

COMPARISON OF INSTRUMENTS FOR MEASURING RELATIVE HUMIDITY

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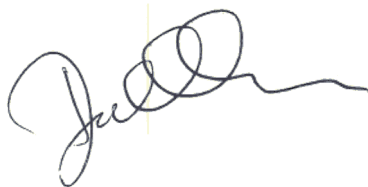
ABSTRACT

The measurement of relative humidity (rh) has implications throughout industry. Traditional methods for accurately determining rh have been to use wet- and dry-bulb psychrometers or to make a dew point measurement with a separate temperature measurement and convert into rh. The development of electronic devices for measuring rh has now achieved a position where the uncertainties compare favourably with other methods. With the recent commissioning of a relative humidity generation facility as part of the UK's Humidity calibration facility, a direct source of traceability for relative humidity measurements is now available, and the claims made for these devices can be examined. The aim of this work is to identify and examine commercially-available instruments for measuring relative humidity to determine which, if any, of these is suitable for use as a transfer standard of the very best accuracy. This project has been carried out as part of the DTT's National Measurement System Thermal Programme, 1998 to 2001, Project 4.2, Future Humidity Standards.

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A handwritten signature in black ink, appearing to read 'Dr Robinson', with a stylized flourish at the end.

Approved on behalf of Managing Director, NPL
by Dr David Robinson,
Head, Centre for Basic, Thermal and Length Metrology

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EXECUTIVE SUMMARY

This project has been undertaken to improve the dissemination of relative humidity standards in the UK, by identifying those commercially-available instruments which are most suitable for use as high-accuracy transfer standards.

The recent development of a high-accuracy rh calibration facility at National Physical Laboratory (NPL) as part of National Measurement System (NMS) provision of UK humidity standards has enabled relative humidity instruments to be calibrated to a high level of accuracy but in order to disseminate this improved uncertainty of measurement it is necessary for relative humidity transfer standards to be of suitable quality.

The majority of new developments in this field of measurement have been in the use of micro-electronics and signal processing to produce “electronic” RH instruments, but more traditional measurement techniques like wet-and-dry psychrometers, and cooled mirror hygrometers are still widely considered to produce the highest quality measurements.

In this project several hygrometers of different makes and types were selected and their performance examined over a period of time greater than the usual interval between calibrations. The instruments were subjected to calibrations against the standards at NPL at the start of the project, at the mid point and at the end of the project. The calibrations were separated by periods of simulated use at TÜV Product Service, Assessment Service, Fareham.

The ease of use of the electronic RH instruments can give a false impression of the complexity of the measurements they are making. Significant calibration corrections were found and one probe suffered from a stem conduction effect.

The electronic rh instruments tested showed stability and reproducibility similar to that shown by the industrial condensation hygrometers and the psychrometer of better than 1.5%rh. The measurements of temperature were reproducible to better than 0.3 °C

The more traditional instruments, the psychrometer and the dew point meter, actively affected the environment they were trying to measure.

In general the instruments tested performed well, but from the 5 %rh spread in the agreement between the hygrometer initial readings it was apparent calibration is necessary preferably under exact conditions of use. Some of the instruments that were subjected to temperatures up to 70 °C developed faults, and repairs that would not affect the previous calibrations were implemented where possible. But on some instruments, a full range of tests were not able to be performed. This indicated that it is important to consider the appropriateness and robustness of a given method of measurement and instrument.

1 INTRODUCTION

The aim of this project was to improve the dissemination of relative humidity standards to UK industry by identifying those commercially-available instruments which are most suitable for use as high-accuracy transfer standards and for best uncertainty in the measurement of relative humidity (rh) in the most critical applications.

The recent development of a high-accuracy rh calibration facility at National Physical Laboratory (NPL) as part of National Measurement System (NMS) provision of UK humidity standards has enabled relative humidity transfer standards to be calibrated to a high level of accuracy.

In order to disseminate the improved uncertainty of measurement it is necessary to identify suitable instruments for use as transfer standard devices. These will be commercially-available instruments which have been demonstrated to perform to the very highest level across part or all of the measurement range.

The majority of new developments in this field of measurement have been in the use of micro-electronics and signal processing but it is still of value to consider more traditional measurement techniques like wet-and-dry psychrometers, which are still in widespread use.

While it is true that psychrometers are most suited to measurement at higher values of rh, and that electronic probes are often unsuited to use at high ambient temperatures, it is appropriate to test all the devices over the full range of operating conditions specified by the manufacturers.

There have been previous studies^{1,2} of rh devices but the continued development and improvement of these instruments necessitates further evaluations to enable the end user to make sense of the varied claims, and to choose the most appropriate device for their purpose. As psychrometers have been particularly well documented over many years and have undergone limited change, it is therefore worth discussing previous work. For electronic probes which are still evolving, historic literature has less relevance.

While it is valuable to examine the test instruments in ideal conditions it is realized that in practice this is not always how they are used. The issue of "conditions of use" is too large to be fully addressed within this project. For the purpose of the practical evaluation of devices within this project, all the current "best practice techniques" have been adopted as far as possible, consistent with advice from the suppliers of instruments evaluated. However it is recognized that there is the need to set limits on the conditions of use for psychrometers, and a basic summary of previous work in this area involving the effect of the major factors (such as air flow rate, wick construction, preparation and cleanliness) has been carried out.

2 DEFINITIONS

Some simplified definitions

Relative humidity - The ratio of the actual vapour pressure to the saturation vapour pressure over a plane liquid water surface at the same temperature, expressed as a percentage.

Dew point - The temperature at which dew, or condensation, forms, on cooling a gas.

Water vapour pressure - That part of the total pressure contributed by the water vapour.

Hygrometer - An instrument for measuring humidity, water vapour content or moisture content of a gas.

Psychrometer - A hygrometer which measures evaporative cooling, which is related to relative humidity or water vapour pressure.

Electronic relative humidity probe - A hygrometer which senses the change in electrical property of a material with change in relative humidity.

Cooled-mirror hygrometer - A hygrometer which measures dew point by cooling a mirror element and measuring the temperature at which dew or frost begins to form on it.

3 CURRENT STATE OF THE ART

3.1 NATIONAL STANDARD

NPL holds the national standards for many quantities, one of which is humidity. These standards provide the measurement traceability for accredited laboratories, UK industry and a route of traceability for measurements made in many other countries. The humidity facility consists of a gravimetric hygrometer and three humidity generators covering a dew-point range of -75 °C to +82 °C. The NPL Primary Gravimetric Hygrometer (PGH) is the ultimate standard for mixing ratio, with an uncertainty over parts of its range that is ten times better than any humidity generator. The humidity generators provide the calibration service for dew point and now also relative humidity, and have been validated as primary standards in their own right with traceability to temperature standards. An additional route for traceability for the humidity generators is to mass standards via the PGH and an extensive programme of intercomparisons has been carried out against the Standard Humidity Generator (SHG). The uncertainty with which the NPL humidity generators can supply a generated dew point ranges from ± 0.03 °C to ± 0.1 °C.

Recently, a new rh calibration facility has been commissioned at NPL. This facility enables the calibration of rh devices directly against a national standard, with a corresponding improvement in calibration uncertainty. The uncertainty in the generated condition is $\pm (0.5\%$ of reading $+0.1\%$ rh).

3.2 CALIBRATION SYSTEMS

High quality calibrations of rh are in general derived from the measurement of dew point and a separate temperature measurement. The dew point measurement is generally made using a cooled mirror condensation hygrometer calibrated with reference to the national standard dew point generators held by the NPL in the UK. A stable environment with respect to both dew point and temperature has to be created to enable a well defined rh to be generated. The main contributions to the uncertainty of this technique are the stability of the controlled environment and the calibration of the standards used.

The typical uncertainties in the generated condition derived from this method are at best 1% of reading.

It is good practice (e.g. recommended by UKAS) that statements of calibration uncertainties contain a contribution from the instrument performance while under test. Many of the

contributions from the test instrument are not always determined e.g. hysteresis and repeatability, but the resolution and short term stability (e.g. standard deviation of the set of measurements) can easily be incorporated.

INSTRUMENTS

There are principally three types of rh instrument which present the best options for high quality rh transfer standards: dew-point condensation hygrometers with a separate temperature measurement, psychrometers and electronic rh probes.

3.3. Dew point

At present general practice for high quality laboratory rh measurements is to use dew point condensation hygrometer and a separate temperature measurement. These measurements are converted into rh using established formulae.

A small mirrored surface within a measurement head is cooled using a peltier heat exchanger until moisture condenses onto the surface. The thickness of this film is controlled optically and the temperature of the mirror is measured, this is the effective dew-point temperature.

Psychrometers

A psychrometer, or wet- and dry-bulb hygrometer, consists of two temperature elements one covered by a wetted sock with a thermal barrier between the temperature elements. The evaporation of water from the wetted sock causes its temperature to fall. This temperature drop or depression can be converted into a value of rh.

The correct operation of a psychrometer is dependent on an adequate and steady flow of air over the sensing elements, and the best psychrometers are equipped with a fan or impeller to maintain the necessary air flow - typically of 3 m s^{-1} .

Electronic probes

This type of rh measuring instrument typically incorporates a thin-film sensing element in which an electrical property (resistance, capacitance, complex impedance) varies consistently with changes in humidity. The principle of operation of this type of device is not in any sense "fundamental" and so a calibration against a proven standard is essential. The high gas flow rate required for psychrometer calibration is not required for electronic devices, but they have other limitations, such as linearity, repeatability of measurement at maximum and minimum rh values (depending on the sensor type), temperature coefficient and the likelihood of permanent damage if subjected to condensation conditions (i.e. rh of 100%) although many modern probes are specified by the manufacturer to withstand these conditions.

3.4 MEASUREMENT PROBLEM

Manufacturers' uncertainty claims for many rh instruments are now smaller than that achievable for many calibration systems and to substantiate the advertised performance is difficult without access to a top quality calibration system.

4 APPROACH TO THE EVALUATION

4. GENERAL APPROACH

The direct calibration of appropriate high-quality rh measuring instruments against the National standard, will help to reduce some of the limitations on uncertainty of rh measurement. However before this benefit can be disseminated to industry, it is essential to identify the most suitable instruments for use as rh transfer standards

The purpose of the study has been to compare the performance of different types of relative humidity hygrometer to the best uncertainty achievable, using the newly-commissioned rh calibration facility at NPL.

Usage

In assessing the potential of measuring instruments for use as transfer standards it is essential that during the evaluation period the instruments are subjected to use of the type which may be expected in service. The pattern of use may involve both laboratory and field measurements. To ensure a representative pattern of usage during the tests, the instruments have undergone simulated usage at the UKAS-accredited testing laboratory of TÜV Product Service, Assessment Service, Fareham. Details of the tests performed by TÜV are given in their reports which are included in this document as Appendices B and C.

Length of the tests

To investigate the stability of the test instruments it is essential that the time span of the tests is longer than the typical re-calibration interval, which for these types of devices can be up to one year, dependent on conditions of use and required uncertainty of measurement.

4.1.3 Calibration of psychrometers and other sensors

To provide a meaningful and applicable calibration it is sensible to simulate the same conditions as in use. For psychrometers the best approach is to place the device in a chamber through which gas at a controlled humidity flows at a controlled rate. For comparable thermal conditions the impeller must be operating during the calibration. This necessitates the control of the flow rate in the calibration system to closely match that of the psychrometer and simulate operation in free air.

For this reason it is necessary to have a calibration system which is capable of generating a high but variable flow rate.

For the calibration of other devices the rate of flow across the probe in general needs to be less.

4.1.4 Temperature

Although temperature is not the main theme of this project it obviously has a great effect on the measurement of relative humidity. For the electronic rh probes the minimum effect would be the temperature compensation applied, but other more fundamental effects may be less obvious.

Previous work

In selecting a device for use as a transfer standard, consideration must be given to its calibration performance and long term stability, and these issues are addressed by the work described above. However another issue, which is of particular relevance to the use of psychrometers, is that of conditions of use. It is known that the air flow rate, the construction and cleanliness of the “sock” and the cleanliness of the water in the reservoir can significantly affect the performance of a psychrometer. A full study of these issues is beyond the scope of this project. However it is essential to provide some guidance as to the limitations that conditions of use impose on the performance of psychrometers as transfer standards. A small-scale literature study has been carried out detailing the effects of the major factors, and this is summarised in Appendix A

4.2 THE NPL RELATIVE HUMIDITY CALIBRATION SYSTEM

The calibration system^{3,4,5} consists of two parts

High flow rate calibration system

This system consists of a high flow rate humidity generator which has a calibration chamber surrounded by a temperature conditioning coil, immersed in a well-stirred temperature controlled fluid bath. The instrument is located in the re-circulation path of the generator with a flow rate of up to 700 litres per minute, which gives an air flow velocity of 3 meters per second in a chamber big enough to house the test psychrometer.

Low flow rate calibration system

This system also consists of a chamber and conditioning coil immersed in a well-stirred bath. The principal difference in its mode of operation is that it is placed in the “bleed-off” path of the appropriate generator, rather than in the re-circulation path. The gas passing through the chamber is vented to the atmosphere. This has the advantage that the re-circulation system of the generator is protected from contamination, but the flow rate is limited to a maximum of a few litres per minute.

5 TEST PLAN

The work was split into seven stages:

- instrument selection phase
- initial calibration of the set of instruments at NPL
- first industrial simulation period at TÜV
- second calibration at NPL
- second industrial simulation period at TÜV
- final calibration at NPL
- evaluation and report.

The planned interval between the first and last calibrations was 14 months. In this way the performance of the instruments was evaluated over a period longer than the usual calibration interval.

The test instruments were subjected to simulated use, involving temperature and humidity cycling in an environmental chamber. In each case, a log of practical and/or simulated use for each instrument has been maintained.

In parallel with the calibration and use of the devices being evaluated, a study has been made of the principal component uncertainties arising from variations in certain conditions of use for psychrometers has been investigated. In particular the effects of different air flow rates and the selection and cleanliness of the wick or wet sock have been examined.

