

REPORT

NMS Mass Programme, 1999-2002

Final Report - Project 1.2.8

**Investigate Thermal Influence on
Weights and on Mass Comparators**

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ABSTRACT

The following report summarises the work carried out on Project 1.2.8 – Investigate Thermal Influence on Weights and on Mass Comparators. 62 organisations were surveyed to ascertain the types of problems they had experienced on thermal instability and its effects on weighing. Following the conclusions from the survey the proposed content for a Good Practice Guidance Note was drawn up, and laboratory measurements on manual and automatic comparators were investigated.

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1 INTRODUCTION

This report summarises the work carried out as part of the NMS Mass Programme, 1999-2002 Project 1.2.8. The project was carried out by the National Physical Laboratory (NPL) in collaboration with the South Yorkshire Trading Standards Unit (SYTSU) in response to an invitation from DTI National Measurement System Policy Unit (NMSPU) to investigate thermal influence on weights and mass comparators (DTI ITT no. MPU 8/60.3).

The aims of the project were to:

- Establish a technique for measurement of thermal gradients within a balance weighing chamber that does not modify the ambient conditions in which it is used. The technique will be used to measure thermal gradients within a range of automatic and manual comparators;
- Correlate thermal measurements with weighing data and produce mathematical algorithms for the modification of weighing data according to the thermal instability of the balance and the configuration of the artefacts being compared;
- Disseminate information to balance manufacturers and end users regarding Good Practice Guidance Note in the design and usage of automatic and manual mass comparators to minimise the cause and effect of thermal instability.

The report:

- Discusses the results of a survey of manufacturers and end users of mass comparators and high accuracy balances regarding the causes of thermal instability and their effects on weighing accuracy;
- Describes laboratory experiments designed to investigate the thermal instabilities brought about by different methods of operating and using mass comparators;
- Outlines the content of a proposed Good Practice Guidance Note;
- Discusses the thermal gradient measurement techniques that have been investigated;
- Summarises the experimental work carried out in the project and the conclusions drawn.

2 BACKGROUND

Thermal gradients, which can arise from a number of sources, are a cause of instability and possible error in the results obtained from both manual and automatic mass comparators. Thermal gradients cause eddy currents to be set up in the air within the balance case. These currents affect the apparent mass of the weight applied to the balance pan. At best these effects will result in poor balance performance shown by a worse repeatability or standard deviation. At worst they can introduce a systematic error in the results, which is not obvious from the balance performance and is therefore not accounted for in the uncertainty budget.

The effect of thermal gradient on weights and mass comparators is of increasing significance to mass metrology with the growing use of electronic mass comparators and their increasing resolution and performance. Results from automatic comparators are particularly sensitive to thermal effects as they generally have very high resolution (the most accurate giving 1 part in 10^9). This, combined with the mechanism required for weight exchange, can lead to problems of thermal instability. The large amounts of data these comparators are capable of generating

draws attention to their sensitivity to thermal effects both in the short and long term. The problems seen with automatic mass comparators are further exacerbated when comparing weights of different material (e.g. platinum iridium and stainless steel) or different shapes (standard OIML shaped weights with pure cylindrical weights, spheres, air density artefacts and pressure balance components).

3 SURVEY

With an aim to producing a Good Practice Guidance Note and to steer the type of measurements made, a survey of manufacturers and end users of mass comparators, regarding the causes of thermal instability and their effects on weighing accuracy was conducted. Eighty one organisations were contacted, with sixty two of them providing responses. A copy of the survey document is given in Appendix 1 and a list of those companies providing a response is included in Appendix 2.

Results of the survey show that most users of mass comparators use them in a temperature controlled environment for the calibration of weights and other materials. Temperature control limits were set by most organisations, although these varied considerably. Fewer organisations established controls on the rate of temperature change with time. Time limits set for the stabilisation of weights brought into the test environment for calibration varied between up to 30 minutes to more than 7 days, and apart from two organisations, these did not take into account either the size of weight or its class of accuracy. About half of the survey respondents felt that temperature did have an effect on the measurements made, but this was, in many cases, not well identified or quantified. Effects cited included both zero drift and drift in the indicated value.

Responses from industry indicated that, at least in large manufacturing plants, automated regular testing of balances was undertaken. In discussions with end users it was obvious that industry generally paid attention to specifying their requirements and ensuring that purchase of weighing equipment met that specification, which included temperature-operating limits.

Responses from manufacturers of mass comparators and high accuracy balances were obviously limited by the need to maintain a degree of confidentiality about the design process. One manufacturer identified that the biggest problem in designing a mass comparator was that of zero point drift with temperature change.

In conclusion, it appears expedient that a Good Practice Guidance Note should be prepared which includes:

- Recommendations on temperature and operating limits for test areas;
- Recommendations on the minimum stabilisation time for weights (time based on class and size of weight);
- Advice on reducing the temperature effects of external influences, including air conditioning and human observers;
- Advice on the selection and siting of environmental sensors in the test area and in the weighing chambers of mass comparators;
- Research and recommendations into the use of environmental and stability settings on modern weighing machines.

4 LABORATORY MEASUREMENTS

Following the conclusions of the survey and the proposed content of a Good Practice Guidance Note, laboratory measurements on manual and automatic comparators were investigated. The work included:

- Analysis of data from the SYTSU Automated Mass Metrology System (AMMS) on the effects of temperature/stabilisation times for manual calibrations of weights;
- Introductory measurements to determine best place for measuring temperature in manual balances;
- Investigating thermal stability of typical manual balances, and measurement of temperature distribution in the weighing chamber of such equipment;
- Study of the effects of calibration staff, including stabilisation times, use of gloves, long tweezers etc. to minimise thermal instability;
- Making recommendations on the use of pseudo-thermal generators (e.g. light bulbs in place of calibration staff);
- Investigating the use of auto zero, internal calibration cycles etc in manual balances and comparators;
- Making measurements to examine best practise in design of balance cases for manual measurements;
- Investigating the thermal stability of larger weights (i.e. greater than 50 kg);
- Examining the stability of automatic balances;
- Making suggestions on laboratory design to give good thermal performance.

4.1 Data from the Automated Mass Metrology System (AMMS) on the effects of temperature/stabilisation times for manual calibrations of weights

In 1997 the South Yorkshire Trading Standards Unit installed a data information system in its mass calibration laboratories. The Automated Mass Metrology System (AMMS) provides a full environmental monitoring facility, with temperature measurements being made throughout the calibration area and at every balance or mass comparator in routine use; data on air pressure and humidity levels are also collected by the system at regular intervals. The system is designed to monitor each environmental sensor at approximately one minute intervals, day and night, seven days a week.

Data from AMMS on effects of temperature/stabilisation times for manual calibrations of weights has been analysed for the past three years. This data covers many thousands of measurements both in the calibration laboratories and in other areas where lower grade measurements are made. Recommendations taken from this data are summarised in the Good Practice Guidance Note in Appendix 3.

The data gathered and analysed from the AMMS is also used to provide much of the other recommendations outlined in the following sections.

4.2 Measurement to determine best place for measuring temperature in manual balances

Although there are many temperature measuring devices available for measuring the temperature within a balance or mass comparator, some are considered more practical than others. Traditional temperature measuring devices such as mercury-in-glass thermometers have the advantage of being cheap to purchase and calibrate and usually display long-term stability, with little drift between successive calibrations. There are however two distinct disadvantages to this type of thermal sensor: a) they are difficult to interface with data handling equipment, and b) they are usually calibrated in a vertical orientation, which can make them difficult to incorporate in a balance case where it may be easier to lay the thermometer down.

Consequently two types of temperature sensors are now generally used in mass measurements:

- Platinum resistance thermometers (PRTs);
- Thermistors.

PRTs, nominally 100 Ω , are used as reference thermometers in calibration equipment. Typically the sensor is enclosed in a metal or glass sheath of 10 mm to 20 mm in length. Sensitivity is excellent, but the sensor must be mounted in a metal block if the effects of self-heating are not to be significant. A resistance bridge is used to convert the measured value in ohms to temperature units ($^{\circ}\text{C}$). For high accuracy, a reference resistor is required so that the resistance bridge can then be used as a comparator.

Thermistors are generally less accurate than PRTs, but by careful choice of the sensor and annual calibration a high degree of precision and repeatability with time can be achieved. Thermistors with exposed beads are the best choice, as they have lower thermal inertia and quicker response, but care must be given to mounting if they are not to be damaged through strain. In some applications a thin metal sheath can be used to protect the last few millimetres of connecting cable.

In undertaking measurements to determine the best place for measuring temperatures in manual balances, the SYTSU used a series of thermistors mounted inside metal cylinders 10 mm in diameter and 20 mm long to ensure that the temperature being measured was as near as possible to that of the weights being calibrated (in previous experiments it was found that a bare thermistor was highly susceptible to localised heating and to stray temperature gradients caused, for example, by passing of an operator's hand close to the temperature sensor). The choice of thermistors over PRTs was partly made by their ready availability within the laboratory, but cost is also a significant consideration, with PRTs costing considerably more to buy than thermistors. All of the thermistors had previously been calibrated in-house with a typical uncertainty of ± 6 mK ($k=2$).

Measurements were made on a selected range of balances and mass comparators (from micro balances to high capacity balances). Sensors were installed outside of the balance case and in several places within the weight chamber. Sensors were also directly mounted on metal blocks of similar materials and size as the weights to be calibrated on that balance.

