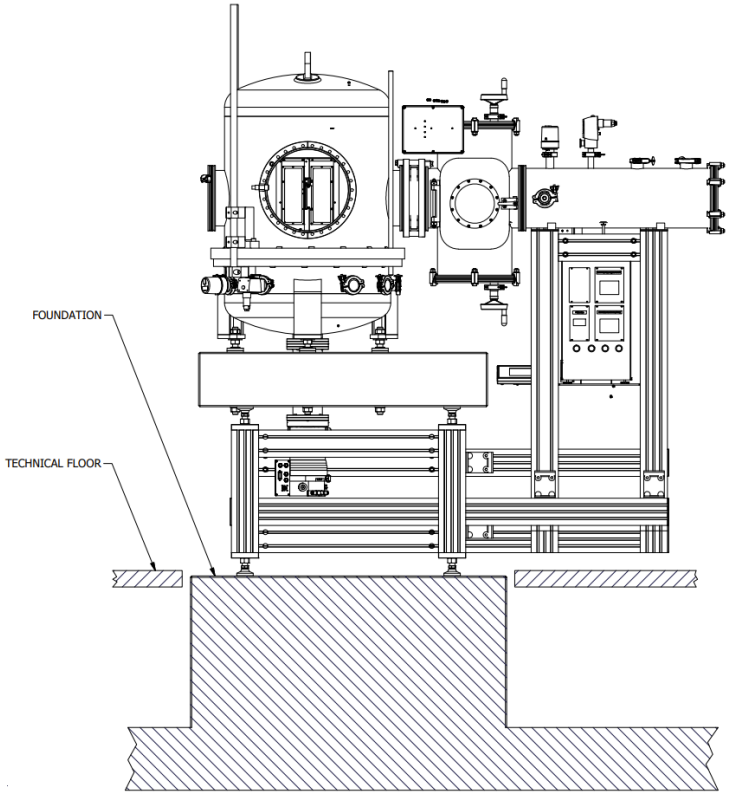
Recommendations to improve the impact of the vibrations on the measurements

In order to reduce the impact of vibrations, it is best to locate measurement laboratories underground, ultimately on the ground floor, and above all, avoid upper floors.



Recommendations to improve the impact of the vibrations on the measurements

A good way is also to increase the mass of the table on which the measuring device is placed. As well as the use of dilatation and the construction of a technical ceiling separated from the ground on which the comparator is located.



Recommendations to improve the impact of the vibrations on the measurements

With the comparators of the lower resolution, simple anti-vibration tables can be used which reduce the impact of vibrations to some extent.

METROLOGY SYMPOSIUM
Third Edition: Future and New Solutions

The offer of comprehensive analysis of ambient conditions

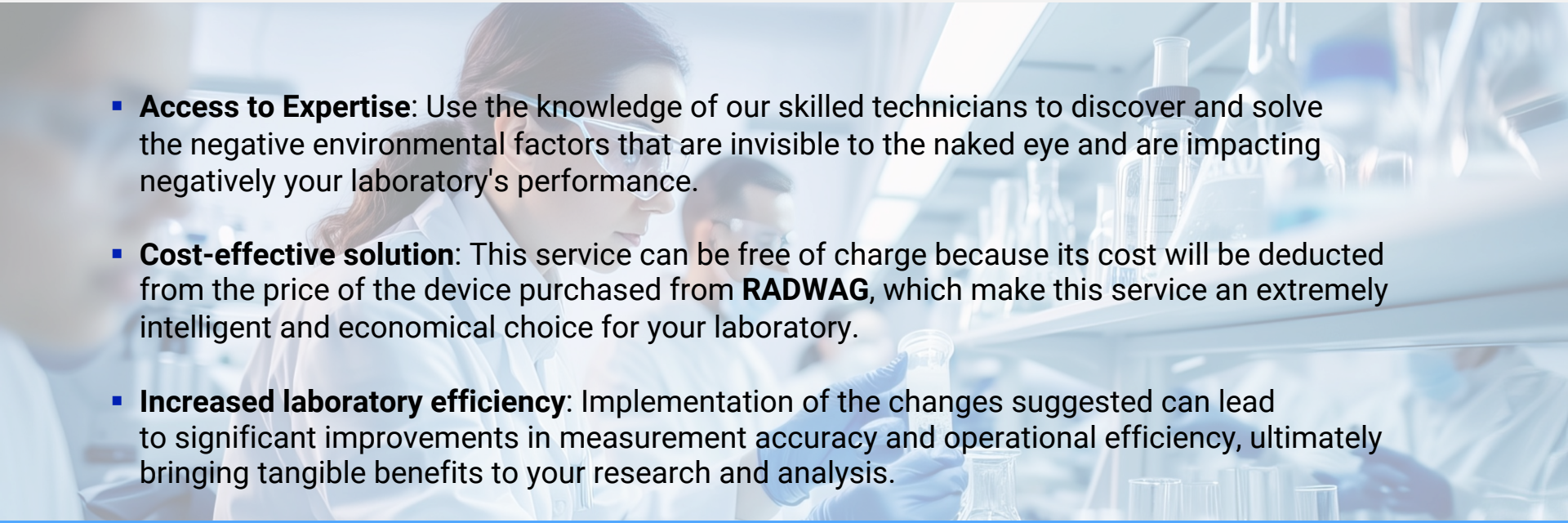
RADWAG presents a unique commercial **offer that increases the efficiency and reliability of measurements in your laboratory**. Our service includes sending an experienced technician to an already built laboratory, who will use dedicated tools to accurately measure current ambient conditions and suggest changes that should have a positive impact on the mass measurement procedures.

SERVICE FEATURES:

- **On-site measurement**: A professional technician will visit your laboratory to measure ambient conditions using specialized equipment.
- **Data Analysis**: The technician will perform a comprehensive analysis of the collected data to identify any negative factors that may affect the accuracy and repeatability of your measurements.
- **Personalized recommendations**: Based on the analysis, our expert will suggest possible changes and improvements in order to eliminate the negative impact of ambient conditions on the mass measurement process and thus to increase the precision and reliability of measurement processes.

The offer of comprehensive analysis of ambient conditions

BENEFITS:



- **Access to Expertise**: Use the knowledge of our skilled technicians to discover and solve the negative environmental factors that are invisible to the naked eye and are impacting negatively your laboratory's performance.
- **Cost-effective solution**: This service can be free of charge because its cost will be deducted from the price of the device purchased from **RADWAG**, which make this service an extremely intelligent and economical choice for your laboratory.
- **Increased laboratory efficiency**: Implementation of the changes suggested can lead to significant improvements in measurement accuracy and operational efficiency, ultimately bringing tangible benefits to your research and analysis.

The design of the new RADWAG laboratory

Our multiannual experience in researching the impact of ambient conditions on the operation of comparators have resulted in the construction of a professional **RADWAG** laboratory.


METROLOGY SYMPOSIUM
DIGITALIZATION AND AUTOMATION IN MASS METROLOGY
Third Edition: Future and New Solutions
Thank you for your attention
www.radwag.com
16-18.04.2024, Radom, Poland