6 INSTRUMENT SELECTION

6.1 SELECTION CRITERIA

In general to be identified as suitable for use as a transfer standard a particular type or class of instrument must demonstrate:

an ability to make repeatable measurements, with an appropriate uncertainty, throughout the specified (rh and temperature) range

a robustness such that performance is not adversely affected by typical conditions of use

a long-term stability consistent with an appropriate re-calibration interval (typically one year, though if appropriate a shorter re-calibration interval may be recommended).

6.2 RELATIVE HUMIDITY HYGROMETERS

A number of leading suppliers of electronic rh probes consider their instruments suitable for use as transfer standards, and Rotronic Instruments, Vaisala UK, Testo and Novasina submitted instruments for this evaluation. One of the UK's leading suppliers of standards-quality psychrometers, Automatic Systems Laboratories plc, submitted an instrument for the evaluation, and Michell Instruments submitted an rh system based on an industrial cooled mirror hygrometer. The manufacturer of each instrument for the assessment specified an appropriate measurement range.

In past experience, electronic rh probes have suffered from drift after being subjected to extremes of condition or cycling to high temperatures, so to obtain meaningful results two sets of electronic probes have been tested. One set were subjected only to ambient temperatures of approx. 20 °C to 25 °C and rh values from 20%rh to 80%rh. The other set were subjected to a greater temperature and rh range, but within their specifications.

6.3 INSTRUMENTS SELECTED

The instruments selected for the tests at an ambient temperature of approximately 23 °C were:

Manufacturer	Model	Range	Quoted Accuracy*
Vaisala	230	-40 °C to 60 °C / 0%rh to 100%rh	±1%rh
Testo	650	-40 °C to 70 °C / 0%rh to 100%rh	±1%rh
Novasina	MS1	0 °C to 50 °C / 5%rh to 98%rh	±1%rh
Rotronic	A1	-20 °C to 75 °C / 5%rh to 99.9%rh	±1.5%rh

The instruments selected for tests at elevated ambient temperatures were:

Manufacturer	Model	Range	Quoted Accuracy*
Vaisala	243	-40 °C to 100 °C / 2%rh to 98%rh	$\pm(0.5\%rh + 2.5\%$ of reading)
Testo	650	-20 °C to 180 °C / 0%rh to 100%rh	$\pm 2\%rh$
Novasina	Hygrodat 20	-20 °C to 60 °C / 5%rh to 100%rh	$\pm 1\%rh$
Rotronic	A2	-50 °C to 150 °C / 0%rh to 99.9%rh	$\pm 1.5\%rh$
Michell	Dewmet cooled mirror	-20 °C to 100 °C / 0%rh to 100%rh	$\pm 1\%rh$
ASL	PS250 psychrometer	0 °C to 100 °C / 10%rh to 100%rh	$\pm 0.5\%rh$

* Accuracy is a poorly defined term and is assumed to mean either; maximum calibration correction, or maximum deviation from the true value between calibrations, or projected uncertainty

Manufacturers specifications (where available) are given in Appendix B

7 EVALUATION PHASE

On arrival at NPL the instruments were calibrated using one of the NPL humidity generators. The low temperature probes were subjected to relative humidities of 20%, 40%, 60%, and 80% at an ambient temperature of approximately 23 °C. The high temperature probes were subjected to relative humidities of 20%, 40%, 60% and 80% at ambient temperatures of 20 °C, 50 °C and 70 °C. Some additional points at 10% and 90% were taken and some points at 80 °C were also examined.

This first calibration was followed by a period of simulated use at TÜV detailed in Appendix C. The second calibration was performed similar to the first and again followed by a period of simulated use at TÜV detailed in Appendix D. A third calibration was performed followed by a further calibration of the high temperature probes, this was an attempt to gain a full set of data for each probe, due to the unexpected breakdown of several of the instruments during earlier tests.

8 RESULTS

8.1 MEASUREMENT RESULTS

As there have been extensive measurements the results are presented graphically for simplicity. The data points are joined by lines only to guide the eye. A full set of calibration corrections are detailed in Appendix E.

The graphs show the maximum deviation of the calibration corrections from the mean correction for the calibration runs. In this way a quantitative comparison of the stability of each instrument can be made.

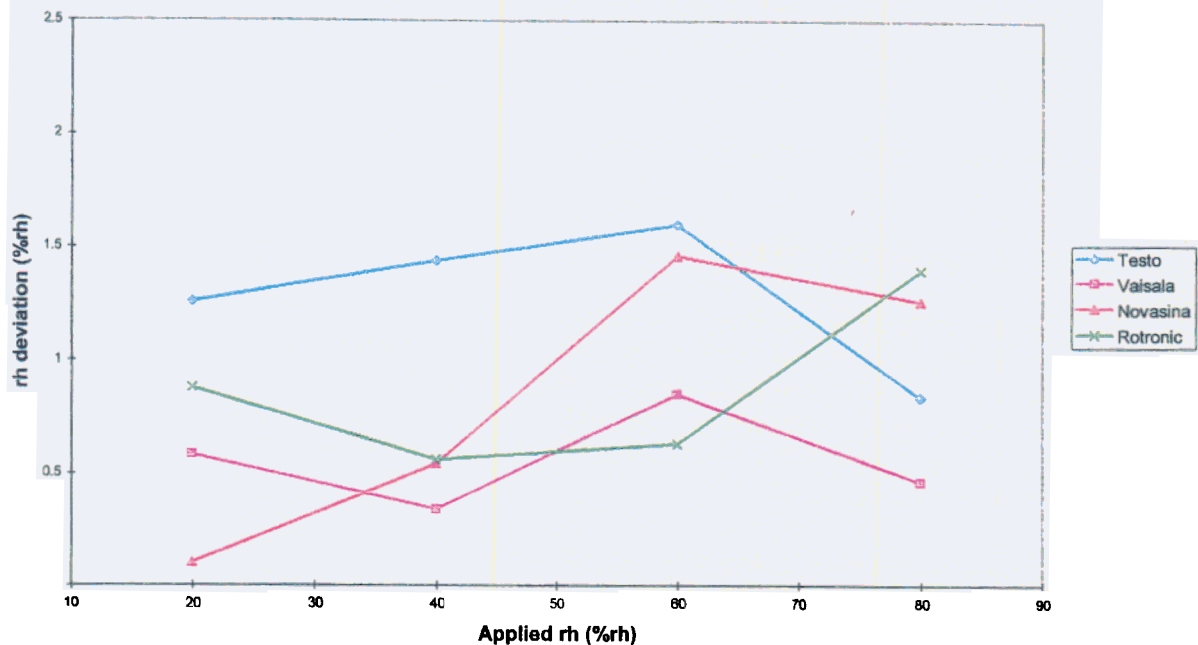
Graph (a) shows the values for the electronic probes subjected to only 23 °C.

Graph (b) shows the values obtained for the psychrometer and the dew-point meter at temperatures of 23 °C, 50 °C, and 70 °C.

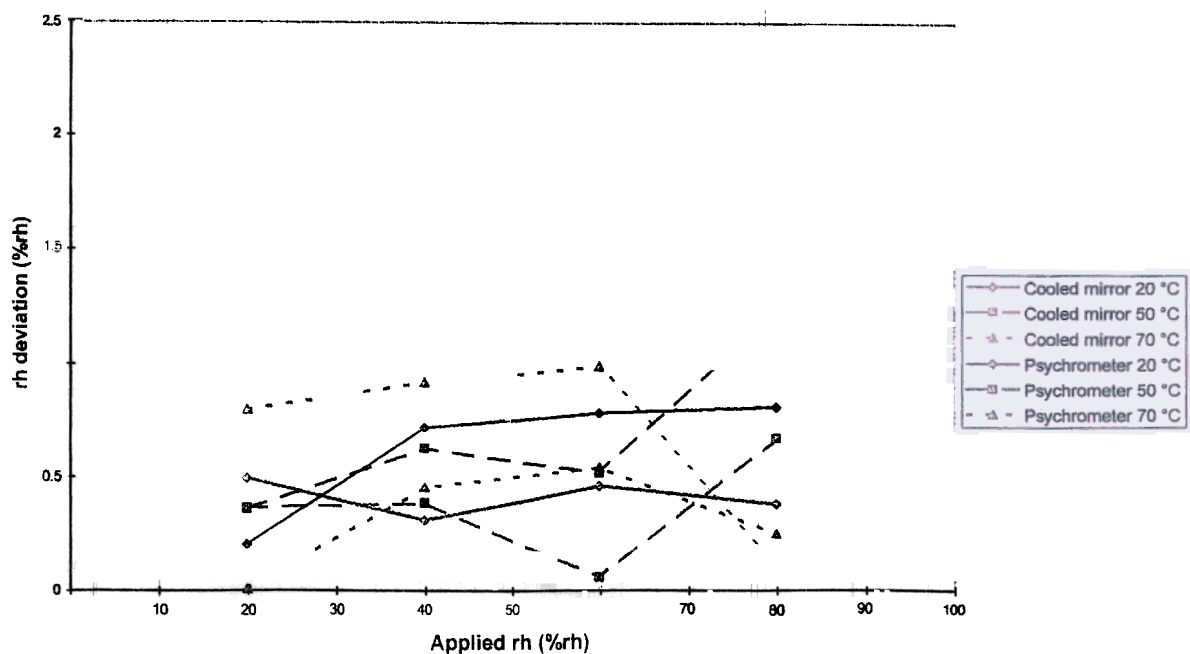
Graph (c),(d) and (e) show the values for the electronic probes subjected to ambient temperatures of 23 °C, 50 °C and 70 °C. For the Testo probe there is also a maximum deviation from the mean for runs 2,3,4 as will be discussed later, problems with stem conduction were encountered during run 1.

In general the results show good repeatability of better than 1.5%rh over the length of the project, with the psychrometer, dew-point meter and some electronic probes repeating to better than 1%rh.

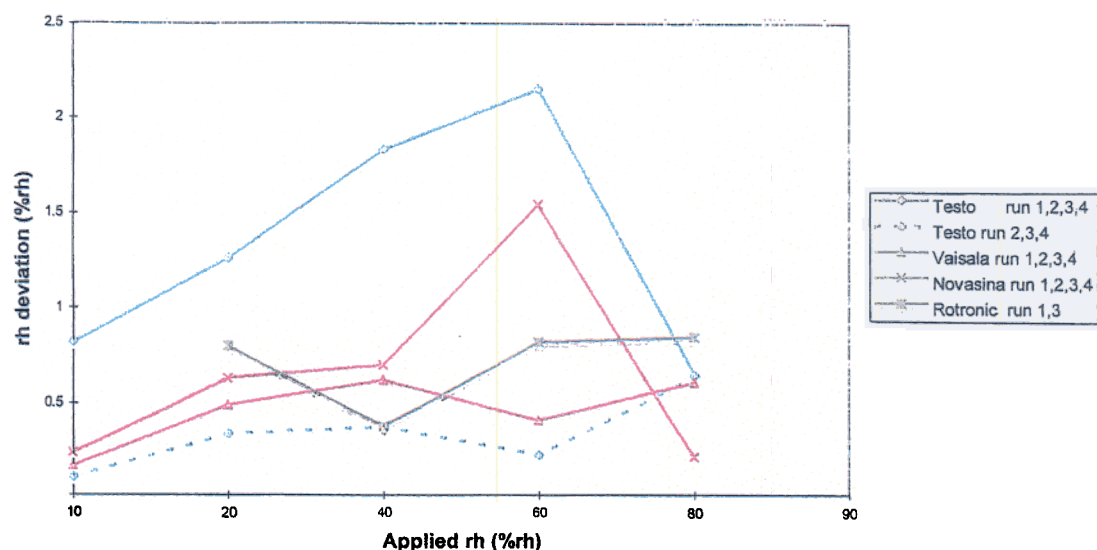
The measurement of temperature was in general reproducible to within 0.3 °C.



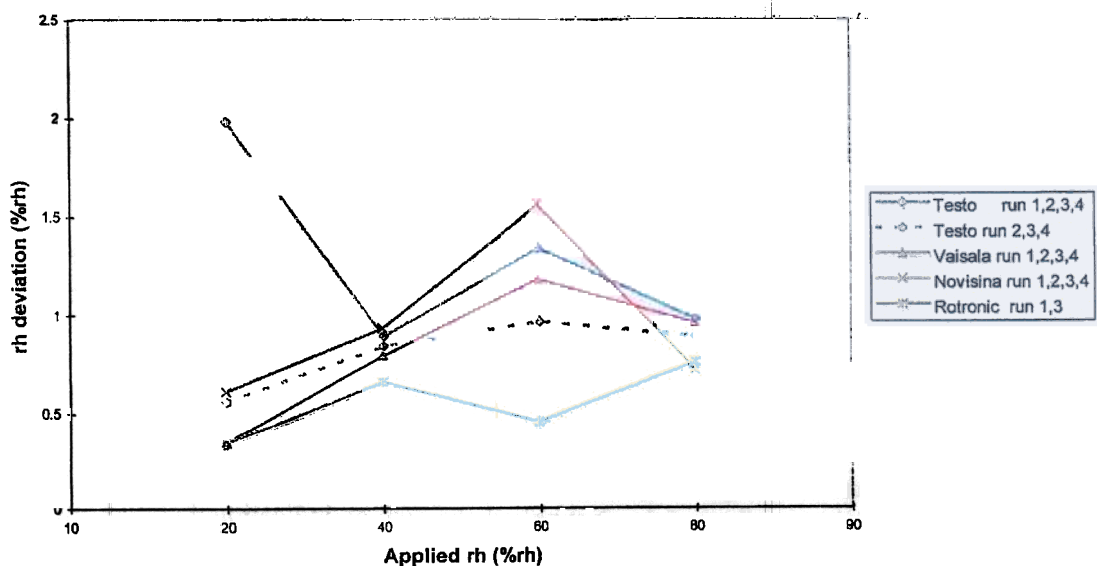
Graph (a). Shows the maximum deviation from the mean correction for the electronic probes subjected only to ambient temperatures of approximately 23 °C.