In general, measurements made on balances and mass comparators of weighing capacities exceeding 200 g indicated that when used in a test area dedicated to weighing, with good

temperature stability and little variation from 20 °C, measurements were probably best made with a single sensor (thermistor) installed in the centre back of the balance case. Providing that there was no local heat source adjacent to the wall of the balance, temperatures measured at this point were generally within 0.01 °C of the temperature of the weights being used in the calibration.

Balances and mass comparators of a capacity 200 g or less were much more susceptible to local heating caused by motorised doors, the presence of transformers or the movement of an operator's hand near to the temperature sensor which caused variations in the recorded temperatures in parts of the balance case which did not represent the temperature of the weights being calibrated. Placing a sensor outside the weighing chamber to the rear of the balance seems to give a temperature value, which is in closer agreement with the temperature of the weights. However, there are exceptions to this general rule and it is evident that for the highest accuracy a temperature profile of the balance or mass comparator is necessary using multiple sensors at the location it is used.

4.3 Thermal stability of typical manual balances, and measurement of temperature distribution in the weighing chamber of such equipment

Measurements have been made and data analysed to establish the thermal stability of typical balances used for calibrating weights. Obviously, the thermal stability of a balance or mass comparator will be influenced by the temperature stability of the calibration area in which it is located. For high precision measurements, the test area should ideally have a temperature of 20 °C $\pm$ 0.5 °C, with a stability being maintained within 0.1 °C or 0.2 °C during an eight hour period. It is important that temperature stability is maintained during the working day and night time, as well as weekends or public holidays. For measurements made to lower precision (above F1) the temperature of the test area might be in the range 15 °C to 27 °C, although the thermal stability over an eight hour period should, if possible, be maintained within 2 °C (ideally 0.5 °C).

Within the limits suggested above, most balances and mass comparators will exhibit a reasonable degree of thermal stability, providing simple precautions are maintained:

1. They are left on or in electrical standby mode at all times.
2. They are not in the path of any direct air currents from air conditioners.
3. The balance operator weight handling recommendations outlined in Section 4.4 are followed.

It is also important that both the reference weights and test weights are located in the test area, either in the weighing chamber or, when this is not practical, adjacent to the balance for a sufficient time beforehand to facilitate good thermal stability of the weights. Stabilisation time recommendations are given in the Good Practice Guidance Note in Appendix 3.

A graphical example of the temperature distribution investigated on a Sartorius C5S microbalance is given in Figure 2. The position of the probes is indicated in Figure 1.



Figure 1: C5S with relative position of thermistor probes

Probe 1 was positioned within the inner weighing chamber, probes 2, 3 and 4 were positioned in the left hand side, centre and right hand side of the outer enclosure respectively. Probe 5 was positioned centrally outside the front of the balance enclosure and probe 6 (although not shown in the schematic) was positioned centrally outside on top of the balance enclosure. The balance was loaded and unloaded from the right hand side. The graph in Figure 2 shows the thermal distribution of the balance measured during the calibration of a decade of fractional weights. For the first hour the balance was left undisturbed. The twelve test and check weights were then placed in the right hand side of the outer enclosure and left for approximately three hours to stabilise. The calibration of the weights was then performed taking again approximately one and half hours, and finally the balance was once again left undisturbed and thermal distribution monitored for a further hour.

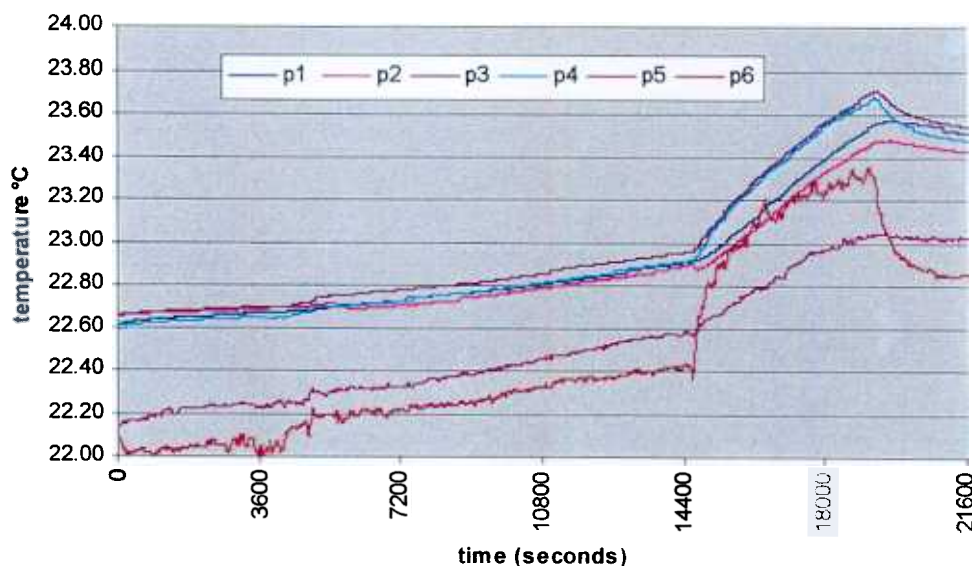


Figure 2: Temperature profile of the C5S

Figure 2 shows that the inside probes 1 to 4 are generally at a similar temperature as are the outside probes 5 and 6. When the twelve weights are placed in the right hand side of the enclosure to stabilise there is a slight jump in temperature measured from probe 4. Then when an operator is present to perform a series of weighings all probes show an increase in temperature (approximately between 0.4 °C to 1 °C over an hour and a half period). The most rapid and distinct increase is measured from probe 5 positioned directly closest to the operator, but the four enclosed probes also show a distinct rise in temperature over the calibration period. When the mass comparator is once again left undisturbed the measured temperature falls rapidly initially and then continues to decrease at a steady rate. The effect of this distinct temperature rise, and its distribution in the weighing chamber, has on mass comparisons is illustrated in more detail in Figure 3, Section 4.6.

4.4 Effects of calibration staff, including stabilisation time, use of gloves, long tweezers etc to minimise thermal instability

Measurements have been made and existing data analysed to establish the effects of the operator. Assuming the operator uses tweezers or weight handlers and wears chamois leather gloves on the hand used for weight loading, a localised temperature increase can be detected which is of the order of 0.1 °C. If the operator does not wear gloves this temperature increase is typically 0.3 °C or more. It is therefore important for all calibration staff to wear chamois leather gloves, even when using tweezers or weight handling forks.

Furthermore, the length of the tweezers or weight handling forks is important. Too small length can cause heat transfer from the gloved hand to the weighing chamber and to the weights being calibrated. However, it is important the weighing forks are not too long and are well designed to allow adequate control of the loading and unloading of a weight onto the balance pan. Inadequate control apart from potentially enlarging repeatability values also causes an irregular weighing action with time, such that any thermal drift has an irregular effect on successive weighings of the reference standard and the weight being tested. Ideally,

the tweezers should be of suitable length to allow the operator to load and unload the balance pan without their hand entering the weighing chamber.

Experiments are reported in Section 4.5 on the use of pseudo-thermal generators to stabilise the temperature in the weighing area when the operator is not present. However, it is noted that the effects of a calibration operator can sometimes be seen as an increase in temperature of the weights being tested if temperature sensors are not well located, see Section 4.2: thermal effects can be measured when an operator's hand passes near the temperature sensor when weights are loaded on and off the balance pan. Likewise, a temperature sensor located in line with the operator may detect localised thermal effects caused by the operator's breathing or body heat.

4.5 Recommendations on use of pseudo-thermal generators to give good thermal performance

The use of pseudo-thermal generators such as light bulbs has been used in the calibration area to maintain temperature stability, switching on and off to compensate for the presence of the operator. In some laboratories using a 60 watt or 100 watt light bulb as pseudo-thermal generators, this technique can achieve improvements in thermal stability. The presence of a human operator can increase the temperature where the balance or mass comparator is situated by 1 °C or more (see Figure 2) the use of a light bulb can reduce this initial temperature rise to perhaps half. However it is recommended that the user experiments for themselves as each situation will need individual assessment. However, based on measurements made over a limited period it was not felt that, under the laboratory conditions experienced, any practical benefit was to be gained by using pseudo-thermal generators, when compared with the use of suitable weighing techniques and good mass measurement practice.

4.6 Use of auto zero, internal calibration cycles etc in manual balances and comparators

Balances can be fitted with auto-zero devices that automatically re-zero the balance when it has drifted from zero by a specified number of digits. Sometimes the operator may set this level of drift. But on some balances it is factory set. However, the auto-zero facility can usually be turned on or off by the operator.

In assessing the effectiveness of the auto-zero facility, measurements were made using the balance or mass comparator both for direct reading (such as might occur when undertaking lower grade measurements or calibrating volume measures or pipettes gravimetrically) and for comparison measurements.

It is recommended that the use of auto zero should be:

- Switched off – for comparison weighings;
- Switched off – for direct reading weighings when a correction is made for the zero reading before and after the weighing;
- Switched on - for direct reading weighings when only the loaded balance reading is taken.

For comparison weighings the selection of a symmetric weighing scheme such as ABA or ABBA will eliminate any drift due to temperature. The use of the auto zero function may cause a discontinuity in these readings and therefore an error in the measured weight difference.

For direct weighings, recording zero readings and monitoring the change in the zero can correct any drift due to temperature effects.

If the balance is used intermittently the auto-zero facility should be enabled, as this will provide a more accurate measurement for a single weighing when only the loaded value of the balance reading is recorded. However if zero readings are also being recorded the auto zero facility should be disabled.

When a balance or mass comparator is first used after a period of inactivity (e.g. overnight or after a break), several preliminary weighings are essential to ensure that the initial rise in temperature brought about by use and the presence of an operator has a minimum effect on the results of the calibration process. Exercising the balance will also have a beneficial effect on the repeatability of reading. It is estimated that a minimum of three up to maximum of five ABA or ABBA cycles (equating to a period of approximately 10 minutes) are needed to minimise drift when the balance is first used after a period of inactivity exceeding 30 minutes. This procedure will negate the period of rapid temperature gain illustrated in Figure 3, when the balance will not give repeatable readings (t = 20 to t = 30 minutes).

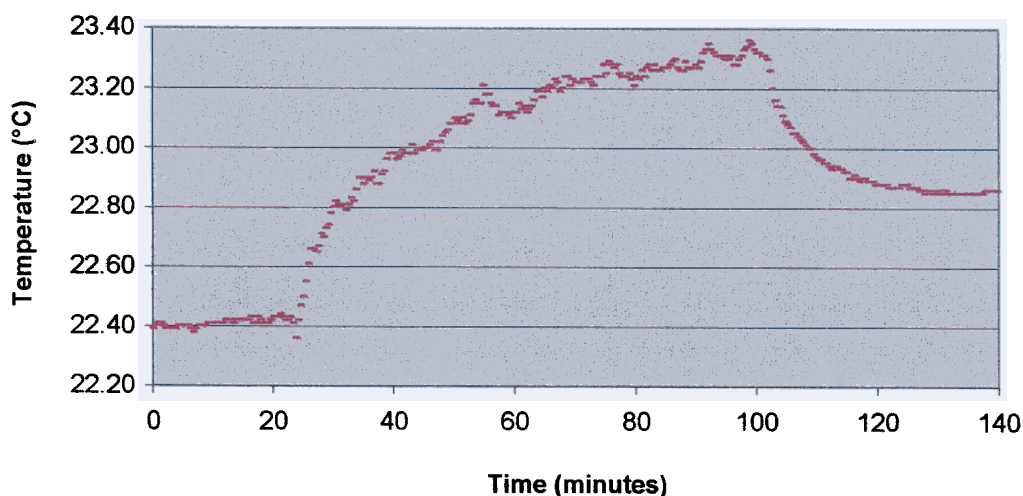


Figure 3. Drift in balance temperature due to presence of user.

4.7 Measurements to examine best practice in design of balance cases for manual measurements

Following on from work conducted in Section 4.3, tests were carried out on a variety of balances and mass comparators to examine whether improvements were possible in the design of balance cases and mass comparator housings. As a result of many measurements made it was possible to identify potential improvements.

Where possible, all transformers, display units and door motors should be removed from the balance housing and located outside the immediate weighing area. In the case of motorised doors, consideration should be given to ensuring that the motors generate as little heat as possible, the doors are capable of manual operation if required, and can easily be adjusted. On more than one third of balances surveyed it was found that doors were not a good fit, leaving gaps at the edges, or did not close smoothly, causing vibrations to be transmitted to the weighing cell. Many weighing machine manufacturers offer the option of remote electronics – balance users should have this option fitted wherever possible. Likewise additional or secondary housing are sometimes available from the weighing machine manufacturer.

Mass comparators fitted with weight handlers or alternators for automatic calibration of weights should be designed so that motors do not give off excessive heat into the weighing chamber. In some cases rises of more than 1 °C were measured when the weighing programme was started and the weight handlers commenced motion. In some cases, particularly for weights of 20 kg and above, this temperature rise led to potential instability of the mass value for several hours, even when weights were initially located close by in the weighing chamber. It is recommended that pre-runs be used to stabilise the temperature.

It was noted that thermal glass was fitted to some balances and mass comparators, particularly of capacities of 200 g and less. This was designed to reduce the effect of heat generated by the balance user. However, it should be checked that the thermal shields are installed the correct way round.

Where it is not possible to install a balance or mass comparator in an ideal location, consideration should be given to installing insulation to avoid effects of temperature changes caused by adjacent wall or windows which are at different temperatures, or from thermal effects caused by lighting or air conditioning.

4.8 Thermal stability of larger weights >50 kg

Measurements have been made to ascertain the time taken for larger weights of mass greater than 50 kg to achieve thermal stability.

Weights of solid stainless steel, cased weights made of stainless steel with an inner core of lead, and painted cast iron weights were all measured. Stabilisation times have been established and are listed in the Good Practice Guidance Note in Appendix 3. As a general rule weights of the highest accuracy may need to be located in the calibration laboratory for several days to achieve thermal equilibrium, particularly if transported to the calibration laboratory at a temperature significantly different from that at which they will be tested. The figures given in Table 2 of the Appendix 3 represent the acclimatisation times for weights of defined class. The times are defined as the time taken for a weight to change from a temperature differing from the reference temperature by ± 5 °C to a temperature within half the values specified in Table 1 for a particular class and size of weight. For example a 1 kg E₂ weight should be left to acclimatise for a period of 6 hours to reach a thermal stability within 0.25°C of the balance temperature.

Measurements were made on some stainless steel weights which are of cased construction - they have an outside case of stainless steel, with a central core of lead, covered by a stainless

steel plate welded to the inside of the case. It has been known that these weights are particularly susceptible to changes in air pressure (as well as surface corrosion due to the quality of stainless steel often used in the manufacture of these weights). Compared with a stainless steel weight, which is of an integral construction, these weights generally took about 60 % longer to achieve initial thermal stability. They also displayed a greater susceptibility to thermal or pressure drifts (generally remaining stable in laboratory conditions only to 1 ppm or greater).

In the case of cast iron weights, problems arise from corrosion of the surface of the weight, from dirt accumulated in defects on the surface and from the ingress of moisture into the weight adjustment chamber. However, measurable changes can occur when a weight is brought into the calibration area off a vehicle particularly when the ambient temperature is more than 5 °C different from the calibration temperature. It is suggested that at least forty eight hours should elapse after the weights are brought into the calibration environment before testing commences. Furthermore, it is recommended that the value is not reported to an uncertainty of better than 50 ppm (ideally 100 ppm) due to changes which may occur when the test weight has been or is exposed to significant changes of temperature and humidity.

4.9 Examination of the thermal stability of automatic balances

The thermal stability of four automatic mass comparators Sartorius C1000S and C10000S, Mettler HK1000MC and AT10005 and the Metrotech 'A' series robot balances have been investigated. All have delayed start and pre-run as options in their control software and recommendations on the use of these options in order to minimise thermal problems are suggested.

The problem of initial temperature rise in the enclosure of the C10000S mass comparator and 'A' series robot balances fitted with weight handlers or alternators for automatic calibration of weights has been discussed already in Section 4.7. In both automatic comparators and robot balances it was found that the location of the motors used for interchanging the reference standards and the weights under test caused an initial increase in the temperature of the weighing chamber by up to 1.3 °C. Although it is not difficult to make measurements when temperatures are above the initial stabilisation temperature, the first weighings must not be used in the final mass calculations (despite the use of trend eliminating symmetric weighing schemes). The first weighings may be subjected to excessive thermal drift, which may not be the same for the reference standard and the test weight. This is particularly true if the test weight has not been located in the calibration area for an adequate length of time, or is perhaps of different materials or of a different construction to the standard.

Figure 4 shows the AT10005 weighing chamber with two spheres (solid density artefacts) being calibrated against two stainless steel OIML shaped standards and the relative positions of the eight thermistor probes. Figure 5 shows the temperature profile of the weighing before, during and after the calibration of these artefacts.

For the AT10005 and HK1000 automatic comparators the weight handler motor and control electronics are separated from the weighing chamber and connected across an air gap. This gap limits the effect of initial heating, however it is still of the order of 0.04 °C/hour as can be seen in Figure 5.



Figure 4: AT10005 with relative position of thermistor probes.

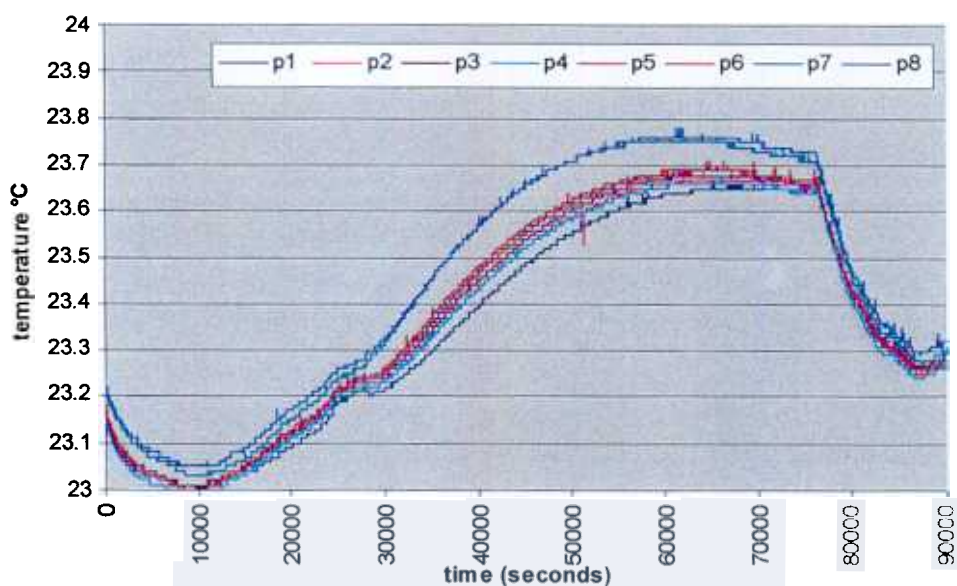


Figure 5: Temperature profile of the AT10005

Figure 6 shows a rise in temperature of approximately 0.6 °C during the calibration, or the activation of the automatic weight handler, and a distinct fall in temperature once the calibration (or use of the weight handler) has ceased. This temperature rise equates to a drift in the measured mass difference of approximately 300 μg . Using the measured temperature in

the balance enclosure the drift in the balance reading can be corrected. Algorithms for these corrections are given in Section 5.8.