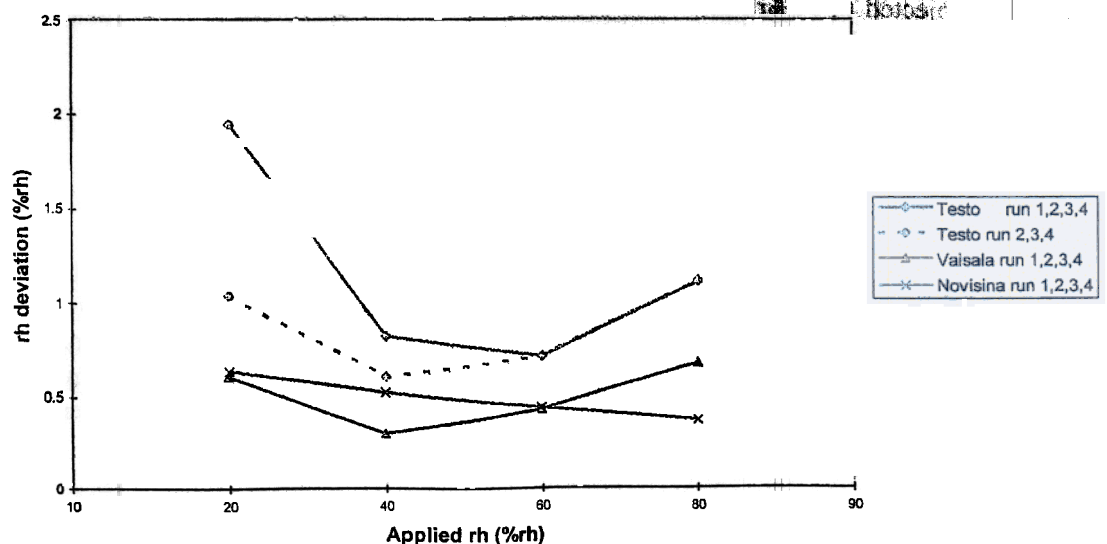
Graph (b). Shows the maximum deviation from the mean correction at 23 °C, 50 °C and 70 °C for the cooled mirror hygrometer and the psychrometer.



Graph (c). Shows the maximum deviation from the mean correction at 23 °C for the electronic probes subjected to high ambient temperatures.



Graph (d). Shows the maximum deviation from the mean correction at 50 °C for the electronic probes subjected to high ambient temperatures.



Graph (e). Shows the maximum deviation from the mean correction at 70 °C for the electronic probes subjected to high ambient temperatures.

8.2 PROBLEMS ENCOUNTERED

The first calibration run on the electronic rh probes was performed using a chamber approximately 150 mm diameter and 200 mm deep. The sensing element of the probes were positioned centrally in the chamber. By examining the calibration data it appeared that, at the higher temperatures the long Testo probe had suffered from an effect known as stem conduction. This is where thermal transfer along the stem or shaft of the probe is seen as an error in the temperature reading. In this case it could either be the temperature effect on the electronics in the handle or the to the sensor itself. The probe had a metal shaft approximately 300 mm long and had approximately 150 mm protruding from the measurement chamber into an outer chamber held at up to 60 °C, which was the maximum temperature specified for the handle. To overcome this effect subsequent calibration runs were performed in a larger chamber enclosing at least 250 mm of the probe shaft.

During the first calibration the sensor terminals of the psychrometer corroded and one of the matched pair of PRTs malfunctioned. Consequently both PRTs were replaced, and the psychrometer recalibrated.

The dew point hygrometer at first would not give a stable output at elevated temperatures and an adjustment to the electro-optics to alter the light intensity of the photodiode was required. This adjustment is detailed in the instrument manual and required the removal of the front cover of the instrument electronics.

During the first simulated use tests the high temperature Rotronic A2 probe developed a fault, where the temperature read -160 °C but the humidity read correctly. The instrument was sent for repair. The electronic indicator for the high temperature Testo probe developed a fault, possibly the effect of replacing the batteries in the wrong way round. The electronic display unit was sent for repair.

No problems were encountered during calibration run 2 and the second industrial tests.

During Calibration Run 3 the high temperature Rotronic A2 instrument developed a fault, where it displayed 13%rh regardless of the rh supplied and with no indication that the reading was erroneous. Also part of the casing for the end protection screen broke off.

During calibration Run 4 in the larger chamber, the high temperature Testo probe developed a fault when subjected to 90%rh at 70 °C, possibly due to the ingress of steam which may have condensed inside the colder handle adjacent to the chamber exit port.

9 DISCUSSION

9.1 GENERAL

From the spread of humidity results of the first calibration it can be seen that some of the instruments readings were outside the manufacturers specification by more than 4%rh, highlighting the need to have a traceable calibration to provide the correct value. From the sets of results it can be seen that after this initial calibration, in general, the readings from the electronic rh instruments vary from the mean of the sets by a little more than 1%rh whereas the cooled mirror hygrometer and the psychrometer varied by a little less than 1% rh.

The operational aspects of the dew point meter and the psychrometer were more labour intensive than other rh sensors, e.g. cleaning the mirror and wick which are active checks on

the operation of the instrument. To clean the mirror the instrument must be re-balanced, which heats the mirror to removing the dew film. During this operation the displayed temperature of the mirror can be observed ensuring that both heating and cooling are operational. The wick of the psychrometer must be removed to clean it, while the wick is off the temperature of the two probes can be observed and should read closely the same temperature. These observations are extremely useful and check part of the operation of the instruments at regular intervals. A more definitive check would be to compare the humidity reading with a second instrument. These are checks that can also be performed with the electronic rh instruments. Additionally these electronic probes can be checked against verified salt solutions.

9.2 TEMPERATURE

Apart from the initial stem conduction effect in run 1, all the hygrometers tested showed reproducible measurement of temperature to better than 0.3 °C

9.3 ELECTRONIC PROBES

The results show the rh deviation from the mean correction for each instrument. In this way the performance in terms of repeatability for all the instruments can be compared. The correction graphs at different temperatures show distinct differences in shape. This reinforces the need for calibration throughout the temperature and humidity range of use.

No failures were encountered with the instruments maintained at ambient temperatures of approximately 23 °C, the drift and repeatability over an interval of one year were better than 1.5% rh and in general within the manufacturers specification.

The probes that were subjected to elevated temperatures experienced some problems, This suggests that their suitability could be improved in terms of robustness.

The anomalous readings given by malfunctioning probes suggests that good practice would be to perform periodic checks against a bench mark (e.g. a separate probe or a salt solution capsule) to ensure that the instrument is operating correctly.

In general we found the probes that were entirely enclosed in the measurement chamber performed better, being more robust and did not suffer from “stem conduction” effects at elevated chamber temperatures. On the other hand the probes with long stems that protrude into the measurement chamber have the advantage of instant and easy maneuverability.

9.4 PSYCHROMETERS

The operation of the psychrometer necessitates the evaporation of water from a wetted sock. Consequently this water mixes with the surrounding air effectively locally increasing the relative humidity. If the psychrometer is used to measure in an enclosed space the increase in rh could be significant.

9.5 COOLED MIRROR HYGROMETER

The problem of a different calibration curve for different temperatures encountered by the electronic probes is to a great extent avoided by using a dew point and separate temperature measurement. The problem in this case is that for very low rh values the cooled mirror is some tens of degrees below the ambient temperature. To attain this temperature the peltier heat exchanger will rise significantly in temperature. The variations in the thermal

distribution across the cooled mirror are therefore significantly greater than if the same dew point were to be measured at a lower ambient temperature. This effect can be overcome by removing the cooled mirror hygrometer from the measurement chamber and sampling the gas through a tube, maintaining the hygrometer in the ambient temperature conditions in which it was calibrated. Additionally this would also remove the possibility of the excess heat from peltier heat exchanger locally heating the chamber. For static environments and chambers with a slow air flow rate this could present a problem.

The cooled mirror dew-point hygrometer light intensity needed to be adjusted to work at elevated temperatures. This was not initially obvious.

With a cooled mirror dew-point hygrometer there is a need to clean the mirror properly at regular intervals to avoid the buildup of contamination, as this can effect the reflectivity of the mirror and also means that the film is no longer pure water but a solution which will introduce errors.

At some rh values measured, the corresponding dew point was below 0 °C. The dew-point meter supplied did not indicate whether the condensate on the cooled mirror was ice or supercooled water. The effect of using the incorrect phase would give an error corresponding to 1%rh at 10%rh and 20 °C

10 CONCLUSION

The ease of use of the electronic RH instruments can give a false impression of the complexity of the measurements they are making, as demonstrated by the experienced users during this test. The significant calibration corrections, the effect of stem conduction, the need for adjustment to the dew-point instrument light intensity and the erroneous results were only evident after close examination of the calibration results.

Out of the hygrometers tested, the psychrometer and the dew point meter actively affected the environment they were trying to measure.

The electronic rh instruments tested showed stability and reproducibility similar to that shown by the industrial condensation hygrometers and the psychrometer of better than 1.5%rh. All the measurements of temperature were stable to better than 0.3 °C over the entire study.

Some of the instruments that were subjected to temperatures up to 70 °C developed faults (this extended the time scale of the project). Repairs that would not affect the previous calibrations were implemented where possible. But on some instruments a full range of tests were not able to be performed, indicating that the robustness of some of the instruments was not up to that required for the full temperature range specified for the instrument.

When an instrument is to be used for calibration, adjustment is discouraged so that the calibration history can be built up and the long term performance of the instrument can be evaluated.

An aspect of the identification of appropriate transfer standards which has been partially addressed by this project is that of "conditions of use" of the various instruments. This issue is particularly relevant to psychrometers, in which the performance can be severely affected by a number of factors, ranging from the flow rate of the air over the sensors to the purity of the water in the reservoir and the construction and cleanliness of the wick. For electronic rh

probes consideration should be given to the selection of an appropriate screen or baffle for the active element. As the operation of the electronic probes normally have no intrinsic checks (unlike psychrometers where the two temperature probes can be compared against each other) periodic checks should be carried out against another standard or salt solutions that generate stable values of humidity.

This study can only report on the individual sensors tested. Only a small selection of different instrument manufacturers were used to obtain an illustrative sample of the types of instrument available and there is no suggestion that instruments not used in these tests are in anyway inferior.

11 ACKNOWLEDGEMENTS

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12 REFERENCES

- [1] SONNTAG, D., WMO Assmann Aspiration Psychrometer Intercomparison, *Instruments and Observing Methods, Report No. 34*, 1987, World Meteorological Organization
- [2] VISSCHER G.J.W. and KONRNET J.G., Long-term Tests of Capacitive Humidity Sensors *Meas. Sci. Technol.* 1994, pp 1294-1302.
- [3] STEVENS, M. and BELL, S.A., The NPL standard humidity generator: an analysis of uncertainty by validation of individual component performance, *Meas. Sci. Technol.* 1992, 3, pp 943-952.
- [4] STEVENS, M. and ARMITAGE, D., Uncertainty evaluation of the NPL High Humidity Generator, NPL Report MOT 8, 1996.
- [5] STEVENS, M., Uncertainty evaluation of the Relative Humidity Facility at NPL, NPL Report CMAM 15, 1998.

A1 APPENDIX 1 - LITERATURE STUDY ON PSYCHROMETERS

A1. SUMMARY OF LITERATURE SURVEY

This is a summary of a literature survey carried out in order to investigate the influence of a number of factors that affect the function and repeatability of psychrometric devices and the determination of a value of the psychrometer coefficient, A . This survey looked at a small selection of the literature available relating to the use and design of a psychrometric device under the following headings:

- The choice of measuring element
- The effect of the shape and size of the measuring element
- The effects of changing the orientation of the element
- The effect of the length of the wick
- The choice of material for the wick
- The effects of wick contamination
- The effects of air velocity on the function of the device

Other factors which could potentially affect the function of psychrometric devices were also noted.

A1.2 INTRODUCTION

A psychrometer is a device used to measure relative humidity. It works by comparing the temperatures of two measuring elements, one of which is covered by a sheath of material that is soaked with water or ice (wet sheath or wet bulb). The effect of the wet sheath is to reduce the temperature of one of the elements, and this effect is known as depression. The measured temperatures are converted into vapour pressure values which are then used to determine the relative humidity (rh) value. For ventilation in a given range of air velocities the depression is directly related to the relative humidity.

The vapour pressure is calculated using the following formula known as the psychrometric formula

$$e = e' - AP(t - t_w)$$

Where e' is the saturation vapour pressure of water at temperature t_w , P is the total barometric pressure (in the same units), and A is the established value of the psychrometer coefficient (e can be calculated using the formulae due to Sonntag 1990, updated from formulae given by Wexler, 1976 and 1977).^{1,20}

A nominal value for A may be used which will lead to approximate values for relative humidity to which corrections may be applied. The applied corrections will depend on the individual psychrometer being calibrated against a traceable humidity standard in terms of relative humidity.^{1,23,28,29}

Relative humidity values are then calculated from the vapour pressure values obtained, using the following formula:

$$\text{Relative humidity (in \%)} = \frac{e}{e_s} \times 100$$

where e is the actual vapour pressure of water and e_s is the saturation vapour pressure of water at the prevailing temperature and barometric pressure.¹

A1.3 BACKGROUND

The first recorded measurements of humidity were in China in 150 BC but it was not until the late 18th century that the psychrometer first appeared and the principle of a temperature drop due to the effect of evaporative cooling of a wetted temperature element, used as a measure of relative humidity. The Englishman Hutton experimented with the principle in 1792 but it was not until 1887 that significant progress was made, when Assmann developed the ventilated psychrometer. His development led to a more accurate and faster responding instrument and the principle and design are still in use today.^{21,29}

Since this time there have been more than a thousand papers written about psychrometers. The literature has been reviewed on several occasions, most notably by Sonntag (1967), Wylie (1978) and Visscher (1995). Although there is some difference of opinion between the authors of these reviews as to the relevance of some of the references, it is clear that there are a considerable number of factors related to the fundamental design and use of psychrometers which have been found to be important and repeatedly investigated.^{23,29}

This survey has taken a few of these factors and looked at the information relating to them in a number of papers. All of the factors investigated, relate to the basic design and operation of a psychrometer in normal ambient conditions. If a psychrometer is to be used in an unusual location or condition then there may need to be further refinement to its design and mode of operation to cope with local conditions.^{14,15}

As well as examining the effects of choice of element, size and shape of element, orientation of element, choice of wick material, effects of wick contamination and effects of changes in air velocity there are a number of other factors to consider when designing and operating a psychrometer. These include the effect of the psychrometer on its environment, the effects of radiation from the temperature elements, the effects of stem heat conduction, the influence of radiation shielding in the body of the psychrometer for the temperature elements, radiation effects due to the material and surface of the body of the psychrometer and radiation effects due to the sun. These factors are particularly important if the psychrometer is to be used in the field. Shielding is required to prevent the close proximity of the temperature elements affecting each other and reduce radiation effects from the sun.^{20,24} For a standards level psychrometer, a black body has been suggested as the best solution to reduce the affects of thermal radiation but in the laboratory or field it may be more usual to use a highly polished stainless steel body. The design of the frame or body of the psychrometer is also important as there is a requirement to ensure that there is no disruption to the flow across the temperature elements, and that the heat from the motor on the fan is dispersed and does not introduce extraneous thermal effects. Visscher, Wylie and Lalas all comment on the importance of the psychrometer frame design.^{23,24}

Another important factor which affects the validity of the data obtained using psychrometric device, is the size and fit of the wick. This is particularly significant as a poorly fitting wick will impair accurate measurement of depression on the “wet bulb” and thus the final values of relative humidity obtained from the temperature measurement.¹²

All of these factors combine to affect the validity of the results obtained using a psychrometer. The survey shows that in past studies, the main approach has been to characterise a specific instrument design, and either by experiment or theoretically, to produce a global coefficient for any instrument conforming to that design. However there is evidence to show that this coefficient can vary significantly from one instrument to another as well as from one design to another.