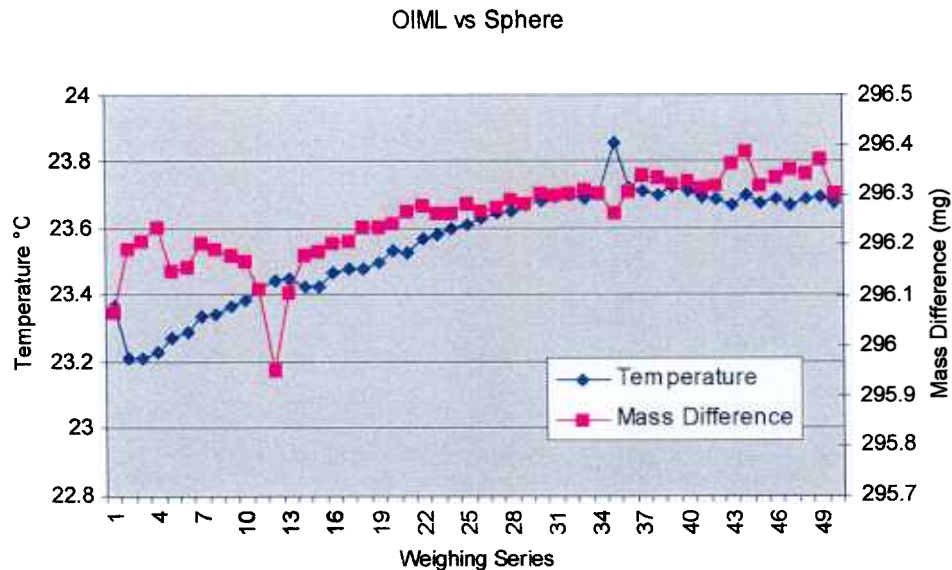


Figure 6: Correlation between weighing data and temperature form AT10005

The C1000S also has a temperature stability problem. The comparators weight handler motor and control electronics are housed above the weighing chamber, but the weighing cell and associated electronics are housed directly below the weighing chamber. It has been observed that there is a localised heating effect or hot spot in the weighing chamber of the order of $+0.2^{\circ}\text{C}$ to $+0.3^{\circ}\text{C}$ above the ambient temperature in the balance enclosure. This hot spot has the effect of influencing the temperature of the artefacts during their stabilisation period; such that one is hotter than the other or others. Once the weight handler is activated this hot spot is cancelled out as it then affects each of the artefacts equally. However, until the period of thermal equilibrium is reached between the artefacts being compared, the first few series of weighings will need to be discarded. In this case the thermal equilibrium between the ambient temperature and all the weights being compared will be better than 0.1°C . The inequality in temperature between the weights can be overcome by the use of pre runs or by modifying the control software to rotate continually the weight handler carousel during the delayed start period. In general 2 to 4 pre-runs will be necessary. Preliminary weighings should be ignored if their results are more than three times the standard deviation of the normal balance performance.

In making measurements using the C1000S repeatability was found to be $42\text{ }\mu\text{g}$. Aluminium cylindrical cans were manufactured to sit over the top of the reference and test weights. The cans were open at the bottom. Using these covers produced significant improvement in performance with repeatability reduced to less than $10\text{ }\mu\text{g}$. Investigations suggest that performance is improved because the effect of localised drafts caused by rotation of the weights by the handler is eliminated by covering the weight with aluminium cans, illustrated in Figure 7. Reducing the speed of rotation can improve performance, but the use of these cans is recommended as the preferred method when calibrating weights. As a result of these tests, similar measurements were made on other balances, such as the AT10005. Although each balance showed some improvement in repeatability when used with aluminium cans

placed over the weights, the performance improvement seen in the case of C10000S was not necessarily achieved to the same degree on other mass comparators.



Figure 7: Aluminium cylindrical cans used on the C10000S as individual draft shields

In both automatic comparators and robot balances it is possible to calibrate a sequence of several weights, one after the other (e.g. 1 v 2, 1 v 3,etc.). This is especially significant in the case of the 'A' series robots where a large number of test weights may be located on the weight storage racks. When calibrating weights in such a sequence, weight 1 will be used in both of the first two comparisons (against 2 and then against 3), but in the second comparison weight 3 may initially be at a slightly different temperature because it was not used in the first comparison. The calibration officer must consider this when using the software, and it is recommended that a few weighings at the start of every comparison should be treated as preliminary weighings. In most cases one or two ABA or ABBA weighings may be discarded, but as the size of the weight increases then the number of weighings, which are discarded, must also be increased, as larger weights take longer to achieve thermal stability. Preliminary weighings for each series should be ignored if their results are more than three times the standard deviation of the normal balance performance.

It is recommended that two temperature measuring probes (taking an average) are used. Each placed on opposite sides of the weighing chamber, positioned such that they are in the same vertical plane as the artefacts being weighed.

4.10 Laboratory design suggestions to give good thermal performance

Temperature instability in laboratories may arise from:

- The presences of heat or cold arising from windows, heating pipes and through the transmission of heat through the walls caused by processes taking place in other adjoining rooms;

- The location of heat sources in equipment located in the calibration area, including computers and monitors weight handlers and other ancillary equipment;
- The effect of lighting. The choice of luminaries can have a significant effect on the laboratory environment. Fluorescent lighting is probably best, and for good stability should be left on at all times;
- The presence of human operators, who generate heat and create air turbulence and temperature instability through movement.

In a perfect world, a calibration laboratory should probably be located away from traffic and industry in a specially constructed facility set deep into the ground for good thermal stability. A number of NMIs and some industrial calibration laboratories have been constructed in this manner. However, for most organisations this simply is not possible and good laboratory construction can give good thermal stability.

Where the mass laboratory has an outside wall it is suggested that this be provided with additional insulation and perhaps with a secondary internal wall up to 300 mm inside the room. Windows, if provided at all, should be double or triple glazed (with double glazing and a single secondary window located at least 100 mm inside). The aim of this additional insulation and the provision of a large air gap is to minimise the effects of external temperatures on the calibration process.

Internal walls should also be fitted, if this is possible, with an additional wall of at least 100 mm thickness on the inside, with the gap between the walls filled with insulation. A secondary door system should be installed to give an air lock between the outside area and the mass laboratory.

In spite of all the additional insulation installed around the adjoining walls, it is possible that the temperature of the walls may be different from that of the remaining calibration laboratory. It is therefore recommended that balances and mass comparators be installed on balance tables situated away from any vertical surface.

It is not absolutely necessary for the laboratory to be air conditioned but it is very important to maintain the laboratory temperature within the stability limits recommended in The Good Practice Guidance Note Appendix 3, if the effects of temperature instability are to be less than 10% of the overall uncertainty on the weighing. Where air conditioning is installed, the effects of temperature and pressure variations must be carefully considered. It is recommended that the air conditioner does not blow directly into the calibration room. If possible arrange for the conditioned air to be blown into an upper ceiling. Air in the upper ceiling is then allowed to enter the main measurement area through perforated ceiling panels fitted with filter material. This reduces the pressure effect of forced air from the air conditioner directly affecting the balances or mass comparators. Air is drawn directly from the calibration laboratory back into the air conditioner. Measurements within the calibration laboratory area will enable adjustments to be made to the fan speed and thermostat settings of the air conditioner to give a uniform but not excessive supply of conditioned air within the calibration room. Measurements should be made throughout the full area of the calibration room to ensure an even distribution of stable air – any instability may be rectified by the positioning of deflectors within the upper ceiling or by the addition of extra filter material above the perforated ceiling panels. Temperature measurements should specifically be made at the positions where the balances will be located to ensure maximum thermal stability.

Heat from motors for mass comparator weight handlers and from computers can be reduced by careful choice of the equipment and its location. Where this is not possible heat from computers and similar equipment can be ducted to outside.

There will be some thermal gain from the presence of human operators. Psuedo-thermal generators may be used to compensate for this (see Section 4.5). If this recommendation is followed it is still necessary to carry out some preliminary weighings when the calibration process commences (see section 4.6). In a well regulated environment it is suggested that good thermal stability can be attained without the use of thermal generators. There must, of course, be a limit to the number of humans in the calibration area at any one time. This limit is probably around one operator for each 3 – 4 m³. Sensible positioning of the inlet and extraction points for the air conditioning will mean that air flow can be channelled to guide the thermal effect of balance users away from the balance.