From the survey it can be seen that the values of rh obtained using a psychrometer, and the value of the psychrometer coefficient, A, depend on the design, construction, components and operating procedures used. The factors investigated during this survey have a direct influence on the repeatability and accuracy of a psychrometric device and should be taken into account in design, construction or operation.

CHOICE OF TEMPERATURE MEASURING ELEMENT

The choice of the temperature measuring element depends on the preference of the manufacturer and the environment in which the device is to be used. Most types of temperature measuring element can be used providing they are calibrated and the characteristics known. However, consideration of factors such as response time or for example, the effect of a break in the liquid column of a liquid-in-glass thermometer need to be taken into account. For convenience, the choice is most likely to be a platinum resistance thermometers as the data from this type of element can be easily (and remotely) collected using a data logger but liquid-in-glass thermometers and thermocouples also have their advantages. Ideally the temperature element chosen, should be such that, when calibrated, it has an uncertainty of $\pm 0.05\text{K}$ but no worse than $\pm 0.1\text{K}$.²⁰

SIZE AND SHAPE OF THE TEMPERATURE ELEMENT

Published reports of work relating to the size and shape of the temperature element indicate that a difference in the shape and dimensions can have a direct effect on the response time of the thermometer.¹² This can lead to a false depression value and so it is important to ensure that the thermometers chosen for the wet and dry bulb measurements are of matched shape and size, otherwise comparison of the temperatures will lead to greater uncertainty. For example, if the two PRT's (platinum resistance thermometers) in a psychrometer are calibrated with an uncertainty of $\pm 0.05\text{ }^{\circ}\text{C}$ (at the 95% confidence level), this would give a worst case total of $0.1\text{ }^{\circ}\text{C}$. An error of $0.1\text{ }^{\circ}\text{C}$ between the two temperatures, could in turn lead to an error of over 2% rh. This indicates that matching of the temperature elements is important and that it applies to all types of temperature element, but evidence indicates that it is particularly significant when liquid in glass thermometers are used.^{12,23,24} This highlights the need to apply calibration corrections to thermometers wherever possible.

ORIENTATION OF THE ELEMENTS

The orientation of the elements in the air stream and their positions relative to each other can affect the depression values. In general, the preferred option seems to be that, the orientation of the element should be transverse to the flow. This ensures that the sensing part of the element is fully immersed in the flow path of the saturated gas and is more likely to indicate the correct temperature. Relative positioning of the elements is also important as this may affect the wet and dry bulb temperatures. The elements should be positioned so that they are both subject to the same conditions and so that the elements do not influence each other through radiation effects or by causing an interference in the flow path across the measuring elements.^{14,15,24,26}

THE LENGTH OF THE WICK

The type of temperature element chosen will partially determine the length of the wick. Investigations into the importance of the length of wick (or sheath) used, have shown that this is a significant factor and that it directly influences the effects of stem heat conduction. This is because the effects of stem heat conduction vary according to the type of temperature measuring element used. Evidence shows, that in order to compare two psychrometers with different types of temperature element, the effects of stem heat conduction need to be minimised so that in effect they are the same for both types of temperature element. This is achieved by using different lengths of wick material. Combating the effects of stem heat conduction will ensure that the values relative humidity can be calculated more reliably.^{7,12,14,15,24}

A1.8 THE CHOICE OF WICK MATERIAL

The aim when choosing a material for the wick, is to use a material which will form as smooth a surface as possible (so as to emulate a smooth cylinder of water). Also the material should supply water to the wet bulb from the reservoir in a uniform manner so that the ice or water sheath is consistent and the depression values are not adversely affected. In determining the choice of material for the wick there seems to be universal agreement that natural fibres, cotton, muslin or linen are the best choice.^{2,3,12,24,26} The material chosen should

also not be too thick as this will affect the depression values. There is some evidence of the use of man-made fibres and other substances such as gelatine, but the evidence also suggests that use of these will increase the value of the psychrometric coefficient, A and so should not be used for accurate work.^{24,25,27} As a general rule, the wick material supplied with the psychrometer should be used. This should ensure that the wick material is of the correct size to fit the temperature measuring elements, that the material is suitable for the purpose and that (once the wick has been cleaned) that there should be no contamination problems. Some of the literature surveyed recommends the use of cotton windings for the wick but in practical terms and for convenience this may not be the best option^{24,26}

A1.9 EFFECTS OF WICK CONTAMINATION

Contamination of the wick will affect the equilibrium rate of evaporation from the wick and therefore it is necessary to ensure that the wick is clean and free from contamination. The cleaning process should ensure that the wick is grease free and free from other types of contaminant. There is some evidence to suggest that flushing of the wick using purified distilled water is sufficient to remove contaminants and that further flushing or cleaning will not reduce the value of the psychrometric coefficient, A . However other evidence suggests that a more stringent cleaning process is required to eliminate the effects of contamination on the determination of A . Investigations by Wylie indicated that the depression reading was changed by 29mK for a monomolecular contaminant and 290mK (over 4%rh) when the wick was contaminated with hand grease.^{24,26} In practice, in field or industrial use, the effects of contamination could be worse. All of the literature relating to wick contamination recommends that the wick is changed frequently to combat the effects of contamination on the depression values and the validity of the psychrometric coefficient.

A1.10 THE EFFECTS OF AIR VELOCITY

The final factor considered during this survey was the effect of air velocity on the operation of the psychrometer and the determination of the psychrometer coefficient. There is wide agreement between various authors that at speeds in excess of 3m s^{-1} (or 1m s^{-1} for thermocouples) the wet bulb depression approaches a limiting value and above this speed, the psychrometric constant becomes virtually independent of the ventilation rate (up to a limit of 10m s^{-1}) and of the geometry of the wet bulb. However there is also evidence that too low or too high a ventilation rate will introduce other errors which may seriously affect the validity of the data obtained. This is particularly significant for psychrometers which are designed so that they do not have forced ventilation but have to rely on the local conditions to produce a flow of air across the temperature elements and thus produce a depression value.^{2,4,6,7,12,14,15,16,17,18,20,21,23-30}

A1.1 DISCUSSION OF FINDINGS

This survey concentrated on a specific set of influences which can affect the function of a psychrometric device. Whilst these factors are significant, it was also shown during the survey that there are a number of other considerations which need to be taken into account in order to design, construct and operate a psychrometric device effectively.

As the design of a psychrometer can take various forms there are many critical areas to be considered, some of the most important are:-

- Heat conduction from the instrument body to the temperature probes
- Ineffective radiation shield between the wet and dry probes
- Radiation from the instrument body to the wet probe
- Insufficient or varying air speed (aspiration rate)
- Incorrect fitting of the wet sock
- Reservoir at the incorrect temperature
- Poorly matched (or uncalibrated) temperature elements

Most users do not expect to have any control over most of these decisions. They are discussed here mainly to raise awareness.

Much of the literature surveyed concentrates on the evaluation and determination of a value for A , the psychrometric coefficient for a device (or particular design of device). However in practice the value of A can vary between devices of the same design as well as different design. This difference in the value of A may be due to factors such as:

- Presence of water or ice on the wet sock
- The range of use
- Application of enhancement factor to correct vapour pressure values obtained
- Design and construction of device
- Effectiveness of design or specification
- Operation of device

This is illustrated in a study carried out by Sonntag for the World Meteorological Organisation (WMO) on Assman type psychrometers, which showed that even small modifications in design can cause errors when measurements are needed at standards level. Later, (extensive) work by Wiley and by Fan and Jong on the WMO approved psychrometer, showed that with exceptional care taken in the design and manufacture, good agreement (under laboratory conditions) can be achieved between devices of the same design.

However, work by Wylie and Sonntag also put into dispute the traditional psychrometer constant of 6.6×10^{-4} , calculating it to be nearer 6.3×10^{-4} a difference of approximately 6%. This would cause an error at ambient conditions (20 °C and 50% rh) of 1.2% rh. This discrepancy between theoretical and practical values for A , indicates that it is not sufficient to evaluate a psychrometer in terms of thermodynamic theory alone. Only by comparison with a traceable standard in terms of humidity can the device be properly evaluated. The calibration will give the correction to be applied to the data obtained using the device and allow a specific value of A be determined and assigned (which only applies to that particular device).

As the design of psychrometric devices continues to be modified to suit different applications and to keep up with advances in measurement technology there is a need to ensure extra factors are not introduced which will influence or change the usefulness of the data obtained.

A1.12 CONCLUSION

The survey has shown that there are a considerable number of factors which need to be taken into account when designing, constructing and operating a psychrometric device. There is also evidence that an analysis of a particular design in terms of thermodynamic theory is insufficient and is likely to lead to a discrepancy between the theoretical value of A , the psychrometer coefficient assigned to the instrument and the value of A determined through practical evaluation.

This leads to the conclusion that each device should be considered as a single unit (made up of several components). This “unit” should be calibrated against a traceable standard in terms of humidity. This will then allow the determination of a value for A based on the calibration. This value is specific to the calibrated unit and may not be applicable to units of similar design. Improvement in humidity standards over the last 30 years at primary level have been of such a quality that it is now possible to produce accurate, repeatable reference humidities, thus enabling the verification of humidity measuring devices at the highest level.

A1.13 REFERENCES

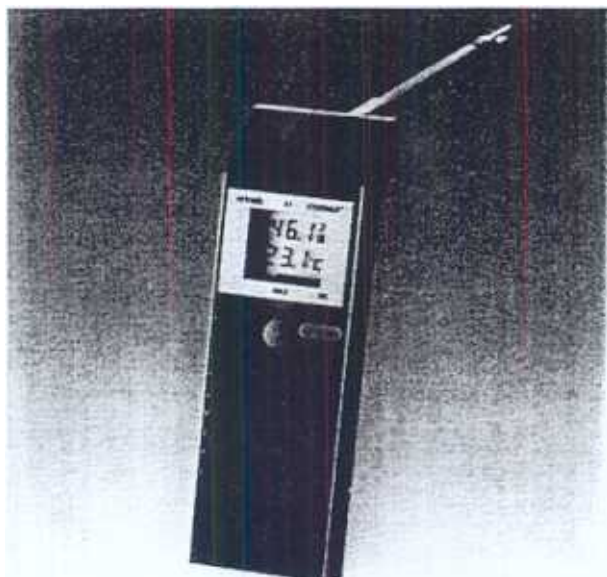
- A Guide to the Measurement of Humidity, London, Institute of Measurement and Control, 1996
- 2 AWBERRY, J.H. and GRIFFITHS, E. An Investigation of the Wet-and-Dry Bulb Hygrometer at Low Temperatures, *Proceedings of the Physical Society*. **47**, P684, 1935.
- 3 AWBERRY, J H and GRIFFITHS, E. The Basic Law of the Wet-and- Dry Bulb Hygrometer at Temperatures from 40 °C to 100 °C. Physics Department, National Physical Laboratory - *Proceedings of the Physical Society*. **44** Part 2 No 242, 1 March 1932.
- 4 BINDON, H. H. A Critical Review of Tables and Charts used in Psychrometry - 1963 International Symposium on Humidity and Moisture , Washington D.C USA, edited by Wexler A editor-in-chief, New York Reinhold Publishing Corporation, 1963 , from Humidity and Moisture, Measurement and Control in Science and Industry Volume 1 Principles and Methods of Measuring Humidity in Gases pp 3-15.
- 5 CHRISTIANSON, K.L. and NEWHOUSE, K.N. Analysis of Wet bulb Psychrometry 1985 *International Symposium on Moisture and Humidity*, Washington D.C, USA, Edwards Brothers, 1985, from Moisture and Humidity 1985 Measurement and Control in Science and Industry pp 75-78.
- 6 EISNER A.D. and MARTONEN T.B. Design and Development of a Micro-thermocouple Sensor for Determining Temperature and Relative Humidity Patterns within an Airstream - Transactions of the ASME, *Journal of Biomechanical Engineering* November 1989. **111** pp 283-287.
- 7 FAN, Jinpeng and ZHAO, Guirong YU, Yipeng and YANG, Guodong. The Determination of the Psychrometer Coefficient and a Commercial WMO Reference Psychrometer – Reference IV.2.
- 8 FAN, Jinpeng, LIANG, Qionglan and WANG, Jingye, YANG, Guodong and ZENG, Yiding. An Intercomparison Between the WMO Reference Psychrometer and Dew Point Hygrometer or EAP2 - Reference IV.3.
- 9 IEC 60068-2-38 (1974-01) Environmental testing - Part 2. Tests. Test Z/AD: Composite temperature/humidity cyclic test.
- 10 KIMBALL, B.A. and MITCHELL, S.T. An Accurate Low Maintenance Psychrometer. *J. Applied Meteorology* December 1981. **20** pp 1533-1537.
- 1 KUSUDA, Tamami. Calculation of the Temperature of a Flat-plate Wet Surface under Adiabatic Conditions with Respect to the Lewis Relations *Section 1 Psychrometry Humidity and Moisture Measurement and Control in Science and Industry – Papers presented at the 1963 International Symposium on Humidity and Moisture, Volume 1, Principles and Methods of Measuring Humidity in gases*, edited by Robert E. Ruskin, New York, 1963, pp 16-32.
- 12 METEOROLOGICAL OFFICE. *Handbook of Meteorological Instruments, Volume 3 Measurement of Humidity*, London, HMSO, 1981 (2nd edition).
- 13 *Papers and Abstracts from the Third International Symposium on Humidity and Moisture*, London, April 1998.
- 14 Section 1 Psychrometry *Humidity and Moisture Measurement and Control in Science and Industry – Papers presented at the 1963 International Symposium on Humidity and Moisture*,