Taking precautions against heat sources and following the above recommendations should ensure a thermal stability within the calibration area spread over several hours of better than 0.1 °C.

5 CORRECTIONS FOR AUTOMATIC MASS COMPARATORS

5.1 Introduction

It is difficult to measure thermal gradients within a balance enclosure without modifying the thermal conditions with the measuring devices. Even the simple measurement of air temperature is difficult due to its low thermal inertia and the potential for local heating due to measurement devices such as platinum resistance thermometers. PRT's produce a self-heating effect due to their measurement current. In order to measure effectively the thermal gradients within a balance, the temperature distribution over a relatively small area needs to be determined. This not only requires a number of sensors in close proximity to each other (and having no interactive effect) but also a resolution to the milli-kelvin level, as temperature variations will be very small. The response time of the temperature sensors used is an important consideration, due to the transient nature of the thermal gradients. The techniques that have been considered for these measurements include: anemometry, thermal imaging, use of small PRT's, thermistors and thermocouple arrays. Their advantages and disadvantages are discussed.

5.2 Techniques for measurement of thermal gradients

5.2.1 Anemometry

Laser Doppler Anemometry is a widely accepted tool for fluid dynamic investigations in gases and liquids. It is a well-established technique that gives information about flow velocity, which could be related to air convection or thermal gradients. Its principle and directional sensitivity make it more suitable for applications where physical sensors are difficult or impossible to use. Unfortunately it would not be able to resolve small flow

velocities associated with air convection in a weighing chamber. It also requires tracer particles in the flow.

Thermal imaging

Thermal imaging detectors are quick, easy to use devices for measuring temperature variances. They detect infrared energy radiated from an object whose temperature is above 0 K. However, they cannot be used to measure air temperature. Light-weight metallic targets could be spatially arranged within the weighing chamber and used to characterise the temperature variances. Such targets would, however, modify the airflow. Also the detector will not work through glass therefore for practical use the weighing chamber door would need to be left open thus modifying the weighing conditions. In addition, all but the most expensive detectors still only have a resolution of hundreds of mK.

5.2.3 Micro PRTs

Micro PRTs are inexpensive easy to buy off the shelf items. They provide the resolution required to measure thermal gradients (milli-kelvin level). They are, however, difficult to spatially arrange in order to cover the areas of interest within the weighing chamber and they also generate a self-heating effect due to their measurement current, although to a much lesser extent than standard PRT's. Even micro PRT's have a relatively high thermal inertia and therefore a relatively slow response time.

Thermistors

Thermistors are generally less accurate than PRTs, but by careful choice of the sensor and annual calibration a high degree of precision and repeatability with time can be achieved. Thermistors with exposed beads are the best choice, as they have lower thermal inertia and quicker response, but care must be given to mounting if they are not to be damaged through strain. The resolution is generally limited to 10 mK.

Thermocouple arrays

Thermocouples are the most widely used temperature sensor in test and measurement work. Accurate temperature measurements can be made at low cost with ordinary digital voltmeters and in-house built probes. Although of limited accuracy when used as absolute temperature measuring devices, thermocouples can be used to measure temperature differences to the resolution required across the areas of interest within the weighing chamber. Using thin wire and the low resistive nature of the metals used to make thermocouples means they have a very quick response time. Again, however, they are quite difficult to spatially arrange.

Selection of measurement technique

Existing research data shows that temperature differences between an artefact and the balance chamber modifies the apparent mass of the artefact. According to previous work [1] these

changes are not buoyancy or sorption effects and have been directly related to free convection air currents and corresponding viscous forces or thermal gradients. This data is based on theoretical considerations and mass measurements. We intend to use the thermocouple technique to test this theory and provide a model for air convection based on thermal gradients within the weighing chamber and the influence it has on mass measurements.

5.4 Differential thermocouple arrays

Type T (copper-constantan) differential thermocouple arrays were used in the measurement of thermal gradients in the balance enclosures. Each Type T junction has an output of about $40\text{ }\mu\text{V/K}$ at ambient temperature. Therefore using a digital voltmeter with a resolution of $1\text{ }\mu\text{V}$ a 10 junction array (five-differential thermocouple) was required to resolve the thermal gradients to approximately 5 mK . Figure 8 shows two schematics, one of the 10 junction array construction and the other of its spatial arrangement, with the five differential thermocouples arranged with a planar spacing of an approximately 20 mm gap.

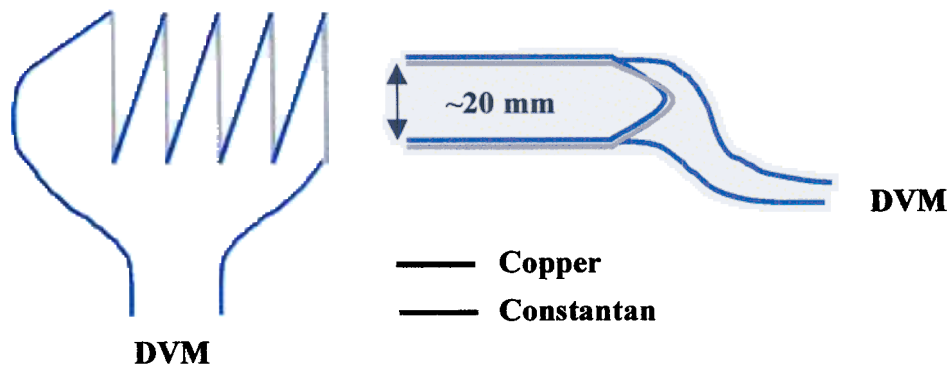


Figure 8: Arrangement of a 10 junction array (five-differential thermocouple)

5.5 Measurement technique

Three 10 junction arrays were placed in the weighing chamber adjacent to the weighing cradle. Figure 9 shows a schematic of the weight carousel with a pair of air density artefacts (bobbin and hollow) and the relative positioning of the thermocouple arrays.

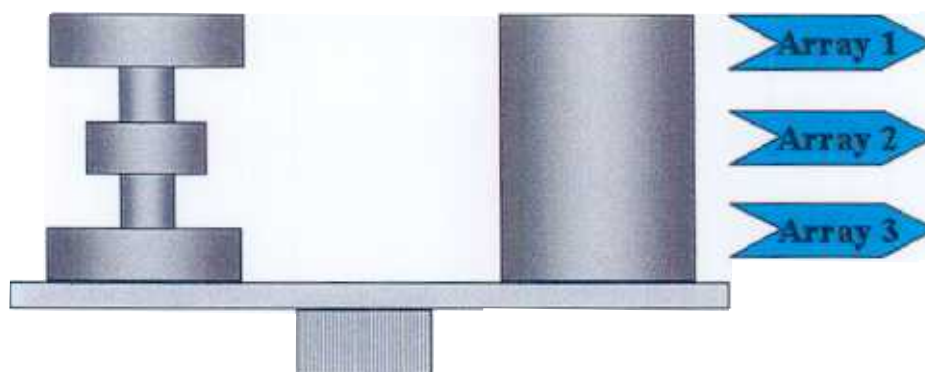


Figure 9: Positioning of the thermocouple arrays in the weighing chamber

5.6 Measurements

The thermal gradient problems seen in automatic comparators are known to increase when comparing weights of different material (e.g. platinum iridium and stainless steel) or different shapes (standard OIML shaped weights with pure cylindrical weights, spheres and air density artefacts). The arrangement of three 10 junction thermocouple arrays shown in Figure 9 was used to measure the thermal gradients when weighing these artefact combinations of different shapes and different materials.

The measured thermal gradients for a pair of air density artefacts (bobbin v hollow) is shown in Figure 10. The measurements show that the differential temperature (or thermal gradient) always rises along the vertical surface of the artefact being weighed. With the rate of change, or gradient of the slope, fluctuating with time. The measured output from the three arrays give temperature differentials in the range of approximately 8 mK to 11 mK. With the array at the top, Array 1 showing the most variation in differential temperature. This fluctuation in differential temperature follows a similar pattern to the variation in the absolute temperature measured in the weighing enclosure using a PRT. This was seen to be the case when comparisons involving weights of different material or different shape were investigated.

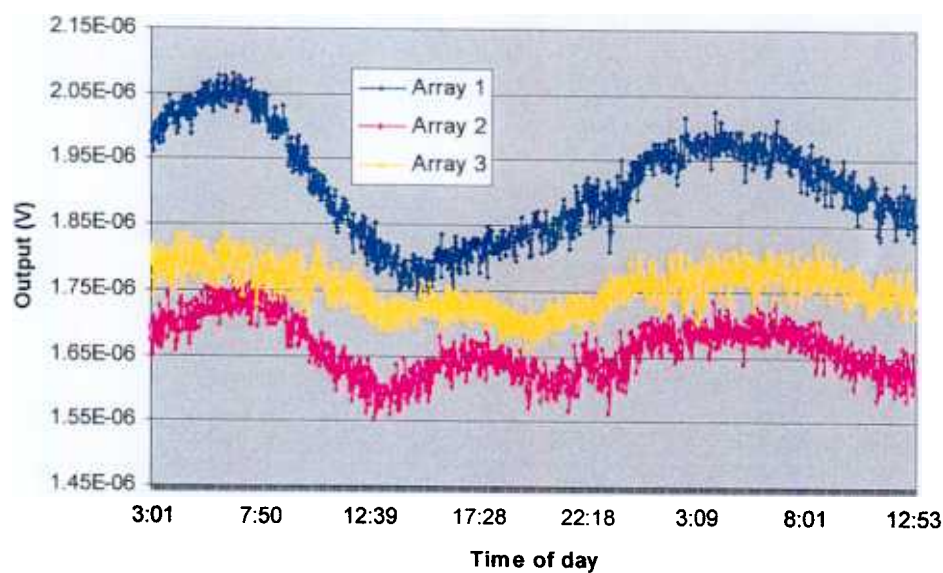
Bobbin v Hollow

Figure 10: Measured output from differential thermocouple arrays for comparison of a bobbin and hollow air density artefacts

Figure 10 shows the differential temperature measurements made in the weighing chamber when comparing a pair of air density artefacts.

5.7 Established model

The established theoretical model proposed by Glaser [†] [2], states that the thermal gradients which are set up in the balance enclosure, when comparing weights which are at a different absolute temperature to the weighing enclosure, follow a path shown in Figure 11. It has also been calculated that the apparent mass change observed when comparing weights in this environment can be directly related to the viscous air flow along the vertical surface of the weight. The measurements carried out in this project have corroborated these proposals.

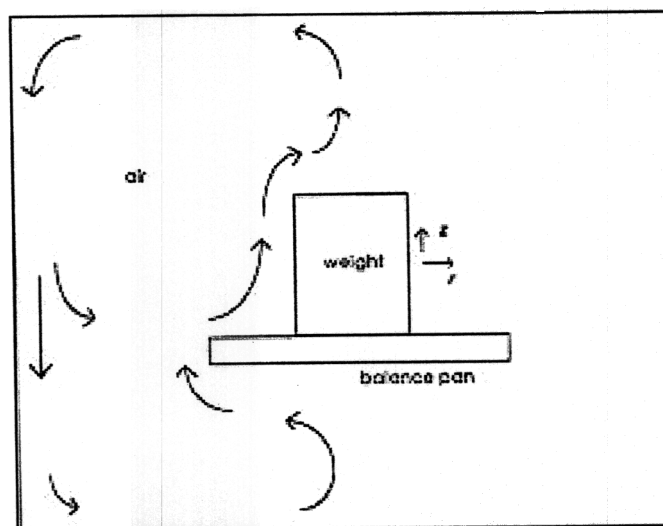


Figure 11: Model of convection currents set up in the weighing chamber

[†] EUROMET Project No. 395. "Convection effects in mass calibration due to temperature differences or gradients". Working documents. Presentations of participants on 18 February 1998 in Oslo (or before).

5.8 Relationship of apparent mass difference with change in absolute temperature

Changes in measured mass difference have been related to the viscous air flow along the vertical surface of the artefact being weighed. This air flow has been measured using the differential thermocouple technique. These measurements have shown that the variation in differential temperature along this surface follows a similar trend to the absolute temperature change within the balance enclosure. Figure 12 shows the change in absolute temperature within the balance enclosure and the apparent mass change for the same comparison of a pair of air density artefacts (bobbin v hollow) that were used for the thermocouple measurements in Figure 10.

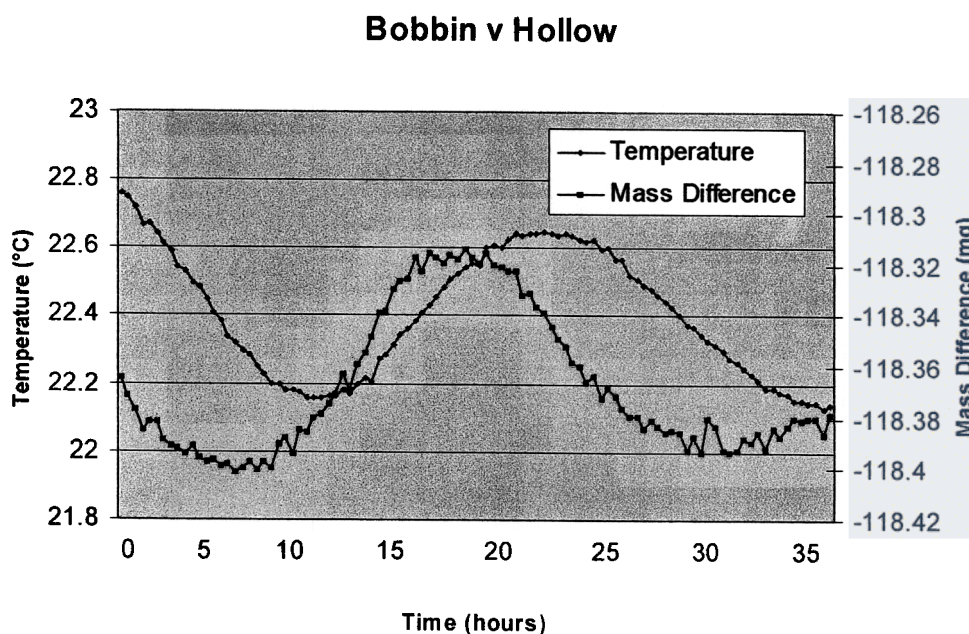


Figure 12: Variation with time of both the absolute measured temperature and the measured mass difference

Figure 12 shows that the variation in the apparent mass difference follows a very similar variation to the absolute temperature with a slight temporal offset. Correcting for this lead time brings the two graphs into alignment, shown in Figure 13.

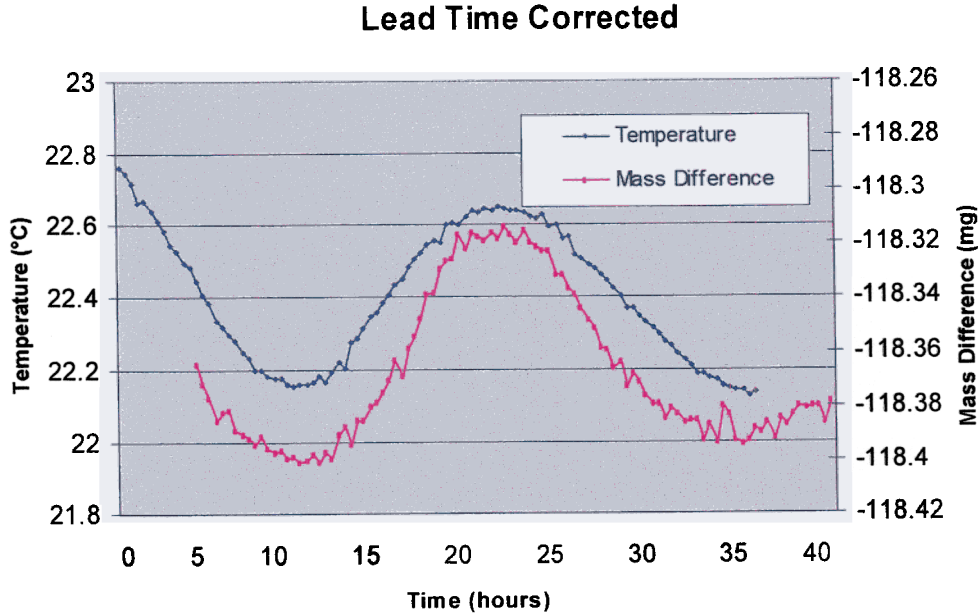


Figure 13: As Figure 8 after correcting the difference for the lead time offset

This time corrected graph can then be used to normalise the apparent mass difference known to result from the viscous air flow using the absolute temperature change measured using a PRT. The corrected mass difference and measured temperature are related by the following general equation:

$$M_i = m_i \left[1 + \left(\frac{T_A - T_i}{c} \right) \right] \quad (1)$$

Where:

- M_i is the corrected mass difference in mg for comparison i ;
- m_i is the measured mass difference in mg for comparison i ;
- T_A is the average measured temperature in °C over the period of calibration;
- T_i is the measured temperature in °C for comparison i ;
- c is the correction factor in °C mg⁻¹.

Figure 14 shows the above comparison (bobbin v hollow) corrected for temperature variations using four values for the correction factor c . The correction factor required to best normalise the weighing data to the fluctuating temperature was $c = 750$ °C mg⁻¹. This correction factor had little effect on the average mass difference for the comparison, however, it reduced the standard deviation of the comparison by a factor of approximately 3 from 28.5 µg to 9.1 µg.

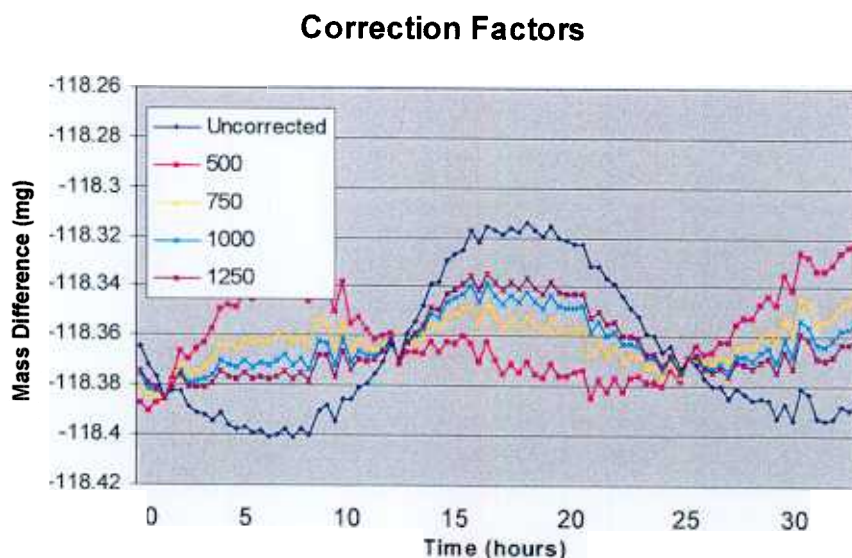


Figure 14: Measured mass difference corrected for temperature variation using different values for the correction factor c

Unfortunately, there is no common correction factor for each combination of different shapes and different materials compared. Each set of weighing data is unique and must be treated as such. However, data collected has shown that the correction factor c has a positive sign for the weighing configurations shown in Table 1. The arrangement of the weighing equation shows that the artefact with the greater continuous vertical surface is always on the right hand side for c to have a positive value.