- Volume 1, Principles and Methods of Measuring Humidity in gases*, edited by Robert E. Ruskin, New York, 1963, pp 3-121.
- 15 Sessions I & II.A Fundamentals, Standards & Calibration *Moisture and Humidity 1985 Measurement in Science and Industry - Proceedings of the 1985 International Symposium on Moisture and Humidity*, North Carolina, 1985, pp 1-110.
 - 16 SHAW, W.J. and TILLMAN, J.E. A correction for Different Wet bulb and Dry bulb Response in Thermocouple Psychrometry, *1985 International Symposium on Moisture and Humidity*, Washington D.C, USA, Edwards Brothers, 1985, from *Moisture and Humidity 1985 Measurement and Control in Science and Industry* pp 779-790.
 - SHIBA, K., UEDA, M. & HARAGUCHI, M. Precision Thermoelectric Psychrometer *1985 International Symposium on Moisture and Humidity*, Washington D.C, USA, Edwards Brothers, 1985, from *Moisture and Humidity 1985 Measurement and Control in Science and Industry* pp 707-716.
 - 18 SKAAR, John and HEGG Kjell The WMO International Hygrometer Intercomparison, Norway 1987-1989 Reference I.1.
 - 19 SONNTAG, D. Important new values of the physical constants of 1986, vapour pressure formulations based on the ITS-90, and psychrometer formulae *Zeitschrift fur Meteorologie* 1990. **40**, (5), pp 340-344.
 - 20 SONNTAG, D., SCHOLZ, G. and SCHULTZ, K. The Psychrometer Equation for the Assmann Aspiration Psychrometer for use in Meteorological Practice - Reference IV.4 *Meteorological Service of the German Democratic Republic, Bureau of Standardization and Quality Control*.
 - 21 SPENCER-GREGORY, H. and ROURKE, E. *Hygrometry*, London, Crosby Lockwood & Son, Ltd, 1957.
 - 22 THOUVENIN, M. Experimenting on a Psychrometer – *Journal of the Society of Environmental Engineers* December 1985 **24-4**, (Issue 107) pp 3-8.
 - 23 VISSCHER, G.J.W. Standard Psychrometers: a matter of (p)references *Meas. Sci. Technol.* (1995) **6** 1451-1461.
 - 24 WYLIE, R.G. and LALAS, T. The WMO Psychrometer , *Division of Applied Physics Technical Paper No.3* Commonwealth Scientific and Industrial Research Organization, Australia 1981.
 - 25 WYLIE, R.G. and LALAS, T. The WMO Psychrometer. Appendix A, Technical Paper No 3 CSIRO Division of Applied Physics Sydney Australia 1981.
 - 26 WYLIE, Russell G. and LALAS, Theo. Accurate Psychrometer Coefficients for Wet and Ice Covered Cylinders in Laminar Transverse Air Streams - *1985 International Symposium on Moisture and Humidity*, Washington D.C, USA, Edwards Brothers, 1985, from *Moisture and Humidity 1985 Measurement and Control in Science and Industry* pp 37-56.
 - 27 WYLIE, Russell G. and LALAS, Theo. Detailed Determination of the Psychrometer Coefficient for the Wet Cylinder in a Transverse Airstream and an Analysis of its Accuracy - *Division of Applied Physics Technical Paper No. 7* Commonwealth Scientific and Industrial Research Organization, Australia 1981.

- 28 WYLIE, Russell G. Psychrometer Coefficients - CSIRO Division of Applied Physics Reference IV.1.
- 29 WYLIE, Russell G. Psychrometric Wet Elements as a Basis for Precise Physico-Chemical Measurements *Journal of Research NBS*, 1978, **84**, No 2, pp 161-177.
- 30 WYLIE, Russell G. The Psychrometer Problem – An Accurate Analysis for Laminar Boundary-Layer Flows *1985 International Symposium on Moisture and Humidity*, Washington D.C, USA, Edwards Brothers, 1985, from Moisture and Humidity 1985 Measurement and Control in Science and Industry pp 57-73.



APPENDIX B INSTRUMENTS SPECIFICATION



A1 – for air measurement

Relative humidity and temperature reference unit

- Integrated, multi-positional air probe
- Large and clear display
- Simple operation
- Display HOLD key
- AUTO POWER OFF
- Low-Bat display
- Battery operated
- °C or °F version

Order code:

Version °C	A1
Version °F	A1/FA
Technical data	Page 11



M1 – for solids, granular product etc.

Quality assurance unit for equilibrium relative humidity and temperature

- Integrated, multi-positional insertion probe made of V4A steel with steel sintered filter
- Large and clear display
- Simple operation
- HOLD key
- AUTO POWER OFF
- Low-Bat display
- Battery operated
- °C or °F version

Order code:

Version °C	M1
Version °F	M1/FA
Technical data	Page 11



S1 – for stacks of paper

Measuring instrument for the paper industry

- Integrated, multi-positional sword probe
- Large and clear display
- Simple operation
- HOLD key
- AUTO POWER OFF
- Low-Bat display
- Battery operated
- °C or °F version

Order code:

Version °C	S1
Version °F	S1/FA
Technical data	Page 11



A2 – Display instruments for relative humidity and temperature

Display instrument with analogue output

- Analogue ROV* output
- Compatible with all probes with ROV* interface
- Large and clear display
- Simple operation
- HOLD key
- AUTO POWER OFF
- Low-Bat display, battery, or mains adapter operation
- °C or °F version
- Handheld probe see page 13
- Probes for water activity measurement see page 75

Order code

Version °C	A2
Version °F	A2/FA



AM3 – Display instrument for relative humidity, two temperatures and dew point, RS232

Display instrument to meet your most demanding requirements

- Dew point computer
- Input for additional Pt100 probe
- Compatible with all probes with ROV* interface
- Trend display
- Min/max value memory
- Windows software with logger and moisture calculation functions
- HOLD key
- AUTO POWER OFF
- Low-Bat display, battery, accumulator or mains adapter operation
- °C or °F version
- Handheld probe see page 13
- Probes for water activity measurement see page 75
- Pt100 probe see page 100
- Selectable display of:
 - % rh/°C
 - % rh/°C external Pt100
 - °C_{DP}/°C
 - °C_{DP}/°C external Pt100

Order code

Version °C	AM3
Version °F	AM3/FA

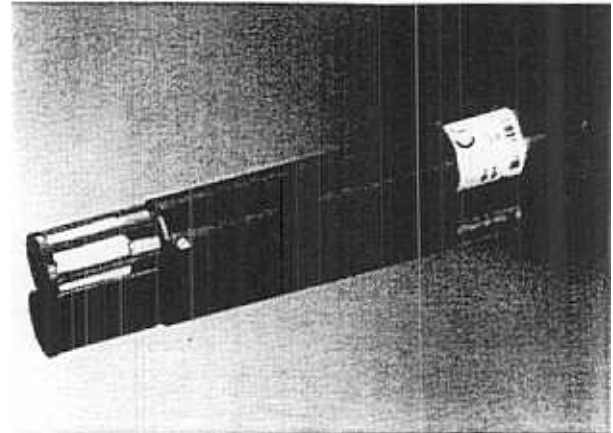
HP100A

25mm Ø air probe

Temperature measuring range: -20 ... +60 °C

Sensor protection: wire mesh filter

Order code: see page 19

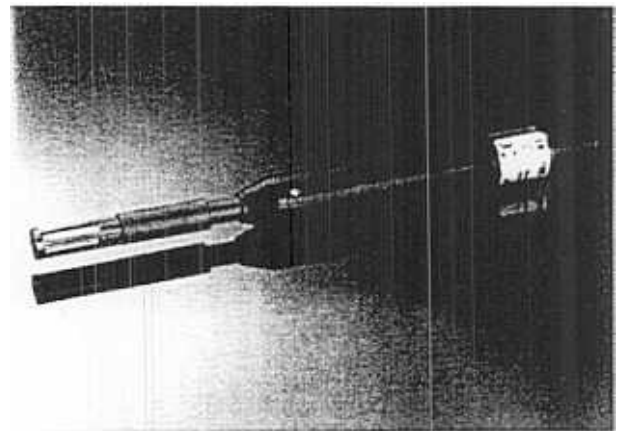
**HP100A - K10**

15 mm Ø air probe for extended range of applications

Temperature measuring range: -20 ... +60 °C

Accuracy: ± 1 % rh with SCS calibration certificate

Order code: see page 19

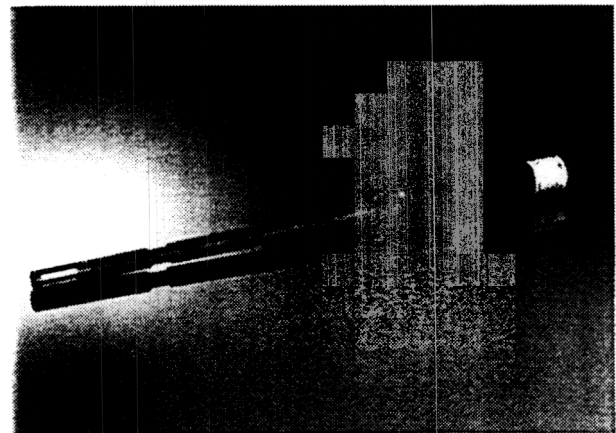
**HP100A - K25**

15 mm Ø air probe for wide temperature range

Temperature measuring range: -50...+150 °C

Sensor protection: wire mesh filter

Order code: see page 19

**HP100A - K40**

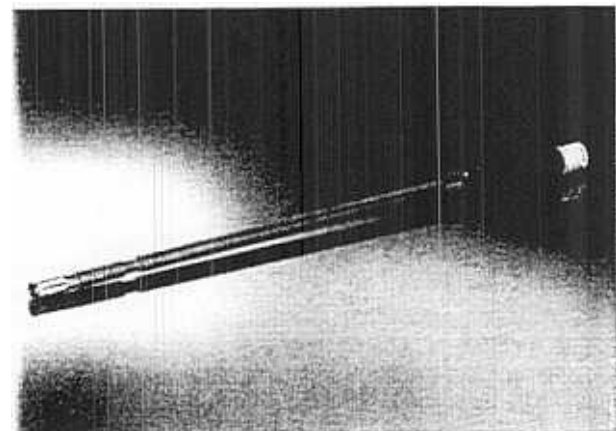
15 mm Ø air probe for widest temperature range

Temperature measuring range: -50...+200 °C

(Type HP101A...)

Sensor protection: wire mesh filter

Order code: see page 19



Instrument series	A1	M1	S1	A2	AM3	BT-RS1	BT-RS8
Protection category	IP 50						
Supply	Battery 9V alkaline						
Accumulator 8.4 V operating duration						< 5.5 h	
	Mains adapter 9 V/500 mW						
Max. current consumption	4 mA			2 mA	18 mA	< 80 mA	< 50 mA
Output signals							
- Analogue					ROV*		ROV*
- Digital					RS232		
Display							
- Humidity/ temperature	Humidity 3 Digit / temperature: 3 ½ Digit/resolution 0.1				2 x 3 ½ Digit/resolution 0.1		
Dew point					yes		
Aw						yes	
ext. Pt100					yes		
- F available	yes						
Battery charging indicator	yes						
Trend display					yes		
Min/max display						yes	
DATA hold	yes						
Auto power OFF	yes						
Probe inputs							
- Integrated probe	yes						
- ROV interface*				yes			
- HYGROLYT interface						yes	
- External PT100 input					yes		
Housing dimensions (mm)	190 x 63 x 26			230 x 80 x 30		179 x 64 x 168	
Housing material	ABS grey						
Probe dimensions (mm)	150 x 10	280 x 10	280 x 18 x 4				
Probe material	ABS	V4A	Aluminium				
Sensor protection	Slotted cap	Sintered filter	Slits				
Sensor							
- Humidity	C94						
- Temperature	Pt100/B						
Measuring range							
- Sensor (humidity) % rh	5...99.9						
- Probe (temperature) °C	-25...+75	-10...+60					
Measuring range							
- Probe input (humidity) % rh				0...99.9	0...100		
- Probe input (temperature) °C				-199...+199	-50...+200	-50...+150	
Accuracy at 23 °C							
- Humidity	±1.5 % rh (±2.5 <15% >90%)						
- Temperature	0.3 K						
Reproducibility							
- Humidity	<0.5 % rh						
- Temperature	<0.1 K						
Long-term stability normal condition	<1 % rh/year						
Time constant at 1 m/s							
- Humidity	<10 s	<15 s	<10 s				
- Temperature	<10 s	<15 s	<10 s				
Electronics							
- Operating range (°C)	-10...+60					0...50	
- Humidity adjustment points (% rh)	35, 80, 10						
- Temperature adjustment points (°C)	Tmin/Tmax			Tmin/Tmax			
Weight (g)	170	200	260	220	250	970	950

ROV = ROTRONIC defined standard interface corresponding to: 10 mV/% rh or 10 mV/°C, (0 % rh or 0 °C = 0 V)
see page 14



VAISALA

Technical information

MEASURED VARIABLES

Relative humidity

Measurement range 0...100 %RH

Accuracy (including nonlinearity and repeatability)

when calibrated against salt solutions (ASTM E104-85):

±2 %RH (0...90 %RH)

±3 %RH (90...100 %RH)

maximum achievable accuracy when calibrated against

high-quality, certified humidity standards:

±1 %RH (0...90 %RH)

±2 %RH (90...100 %RH)

Response time (90 %) at +20 °C

in still air (with sintered filter)

15 s

Humidity sensor

HUMICAP® sensor

Temperature

Measurement range

HMP231 -40...+60 °C

HMP233 -40...+80 °C or -40...+120 °C

HMP234, HMP235 & HMP238 -40...+180 °C

Typical accuracy of electronics at +20 °C

±0.1 °C

Typical temperature dependence

±0.005 °C/°C

of electronics

Temperature sensor

Pt 100 IEC 751 1/3 class B

CALCULATED VARIABLES (DEPENDS ON MODEL TYPE)

Typical ranges

HMP231

dewpoint temperature -40...+60 °C

mixing ratio 0...160 g/kg d.a.

absolute humidity 0...160 g/m³

wet bulb temperature 0...+60 °C

enthalpy -40...+460 kJ/kg

HMP233, HMP234, HMP235 & HMP238

dewpoint temperature -40...+100 °C

mixing ratio 0...500 g/kg d.a.

absolute humidity 0...600 g/m³

wet bulb temperature 0...+100 °C

enthalpy -40...+1500 kJ/kg

CONNECTORS

Vs = power supply

ao = analog outputs

24 V POWER SUPPLY	Analog outputs	Power supply	Serial interface	Alarm output
no connectors	shared cable	shared cable	shared cable	-
no connectors, alarm output unit	shared cable	shared cable	shared cable	cable
shared connector for Vs and Ao	shared connector	-	-	-
as above but with the alarm output unit	shared connector	-	-	cable
connector for the RS232C	shared cable	shared cable	connector	-
2 connectors: RS232C and Ao + Vs	shared connector	-	connector	-
2 connectors: shared for RS485 and Vs	-	shared connector	-	-

115/230 V POWER SUPPLY	Analog outputs	Power supply	Serial interface	Alarm output
no connectors	shared cable	cable	shared cable	-
connector for Ao	connector	cable	-	-

ACCURACIES OF THE VARIABLES

Accuracies of the calculated variables depend on the calibration accuracy of the humidity and temperature sensors; here the accuracies are given for ±2 %RH and ±0.2 °C.

Accuracies of dewpoint temperature °C

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	1.86	1.03	0.76	0.63	0.55	0.50	0.46	0.43	—	—
-20	2.18	1.19	0.88	0.72	0.62	0.56	0.51	0.48	—	—
0	2.51	1.37	1.00	0.81	0.70	0.63	0.57	0.53	0.50	0.48
20	2.97	1.56	1.13	0.92	0.79	0.70	0.64	0.59	0.55	0.53
40	3.24	1.76	1.27	1.03	0.88	0.78	0.71	0.65	0.61	0.58
60	3.60	1.96	1.42	1.14	0.97	0.86	0.78	0.72	0.67	0.64
80	4.01	2.18	1.58	1.27	1.08	0.95	0.86	0.79	0.74	0.70
100	4.42	2.41	1.74	1.40	1.19	1.05	0.95	0.87	0.81	0.76
120	4.86	2.66	1.92	1.54	1.31	1.16	1.04	0.96	0.89	0.84
140	5.31	2.91	2.10	1.69	1.44	1.26	1.14	1.05	0.97	0.91
160	5.80	3.18	2.30	1.85	1.57	1.38	1.24	1.14	1.06	0.99

Accuracies of mixing ratio g/kg (ambient pressure 1013 mbar)

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	—	—
-20	0.017	0.018	0.019	0.021	0.022	0.023	0.025	0.026	—	—
0	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.12	0.13	0.13
20	0.31	0.33	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.49
40	0.97	1.03	1.10	1.17	1.24	1.31	1.38	1.46	1.54	1.62
60	2.68	2.91	3.16	3.43	3.72	4.04	4.38	4.75	5.15	5.58
80	6.73	7.73	8.92	10.34	12.05	14.14	16.71	19.92	24.01	29.29
100	16.26	21.34	28.89	40.75	60.86	98.85	183.66	438.56	—	—
120	40.83	74.66	172.36	—	—	—	—	—	—	—

Accuracies of wet bulb temperature °C (ambient pressure 1013 mbar)

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	—	—
-20	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	—	—
0	0.27	0.28	0.28	0.29	0.29	0.29	0.30	0.30	0.31	0.31
20	0.45	0.45	0.45	0.44	0.44	0.44	0.43	0.43	0.42	0.42
40	0.84	0.77	0.72	0.67	0.64	0.61	0.58	0.56	0.54	0.52
60	1.45	1.20	1.03	0.91	0.83	0.76	0.71	0.67	0.63	0.60
80	2.23	1.64	1.32	1.13	0.99	0.89	0.82	0.76	0.72	0.68
100	3.06	2.04	1.58	1.31	1.14	1.01	0.92	0.85	0.80	0.75
120	3.85	2.40	1.81	1.48	1.28	1.13	1.03	0.95	0.88	0.83
140	4.57	2.73	2.03	1.65	1.41	1.25	1.13	1.04	0.97	0.91
160	5.25	3.06	2.25	1.82	1.55	1.37	1.24	1.13	1.05	0.99

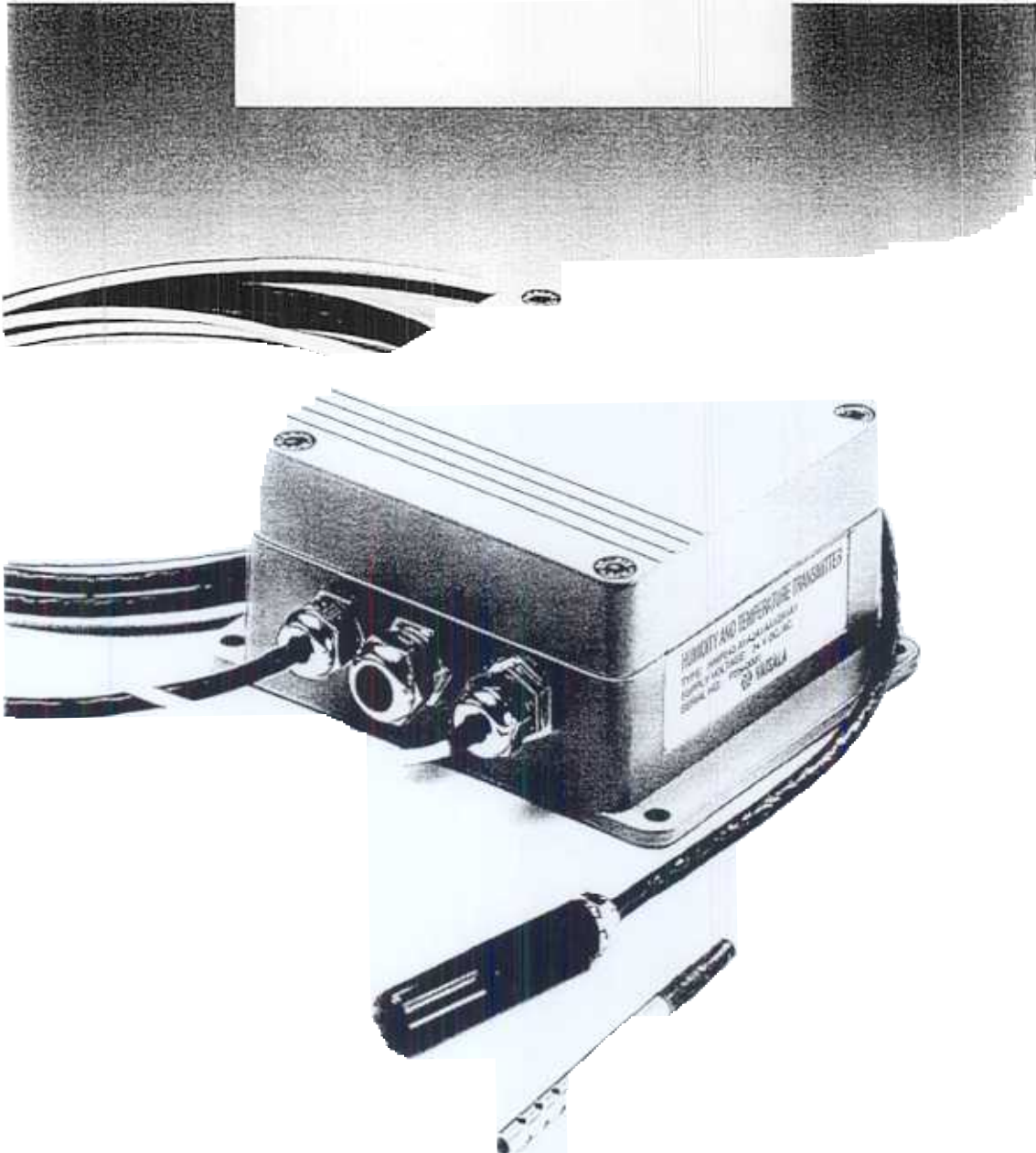
Accuracies of absolute humidity g/m³

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.004	0.004	0.005	0.005	0.005	0.006	0.006	0.006	—	—
-20	0.023	0.025	0.027	0.029	0.031	0.032	0.034	0.036	—	—
0	0.10	0.11	0.12	0.13	0.13	0.14	0.15	0.15	0.16	0.17
20	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51	0.53	0.55
40	1.08	1.13	1.18	1.24	1.29	1.34	1.39	1.44	1.49	1.54
60	2.73	2.84	2.95	3.07	3.18	3.29	3.40	3.52	3.63	3.74
80	6.08	6.30	6.51	6.73	6.95	7.17	7.39	7.61	7.83	8.05
100	12.2	12.6	13.0	13.4	13.8	14.2	14.6	15.0	15.3	15.7
120	22.6	23.3	23.9	24.6	25.2	25.8	26.5	27.1	27.8	28.4
140	39.1	40.0	41.0	42.0	43.0	44.0	45.0	45.9	46.9	47.9
160	63.5	64.9	66.4	67.8	69.2	70.7	72.1	73.5	74.9	76.4

Accuracies of enthalpy kJ/kg (ambient pressure 1013 mbar)

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	—	—
-20	0.24	0.25	0.25	0.25	0.26	0.26	0.26	0.27	—	—
0	0.4	0.42	0.43	0.45	0.46	0.47	0.49	0.5	0.52	0.53
20	0.98	1.03	1.08	1.13	1.18	1.23	1.29	1.34	1.39	1.45
40	2.7	2.87	3.04	3.22	3.4	3.59	3.78	3.98	4.18	4.39
60	7.2	7.82	8.48	9.19	9.96	10.79	11.69	12.65	13.7	14.84
80	18.04	20.72	23.88	27.66	32.22	37.77	44.61	53.17	64.02	78.06
100	43.96	57.64	77.98	109.93	164.1	266.37	494.62	1180.46	—	—
120	111.6	203.93	470.52	—	—	—	—	—	—	—

HMP243 Dewpoint Transmitter

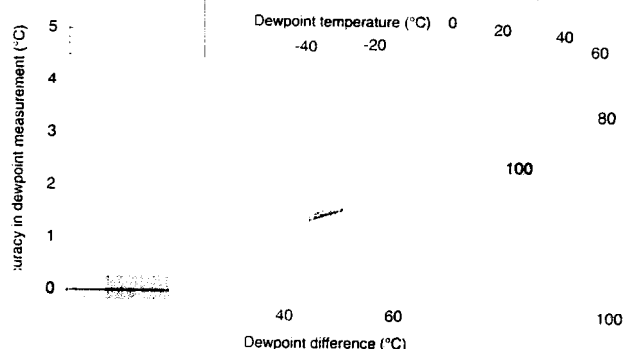


Technical information

DEWPOINT TEMPERATURE

Measurement range -40...+100 °C

Accuracy: find the intersection of the dewpoint temperature curve and the dewpoint difference reading (process temperature - dewpoint temperature) on the x-axis and read the accuracy in dewpoint measurement at the y-axis



Response time (90%) at +20 °C
in still air (with sintered filter)

Sensor HUMICAP[®] HC sensor

TEMPERATURE (option)

Measurement range 0...+180 °C

Typical accuracy at +20 °C ±0.1 °C

Typical temperature dependence of electronics 0.005 °C/°C

Sensor Pt 100 IEC 751, class A B

OUTPUTS

0...20 mA, 4...20 mA,

0...1 V, 0...5 V,

0...10 V

Typical accuracy of analogue output at +20 °C ±0.05 % full scale

Typical temperature dependence of analogue output 0.005 % full scale/°C

Serial output available RS 232C

CALCULATED VARIABLES

Available only when temperature sensor head in use

Typical ranges

relative humidity 0...100 %RH

dewpoint difference 0...+50 °C

mixing ratio 0...500 g/kg d.a.

absolute humidity 0...600 g/m³

wet bulb temperature 0...+100 °C

Accuracy of relative humidity measurement ±(0.5 %RH + 2.5% of reading)

Accuracies of the calculated variables depend on the calibration accuracy of the humidity and temperature sensors: here ±(0.5 %RH + 2% of reading) and ±0.1 °C.

Accuracies of mixing ratio (g/kg) when ambient pressure 1013 mbar

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.001	0.002	0.002	0.002	0.003	0.003	—	—	—	—
-20	0.007	0.010	0.012	0.014	0.017	0.019	0.021	0.024	—	—
0	0.033	0.043	0.053	0.063	0.074	0.084	0.094	0.104	0.115	0.125
20	0.12	0.15	0.19	0.23	0.26	0.30	0.33	0.37	0.41	0.45
40	0.37	0.49	0.61	0.74	0.87	1.00	1.14	1.28	1.42	1.57
60	1.03	1.41	1.82	2.26	2.73	3.25	3.82	4.43	5.10	5.84
80	2.60	3.79	5.23	6.99	9.16	11.85	15.25	19.57	25.17	32.54
100	6.24	10.49	17.10	27.98	47.20	84.96	172.5	446.0	—	—
120	15.45	36.25	100.4	464.4	—	—	—	—	—	—
140	44.97	326.3	—	—	—	—	—	—	—	—
160	228.7	—	—	—	—	—	—	—	—	—

Accuracies of wet bulb temperature (°C)

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.18	0.18	0.18	0.18	0.19	0.19	—	—	—	—
-20	0.15	0.16	0.17	0.18	0.19	0.19	0.2	0.21	—	—
0	0.15	0.17	0.2	0.22	0.24	0.26	0.28	0.3	0.31	0.33
20	0.21	0.25	0.29	0.32	0.35	0.38	0.4	0.43	0.45	0.47
40	0.37	0.43	0.48	0.52	0.55	0.57	0.6	0.61	0.63	0.64
60	0.63	0.68	0.71	0.74	0.76	0.77	0.79	0.8	0.81	0.82
80	0.96	0.94	0.94	0.94	0.94	0.95	0.95	0.96	0.97	0.98
100	1.3	1.18	1.13	1.12	1.11	1.11	1.11	1.12	1.12	1.13
120	1.62	1.39	1.31	1.28	1.27	—	—	—	—	—
140	1.9	1.58	—	—	—	—	—	—	—	—
160	2.17	—	—	—	—	—	—	—	—	—

Accuracies of absolute humidity (g/m³)

Temp.	Relative humidity									
	10	20	30	40	50	60	70	80	90	100
-40	0.002	0.003	0.003	0.004	0.005	0.005	—	—	—	—
-20	0.011	0.014	0.018	0.022	0.026	0.030	0.034	0.037	—	—
0	0.045	0.060	0.075	0.090	0.105	0.120	0.13	0.15	0.16	0.18
20	0.15	0.20	0.24	0.29	0.34	0.38	0.43	0.48	0.53	0.57
40	0.43	0.57	0.71	0.85	0.99	1.12	1.26	1.40	1.54	1.68
60	1.09	1.45	1.81	2.17	2.53	2.88	3.24	3.60	3.96	4.32
80	2.43	3.24	4.06	4.88	5.69	6.51	7.33	8.15	8.96	9.78
100	4.89	6.56	9.23	9.90	11.57	13.25	14.92	16.59	18.26	19.93
120	9.06	12.19	15.33	18.46	21.59	—	—	—	—	—
140	15.66	21.12	—	—	—	—	—	—	—	—
160	25.53	—	—	—	—	—	—	—	—	—

GENERAL

Connections

screw terminals for 0.5 mm²

wires (AWG 20), stranded

wires recommended

Operating voltage 24 VDC/VAC (20...28 V)

Power consumption 200 mA max. (24 VDC)

during re-gaining 270 mA max. (24 VDC)

Recommended external load for

current outputs < 500 ohm

0...1 V output > 2 kohm (to ground)

0...5 & 0...10 V outputs > 10 kohm (to ground)

Electromagnetic compatibility IEC 801-3

with sintered filter 3 V/m

with steel netting PPS grid 10 V/m



Ordering data

Add. probes for testo 950, 650, 400	Meas. range	Accuracy *	t ₉₀ s	Connection cable	Part no.
CO probe	0 to 500 ppm	±5 ppm (0 to 100 ppm) ±5 % of m.v. (rem. range)			0632.1247
CO ₂ probe	0 to 1 vol. % CO ₂ 0 to 10.000 ppm CO ₂	±5 % of m.v. or 50 ppm			0632.1245
Calibration set for CO ₂ probe					0554.0020
Leak detection probe Mechanical rpm probe with plug-in head. With automatic signal attenuation 4 sec.	20 to 20.000 rpm 0.33 to 333 Hz	±1 digit		Please order connection cable (p. 50)	0640.0340
Current/voltage cable (±1 V, ±10 V, 20 mA)	0 to 20mA/4 20mA 0 ± 1V/0 ± 10V	± 0.04 mA ± 0.001 V / ± 0.01 V			0554.0007

Humidity/temperature probes for air conditioning and ventilation sector for testo 650, 400

Standard room conditions probe for measurements up to +70 °C Ø 12 mm (probe tip)	0 to 100 % RH (probe tip) -20 to +70 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	<12 at 2 m/s	Plug-in head Please order connection cable (p. 50)	0636.9740
Duct humidity/temperature probe, telescopic extension can be connected, Ø 12 mm	0 to 100 % RH (probe tip) -20 to +70 °C		<12 at 2 m/s	3 m PUR	0636.9715
Telescope, length: 340 - 800 mm					0430.9715
Highly accurate reference humidity/temperature probe, Ø 21 mm	0 to 100 % RH (probe tip) -20 to +70 °C	± 1 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	1 to 5 min typically 2 min	Plug-in head Please order connection cable (p. 50)	0636.9741
Flexible humidity probe with mini module for measurements, e.g. on material test rigs. Length of module cable: 1500 mm	0 to 100 % RH -20 to +125 °C	± 2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	20	Plug-in head Please order connection cable (p. 50)	0628.0013

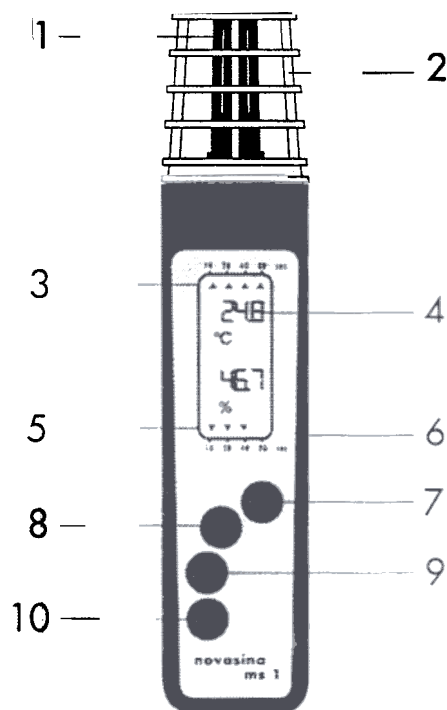
Accuracy data at rated temperature of +25 °C,
Temperature coefficient: ±0.03 % / °C

Ordering data

Humidity/temperature probes for tough industrial applications for testo 650, 400

	Measuring range	Accuracy *	t ₉₀ s	Connection cable	Part no.
Sword probe for humidity/temperature measurement in stacked goods, rated length: 320 mm	0 to 100 % RH (probe tip) -20 to +70 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	<12 at 2 m/s	Plug-in head Please order connection cable (p. 50)	0636.0340
Robust humidity probe e.g. for measuring material compensation humidity or for measurements in extraction ducts, rated length: 300 mm, Ø 12 mm	0 to 100 % RH -20 to +120 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	<30 at 2 m/s	Plug-in head Please order connection cable (p. 50)	0636.2140
Robust high temp. probe for meas. up to +180 °C, rated length: 300 mm, Ø 12 mm	0 to 100 % RH -20 to +180 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	30 at 2 m/s	Plug-in head Please order connection cable (p. 50)	0628.0021
Flexible humidity probe for measurements at inaccessible points.	0 to 100 % RH -20 to +180 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	<30 at 2 m/s	Plug-in head Please order connection cable (p. 50)	
Standard pressure dew point probe for measurements in compressed air systems	0 to 100 % RH -50 to +50 °C t _{pd}	Pressure dew point meas. at rated temp. +25 °C: ± 0.9 to +4 °C t _{pd} (5 to 40 °C)	1 to 5 min typically 2 min	Plug-in head Please order connection cable (p. 50)	0636.9840
Precision dew point probe for measurements in compressed air systems	0 to 100 % RH -50 to +50 °C t _{pd}	Pressure dew point meas. at rated temp. +25 °C: ± 0.8 to 4 °C t _{pd} (5 to 40 °C)	1 to 5 min typically 2 min	Plug-in head Please order connection cable (p. 50)	0636.9841
Flexible humidity probe for measurements at inaccessible points	0 to 100 % RH -20 to +140 °C	±2 % RH (2 to 98 % RH) ± 0.4 °C (0 to 50 °C) ± 0.5 °C (rem. range)	<30 at 2 m/s	Plug-in head Please order connection cable (p. 50)	

Accuracy data at rated temperature of +25 °C,
Temperature coefficient: ±0.03 % / °C



1 Humidity and temperature measuring cell, 2 Protective cage, 3 Temperature stability value indicator, 4 Multiple display, 5 Humidity stability value indicator, 6 Interface for connection to PC, 7 Power supply on/off, 8 min/max value, 9 Menu selection button, 10 Calibration button

Technical data

Application of novasina ms -10 °C...+50 °C
(with extension ...+80 °C)

	Humidity electrolytic measuring cell	Temperature
Measuring element	en CK-3	spez. NTC-element
Measuring range	6...98% rh	-20 °C...+80 °C
Accuracy	±1% rh (20...90% rh)	±0.3 °C
Reproducibility	±0.3% rh	±0.1 °C
Resolution	0.1%	0.1 °C

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NOVATRON LTD



Unit 34 Southwater Ind Est.
Southwater, Horsham,
Sussex RH13 7UD
Tel (01403) 733012
Fax (01403) 733311



novasina ms1

The right measurement set for
each application



novasina ms1-E with electrolytic measuring cell for precise and fast climatic measurements

novasina ms1-Set A with expander tube for measurements of humidity in masonry and concrete

novasina ms1-Set B with a sword sensor for spot-check measurement within paper stacks, granulates...

novasina ms1-Set L with a pin sensor for spot-check measurements of meat products, packaged goods...

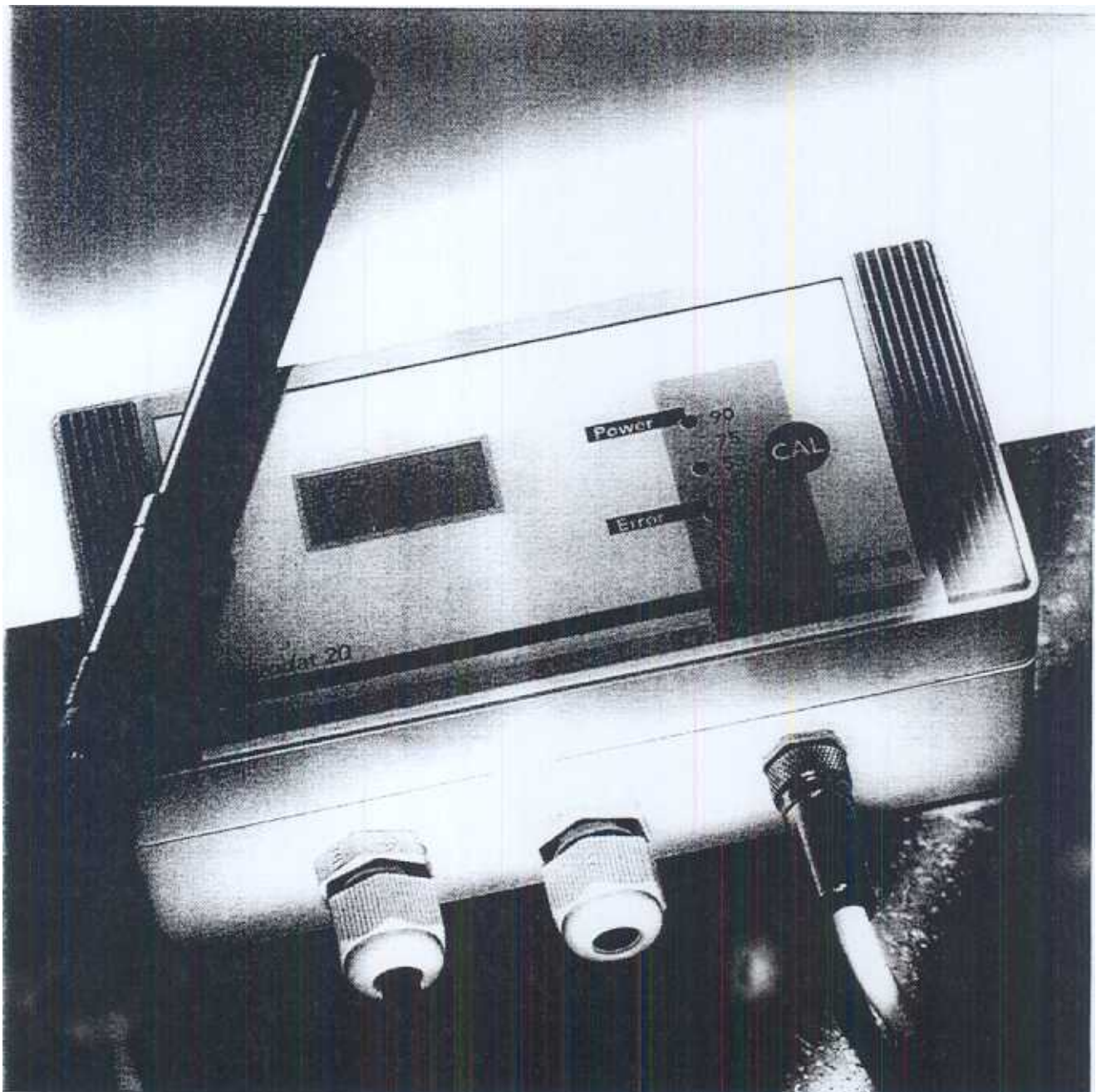
novasina ms1-Set M with a box sensor for measurements of humidity in firm substances, coarse-grain products

Optional accessories

- mains adaptor to power circuit
- surface temperature sensor
- extension tube for measurements in ducts 240 mm
- additional humidity standard sensor check SC or salt tablets SAL
- protective filter
- RS-232 interface and software

novasina

Hygrodat



Novasina Precision-Transmitters Hygrodat 10 & 20
For precise humidity and temperature measurement

Novasina Präzisions-Transmitter Hygrodat 10 & 20
Für präzise Feuchte- und Temperaturmessung

Convertisseurs de précision Hygrodat 10 & 20 de Novasina
Pour une mesure précise de l'humidité et de la température

novasina

Technical data**Technische Daten****Données techniques**

Operating ranges	Einsatzbereiche	Domaines d'application
Humidity measurement		Mesure d'humidité
Measuring range		6 ... 100%
Temperature compensation of whole measuring range		
Accuracy		
• with 5-point calibration at 25 °C		+/- 0.5%
• with 5-point calibration at 0 ... 50 °C		+/- 1%
• without calibration		+/- 2%
Repeatability		Reproductibilité
Long-term stability under typical conditions/year		
Temperature measurement		
Measuring range		- 20 ... 80 °C
Accuracy		
Repeatability		
Operating temperature	Betriebstemperatur	
• Controller box	• Controllerbox	- 10 ... 50 °C
• Sensor	• Sensor	- 20 ... 80 °C
Storage temperature	Lagertemperatur	
Electromagnetic compatibility	Elektromagnetische Verträglichkeit	
Emissions		EN 50081-2