Weighing Equations

$$\begin{array}{rcl}
 \text{Bobbin} & = & \text{Hollow} + \Delta m \\
 \text{PtIr} & = & \text{OIML} + \Delta m \\
 \text{Cylinder} & = & \text{OIML} + \Delta m \\
 \text{Sphere} & = & \text{OIML} + \Delta m
 \end{array}$$

Where Δm is the absolute mass difference between
the two artefacts compared

Table 1: Weighing equation for each combination of different shapes and different materials

6 CONCLUSION

The examples and recommendations given in this report are a product of the practical work carried out on this project and the extensive experience and knowledge both NPL and SYTSU have of mass metrology and its associated problems. The information given here is not considered comprehensive, but includes examples of good mass measurement practice. Other working practices may exist which fall outside the criteria for this study, or which may simply not have been considered during this project. Finally, the findings of this report are summarised in Appendix 3 in the Good Practice Guidance Note.

7 ACKNOWLEDGEMENTS

The authors would like to thank the many organisations that contributed to the survey. Without their help and comments, the project would have lacked a considerable amount of valuable information.

Thanks also to the National Physical Laboratory's Thermophysical Properties Group for their advice and extensive assistance on the measurement of thermal gradients.

8 REFERENCES

- [1] Glaser M. Do J. Y. "Effect of Free Convection on the Apparent Mass of 1 kg Mass Standards". *Metrologia*, 1993, 30, 67-73.
- [2] Glaser M. "Change of the Apparent Mass of Weights Arising from Temperature Differences". *Metrologia*, 1999, 36, 183-197.

9 APPENDICES

9.1 Appendix 1: Survey questionnaire

**THE NATIONAL PHYSICAL LABORATORY
SOUTH YORKSHIRE TRADING STANDARDS UNIT**

**JOINT PROJECT TO STUDY THE PROBLEMS OF THERMAL
INSTABILITY AND ITS EFFECT ON WEIGHING**

This survey is part of a project funded by the Department of Trade and Industry and being carried out jointly by the National Physical Laboratory and the South Yorkshire Trading Standards Unit to carry out an investigation into thermal influences on balances and production of technical report quantifying the effect. A user guide will be produced recommending test practice.

We will not identify individual answers to particular companies in the report that will be published. However, your full and frank answers, comments and advice will be much appreciated as it will help us to prepare a user guide to help those who need to make weighings as part of their business.

Although this is a telephone survey, you can also submit written comments if you wish. All information will be of value.

If you would prefer us to call back at a different time or on a different day we can do so.

Once the project is completed the results of our researches and our recommendations will be published. If you would like to receive details please let us know.

For further enquiries please contact:
National Physical Laboratory, Teddington, Middlesex TW11 0LW
Tel: 020 8943 6224 Fax: 020 8943 6458
South Yorkshire Trading Standards Unit, Thorncliffe Lane, Chapeltown,
Sheffield S35 3XX
Tel: 0114 246 3491 Fax: 0114 240 2536

FAX BACK ON 0114 240 2536

SURVEY ON THERMAL PROBLEMS IN WEIGHING

Name of Company:

Address:

Postcode

Contact Person:

Telephone:

Fax:

E-mail

Date of Survey:

EQUIPMENT AND ITS USE

1 Do you manufacture mass comparators or high accuracy balances?

☐ Yes ☐ No

2 Do you use mass comparators or high accuracy balances?

☐ Yes ☐ No

If the answer to both questions 1 and 2 is no then go to question 25.

3. What sort of weighing equipment do you use:

MAKE	MODEL NUMBER	NUMBER OF THIS TYPE	CAPACITY	READABILITY

Please continue on a separate sheet if needed.

4 What do you use this equipment for?

- ☐ Calibrating weights
- ☐ Other calibrations (give details)
- ☐ Weighing precious metals
- ☐ Weighing pharmaceuticals
- ☐ Other purposes (give details) ...

5. How do you use your weighing equipment. As a direct reading device or do you make comparison weighings?

☐ Direct reading ☐ Comparison weighings

6. Where do you use this equipment?

☐ In a calibration laboratory

- ☐ In a general laboratory
- ☐ On the shop floor
- ☐ Other (give details)

TEMPERATURE

7 Is the place where the equipment is used temperature controlled?

- ☐ Yes ☐ No

If the answer to question 7 is yes go to question 8, otherwise go to question 9.

8 Can you tell me something about the temperature controls?

8(a) What are the temperature limits? maximum
..... minimum

8(b) Do you limit the rate of temperature change with time?

- ☐ Yes ☐ No

If the answer to question 8(b) is yes go to question 8(c), otherwise go to question 9.

8(c) What limits do you put on the temperature change with time?
(For example: at not more than $0.5\text{ }^{\circ}\text{C h}^{-1}$)

details

9 Do you measure the temperature:

- | | | |
|--------------------|------------------------------|-----------------------------|
| In the room | ☐ Yes | ☐ No |
| Inside the balance | ☐ Yes | ☐ No |

If the answer to question 9 is yes go to question 10, otherwise go to question 11.

10. What equipment do you use to measure the temperature?

- ☐ Platinum resistance thermometer
- ☐ Thermistor
- ☐ Thermocouples
- ☐ Mercury-in-glass thermometer
- ☐ Other (give details)

11 Do you see any temperature effects in the weighings that you make?

- ☐ Yes ☐ No

If the answer to question 11 is yes go to question 12, otherwise go to question 13.

12 In what way does the temperature affect the weighing results?

- ☐ Causes measurement errors
- ☐ Causes a lack of repeatability
- ☐ Other (give details)

Please give as much detail as possible if the answer to the above questions is yes.

WHAT ARE YOU WEIGHING

13. What do you generally weigh?

- ☐ Test weights
- ☐ Solids
- ☐ Liquids
- ☐ Powders

14. Please give details of the materials or objects that you weigh.

15. Are the materials that you weigh all of the same composition?

☐ Yes

☐ No

16 Do you weigh items of different shapes?

☐ Yes

☐ No

Please give additional information where available

YOUR BALANCE OR MASS COMPARATOR

If you have several weighing machines please answer the following questions in relation to the majority of your balances or mass comparators.

17. Do you normally leave the balance connected to the electricity supply at all times?

☐ Yes

☐ No

18. When your balances are connected to the mains electricity, do you leave it in the standby mode (if fitted) when you are not using them for weighing?

☐ Yes

☐ No

19 Does some or all of your balances have a calibration cycle?

☐ Yes

☐ No

If the answer to question 19 is yes to go question 20. otherwise go to question 22.

20 Does the calibration cycle use an internal or an external calibration weight?

☐ Internal

☐ External

☐ Both internal and external

21 How often do you use the calibration cycle?

- ☐ Before every weighing
- ☐ Each day before I start weighing
- ☐ Each week
- ☐ Each month
- ☐ I do not use the calibration cycle

Give additional information where available

22. When weighing, do you use any handling equipment?

- ☐ No
- ☐ Yes I use
 - ☐ Tweezers
 - ☐ Weight forks
 - ☐ Other (give details)
.....

23 When weighing, do you wear gloves on your hands?

- ☐ No
- ☐ Yes I use
 - ☐ Chamois leather gloves
 - ☐ Cotton gloves
 - ☐ Other (give details)
.....

24. Do you allow a stabilisation time before starting weighing?

- ☐ No
- ☐ Yes I allow
 - ☐ Up to 30 minutes
 - ☐ Up to 2 hours
 - ☐ Up to 12 hours
 - ☐ Up to 24 hours
 - ☐ Up to 7 days
 - ☐ More than 7 days

(Give additional details where available)

25 Thank you for taking part in this survey. Is there any other information you can give which might help us?

26 Would you like to receive a copy of the Good Practice Guide?

☐ Yes

☐ No

27 If you would also like to send written comments please do so
We would appreciate it if you would send any comments by the
end of September 2000.

9.2 Appendix 2: Organisations providing a response to the survey questionnaire

Aberdeen City, Aberdeenshire and the Moray Councils Mass Calibration Laboratory
Absolute Calibration Limited
ALSTOM Gas Turbines Ltd, ALSTOM Energy Technology Centre
Antech Engineering Ltd
Bestobell Service, A division of Meggit Mobrey Ltd
BG Technology Calibration Laboratory
Cardiff Metrology Services
Cleveland Metrology and Calibration Centre
Daco Scientific Ltd
Dartec Ltd Calibration Facilities
Denison Mayes Group
DERA
Devon Metrology Laboratory
DH·Budenberg Gauge Co Ltd, Budenberg Pressure Standards Laboratory
Durham County Council Metrology Laboratory
Essex County Council Metrology Services
European Instruments
Fife Council Trading Standards Service
Furness Controls Limited
Glasgow City Council Calibration and Test Centre
Glaxo Operations UK Ltd (Barnard Castle)
Glaxo Operations UK Ltd (Ware)
H & D Fitzgerald Ltd
Hampshire Scientific Services Calibration Centre
Hertfordshire Metrology Laboratory
Humitec Ltd
Instrument Services Ltd
James Scott
Johnson Controls Calibration Laboratories
Kent Scientific Services
Laboratory of the Government Chemist
Leicestershire County Council Trading Standards Service
Littlebrook Power Services Ltd
London Borough of Brent Trading Standard Services
London Borough of Havering Trading Standards Services
London Borough of Sutton Trading Standards Services
Marconi Marine (VSEL), Barrow Calibration Centre
Metrotec Engineering AG
Mettler-Toledo Ltd
Midlothian Council Metrology Laboratory
National Physical Laboratory Mass and Density Standards
National Weights and Measures Laboratory
Norfolk County Council Trading Standards Department
Northern Ireland Trading Standards Service
Pressurements Limited
RAPRA Technology Limited
Sartorius Limited
Scotia Instrumentation Limited
Sheffield Assay Office
S I Pressure Instruments Ltd

SIRA Test and Certification Ltd
Soil Mechanics
Solartron – Transducer Standards Laboratory
Southend on Sea Borough Council Trading Standards Service
South Yorkshire Trading Standards Unit
St Helens Metrological Laboratory
Suffolk County Council Trading Standards Laboratory
Henry Troemner Inc
Tyne & Wear Trading Standards Joint Committee Metrology Laboratory
Universal Calibration Laboratories
Warwickshire County Council Trading Standards Department
West Yorkshire Calibration Laboratory

9.3 Appendix 3: Good Practice Guidance Note

THERMAL EFFECTS ON BALANCES AND WEIGHTS

Introduction

The information given in this Guidance Note includes recommendations of good mass measurement practice and should not be considered a comprehensive mass metrology guide. Other working practices may exist which fall outside the criteria for this text, or which simply have not been considered for inclusion in this Guidance Note.

Laboratory Environment

Temperature instability in mass laboratories arises from sources of heat or cold such as

- Windows, heating pipes and the transmission of heat from adjacent rooms;
- Equipment located in the calibration area - computers, monitors, weight handlers etc.;
- Effect of lighting;
- Air-conditioning;
- Human operators, who generate heat and create air turbulence.

In a laboratory environment, good thermal stability can be achieved by considering the following:

- Insulation of outside walls with the possible addition of a secondary internal wall;
- Windows, if provided at all, should be double or triple glazed;
- A secondary door to give an air lock between the mass laboratory and the outside;
- Mass comparators should, where possible, be installed away from vertical surfaces;
- If installed, consider the delivery and extraction of air from air-conditioning units.

Recommended temperature limits and stability ranges for mass laboratories are given in Table 1.

	<i>Class E1</i>	<i>Class E2</i>	<i>Class F1</i>	<i>Class F2</i>	<i>Class M1</i>
<i>Temperature limit (°C)</i>	18 to 22	18 to 22	17 to 23	16 to 25	5 to 27
<i>Temperature stability (8 hours) (°C)</i>	0.2	0.5	1.0	.5	2.0

Table 1: Recommended laboratory temperature limits and stability ranges

Selection and Siting of Environmental Sensors

Many temperature measuring devices are available for measuring the temperature within a balance or mass comparator. Three of the most common types of device used are:

- Platinum resistance thermometers (PRTs);
- Liquid-in-glass thermometers;
- Thermistor probes.

PRTs are used as reference thermometers in calibration equipment. Sensitivity and accuracy at the mK level is achieved, but the sensor should be mounted in a metal block if the effects of self-heating are not to be significant. A resistance bridge is required to convert the measured value in ohms to temperature units ($^{\circ}\text{C}$), thereby making the entire apparatus expensive.

Liquid-in-glass thermometers have the advantage of being cheap to purchase and calibrate and usually display long-term stability, with little drift between successive calibrations. They are however, difficult to interface with data handling equipment, and they are usually calibrated in a vertical orientation, which can make them difficult to incorporate in a balance case where it may be easier to lay the thermometer down.

Thermistor probes are a good compromise, providing versatility of use and good measurement uncertainty. Thermistors with exposed beads are the best choice, as they have lower thermal inertia and therefore quicker response.

Sensors should be mounted within the balance enclosure in the same horizontal plane as the artefacts being calibrated. Figure 1 shows a close up picture of an exposed bead thermistor probe protected by a thin metal sheath (typically 10 mm diameter and 20 mm long) and then an example of this probe positioned inside a balance enclosure.



Figure 1: Thermistor probe and its siting in a balance enclosure

Manual Mass Comparators

Manual mass comparators have thermal stability problems associated with their transformers and display units. Where possible these should be removed from the balance housing and located outside the immediate weighing area. In the case of motorised doors, consideration should be given to ensuring that the motors generate as little heat as possible. The doors should be capable of manual operation if required, and easily adjusted. Doors should be checked for a good fit avoiding gaps at the edges. Secondary housing, either from the manufacturer or custom made, can help to improve thermal stability.

Automatic Mass Comparators

Automatic mass comparators have thermal stability problems associated with the weight handler control motors. These motors have a heating effect, which can raise the temperature of the weighing environment by up to 1 °C on commencing the automatic weighing sequence. Awareness of this heating effect and suitable use of the delayed start and pre-run options in the control software can help to minimise the effects on the weighing data.

Balance Settings

Most modern electronic balances have settings for local environmental conditions such as vibration or the type of weighing application being carried out. However, in practice neither of these settings has any effect on elimination of errors due to thermal drift or thermal influences.

The auto-zero setting automatically re-zeros the balance when it has drifted from zero by a specified number of digits. It is recommended that the use of auto zero should be:

- Switched off – for comparison weighings;
- Switched off – for direct reading weighings when a correction is made for the zero reading before and after the weighing;
- Switched on - for direct reading weighings when only the loaded balance reading is taken.

The balance should always be connected to the power supply in standby mode so that thermal equilibrium is established in the balance. However, if this is not possible the balance should be switched on for a minimum of 1 hour before use.

Weight Handling

The presence of human operators inevitably influences the temperature stability of the weighing environment and the weights. The use of chamois leather gloved hands and suitable handling equipment can help to minimise this effect. Figure 2 shows three examples of loading a mass standard onto a weighing pan. The third example is recommended; using a gloved hand, which does not enter the weighing enclosure. Handling and loading of a mass standard in this way will help to minimise the thermal influence the operator.



Ungloved hand, potential heat transfer to weight and balance enclosure.



Operators hand enters the balance enclosure affecting the thermal stability.



Recommended practice.

Figure 2: Examples of incorrect and correct weight handling

Note: Where possible the weight handling equipment should be of a suitable length to allow the operator to load the mass comparator without their hand entering the weighing chamber, whilst still maintaining a good degree of handling stability.

Stabilisation Times

Before commencing any weighing, all the weights to be used must have had the opportunity to reach thermal equilibrium with the balance environment. The required acclimatisation time will depend on the size of the weight and the difference between the temperature in the balance case and the temperature in which the weights have previously been stored. Table 2 gives suggested minimum acclimatisation times.

<i>Nominal Value</i>	<i>Class E1</i>	<i>Class E2</i>	<i>Class F1</i>	<i>Class F2</i>	<i>Class M1</i>
1 000 kg	72	48	36	24	24
100 kg	36	24	18	12	12
10 kg	24	12	9	6	4
1 kg	12	6	4	3	2
100 g	6	3	2	2	1
10 g	3	2	2	1	1
1 g	2	2	1	1	0.5
< 1 g	2	1	1	0.5	0.5

Table 2: Recommended minimum temperature stabilisation times (in hours)

The data in Table 2 are based on theoretical estimates and, as an example, Figure 3 shows the theoretical exponential decay of temperature against time for a 1 kg mass standard with an initial temperature 5 °C above that of the balance enclosure. The recommended waiting or stabilisation times for the five different classes of weights are indicated.

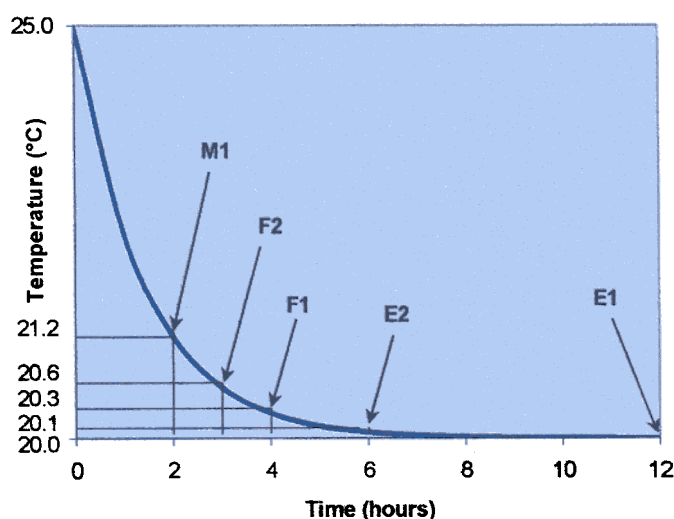


Figure 3: Thermal stabilisation of a 1 kg mass

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