Electrical data	Elektrische Daten	Données électriques
Power supply	Speisung	Alimentation
	Wechselstrom (AC)	Courant alternatif
		90 ... 260 V
Output signals	Ausgangssignale	Signaux de sortie
		0 ... 1 V/0 ... 10 V
Loads		Résistance
External loads to ground (Voltage output)	Bürde gegen Masse (Spannungsausgang)	Résistance à la masse (Sortie du tension)
External loads (Current output)	Bürde (Stromausgang)	Résistance externe (Sortie du courant)
		> 8000 Ohm

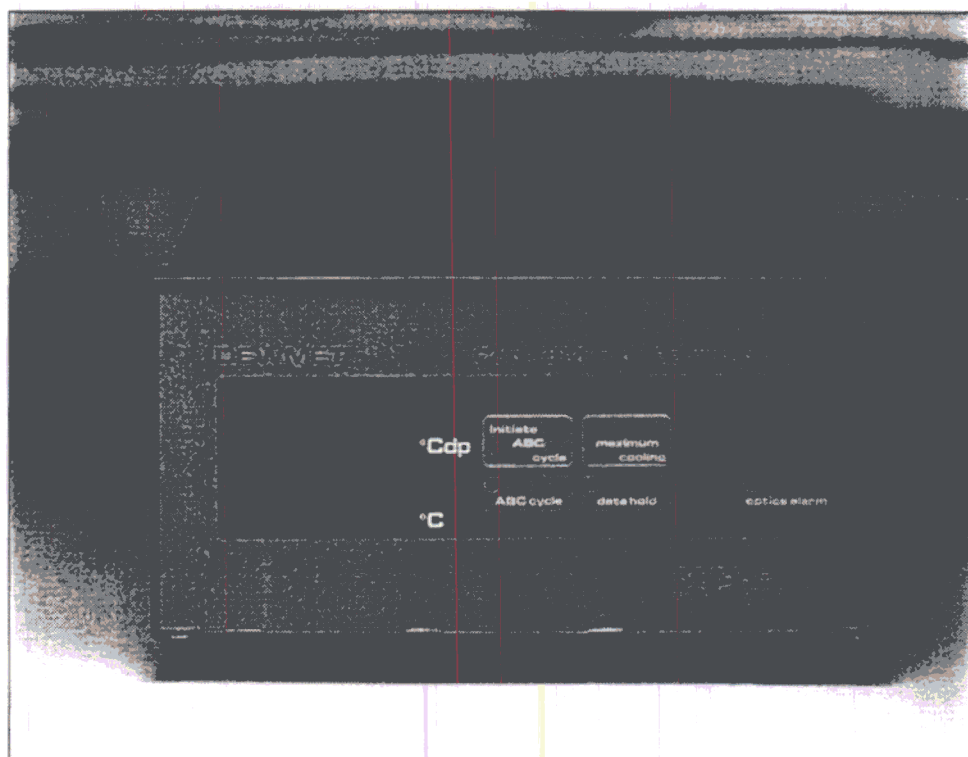
Accessories	Zubehör	Accessoires
Filters	Filter	Filtres
Metal web filter:	Tressenfilter:	Filtre tressé:
For medium dust protection	Für mittlere Staubbelastung	Pour environnement moyennement poussiéreux
		MF-1
Sintered filter:	Sinterfilter:	Filtre compressé:
For high dust protection	Für hohe Staubbelastung	Pour environnement très poussiéreux
		SF-1
Metal web/activated carbon filter:	Tressenfilter mit Aktivkohle:	Filtre tressé avec charbon actif:
Protection against chemical volatiles	Schutz vor chemischen Einflüssen	Protection contre les agents chimiques
		AF-1
Mounting equipment	Montagematerial	Equipement pour montage
		Flasque
		Fixation pour rails DIN
		16 mm

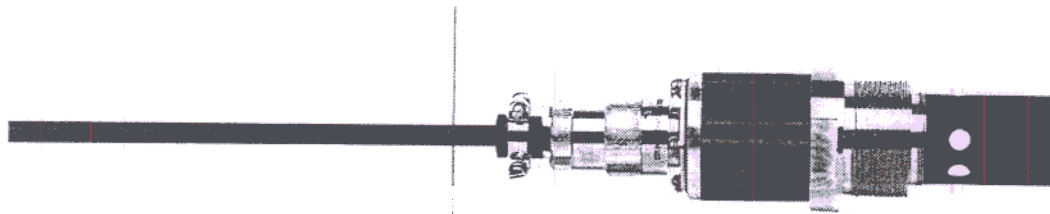
Subject to technical modifications

Technische Änderungen vorbehalten

Sous réserve de modifications techniques

DEWMET COOLED MIRROR DEWPOINTMETERS





● **FUNDAMENTAL
MEASUREMENT
PRINCIPLE**

● **ABSOLUTE
PRECISION
- DRIFT FREE**

● **- 60/+85°C
DEWPOINT RANGE**
-95°C option available -
see data sheet CMD-907

● **- 40/+90°C
OPERATING
TEMPERATURE**
With class leading
depression

● **RECOGNISED BY
STANDARDS
AUTHORITIES
WORLDWIDE**

● **FLEXIBLE SENSOR
OPTIONS:**
Remote sampling or
direct insertion with
membrane protection
available

● **DISPLAY AND
OUTPUT OPTIONS:**
°Cdp, °F dp, RH and
others

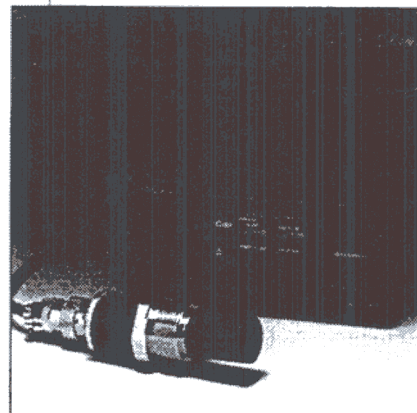
● **CONTINUOUS
MEASUREMENT
AND CONTROL**

INTRODUCTION

Michell's range of Cooled Mirror Dewpointmeters offers extremely high levels of accuracy and measurement stability. This is achieved over the full humidity range, from sub-parts per million moisture levels to saturation at elevated temperatures. The fundamental nature of this method of measurement means that a Michell Cooled Mirror Dewpointmeter can be used either as an extremely reliable and stable field instrument or as a laboratory reference standard for the calibration of other devices.

METHOD OF OPERATION

The **DEWMET** sensor, like all Michell Cooled Mirror Sensors, provides a fundamental, and therefore highly accurate and reliable method of continuously measuring the dewpoint temperature of a gas sample under test. A chemically resistant polished stainless steel mirror is at the heart of the sensor. This is thermally bonded to a Peltier effect Thermoelectric heat pump. The absolute temperature of the mirror is controlled by application of a D.C. current to the heat pump. Heat removed from the mirror is dissipated into the thermally efficient body of the sensor. This control system can reduce the mirror temperature by more than 80°C. Dynamically, current is applied to the Peltier to cool the mirror surface until condensation begins to form. This condensation causes a corresponding reduction in the reflected light intensity seen by the photodetector. Closed loop control of the system response to this signal change results in rapid equilibrium of the mirror surface at the precise temperature at which condensation starts to form. This is, by definition, the dewpoint (or frostpoint) temperature of the gas under test. This is measured by the instrument directly from a highly accurate 100Ω platinum resistance thermometer embedded within the mirror. See Figure 1.



DEWMET Cooled Mirror
Dewpointmeter

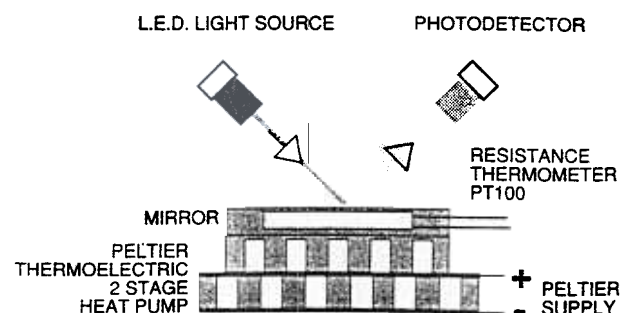


FIGURE 1 - Principle of operation of the Cooled Mirror Sensor

CONTAMINATION COMPENSATION

All Michell Cooled Mirror instruments feature the **ABC** (Automatic Balance Compensation) System. **ABC** ensures continuous optimum operation of the sensor in contaminated environments by periodically driving off condensation to allow the optical loop to be re-balanced. As contamination levels increase the reflected light intensity from the mirror surface will reduce, resulting in poor signal to noise ratio. This signal reduction is electronically compensated by the **ABC** system. Eventually, however, a point is reached where the contamination level is too high for effective automatic compensation. The control electronics then provide an output and visible alarm. The sensors optical system should then be cleaned with water or a weak solvent. The **ABC** frequency and duration of **DEWMET** can be optimised by the user to give a balance between contamination resistance and contamination interference, ensuring the ideal setting for a given application. Throughout the entire process accuracy and control are maintained.

THE DEWMET RANGE

The **DEWMET** Cooled Mirror Dewpointmeter range comprises three main instrument versions, for measurement of dewpoint temperature, gas temperature and percentage relative humidity. Careful sensor design allows the flexibility for measurements to be made either remotely, using a sensor block and sample tube, or by direct insertion with the option of membrane protection to minimise mirror cleaning.

DEWMET COOLED MIRROR SENSOR

The **DEWMET** sensor is the latest development in the established Cooled Mirror range. Using a two stage Peltier heat pump the sensor offers the user class leading measurement depression of over 80°C at elevated temperatures and more than 55°C range at room ambient temperature conditions. The two stage Peltier is highly efficient, as is the design of sensor body, which means that residual heat build up in the sensor, which can compromise performance, is significantly less than that found in many single stage devices. Therefore the sensor can be used for a wide variety of applications with no auxiliary cooling. The addition of an optional water cooling jacket boosts the sensor range even further (see Figure 2 for actual range capabilities).

DEWMET S.D.

This entry level instrument has a single display for dewpoint temperature only. The Cooled Mirror Sensor is capable of operation between -40 and +90°C ambient temperature and at pressures of up to 40 barg. Connected to this, by up to 250 metres of interconnecting signal cable, is the monitor unit which: performs the control and measurement functions; displays the measured dewpoint to a resolution of 0.1°C; and provides voltage, current and logic outputs of instrument status for connection to external devices.

DEWMET T.D.

The T.D. version of **DEWMET** offers a twin display, giving gas temperature and dewpoint temperature indication. Measured values and outputs are continuous and simultaneous for both parameters. Gas temperature is provided by this option with an additional remote stainless steel sheathed PT 100 temperature element.

DEWMET T.D.H

As an option relative humidity can be calculated and displayed continuously by the T.D.H. version.

ACCESSORIES

Sensor Sampling Block

This stainless steel sample housing allows remote measurement of the gas under test. A sample of the gas is admitted to the sensor sampling block via sample tubes connected to the block's 1/4" NPT inlet and outlet ports.

Liquid Cooled Block

A sensor sampling block with an integral liquid cooling jacket for circulation of cooling water or a specific refrigerant. This increases depression capability by effectively extending the low end measurement capability through reducing the sensor body temperature - see Figure 2).

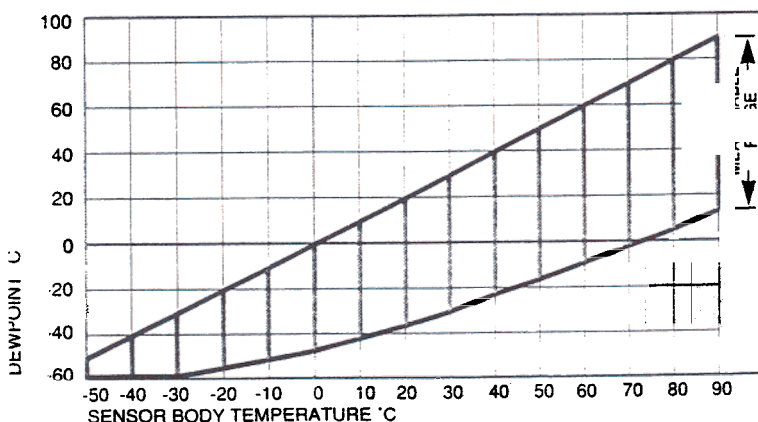


FIGURE 2 - DEWMET measurement capability

SPECIFICATIONS

GENERAL

Accuracy (complete system, nominal)	$\pm 0.2^{\circ}\text{C}$ Dewpoint, $\pm 0.1^{\circ}\text{C}$ Gas temperature
Response speed	$1^{\circ}\text{C}/\text{sec}$
Sensitivity	0.1°C
Hysteresis	None
Power supply	90/260V, 50-60Hz

DEWPOINT SENSOR

Peltier	2 stage
Range (optimum depression)	80°C
RH range equivalent	< 1.5 to 100%
Photodetection system	Single
Mirror	316 Stainless Steel
Temperature measurement	1/3 DIN Class B 3 wire
Operating temperature	-40 to $+90^{\circ}\text{C}$
Sample flow rate	0.1 to 2NI/min (in sampling block)
Flow velocity	0 to 1 m/sec (direct insertion)
Pressure	40 barg
Cable length	250 metres max

MONITOR	DEWMET S.D.	DEWMET T.D.	DEWMET T.D.H.
	0.1	0.1	
	10mV/ $^{\circ}\text{C}$ & 4-20mA		
ORDER CODE FOR DEWMET AND ACCESSORIES			
	DEWMET - 01 -	☐	☐
Dewpoint only			
		(B)	
Cable Length (2m) unless stated (250max)		2M	
4 Feet - Bench mounting option			4F
			(SG)



CERTIFICATE
No. Q 6284

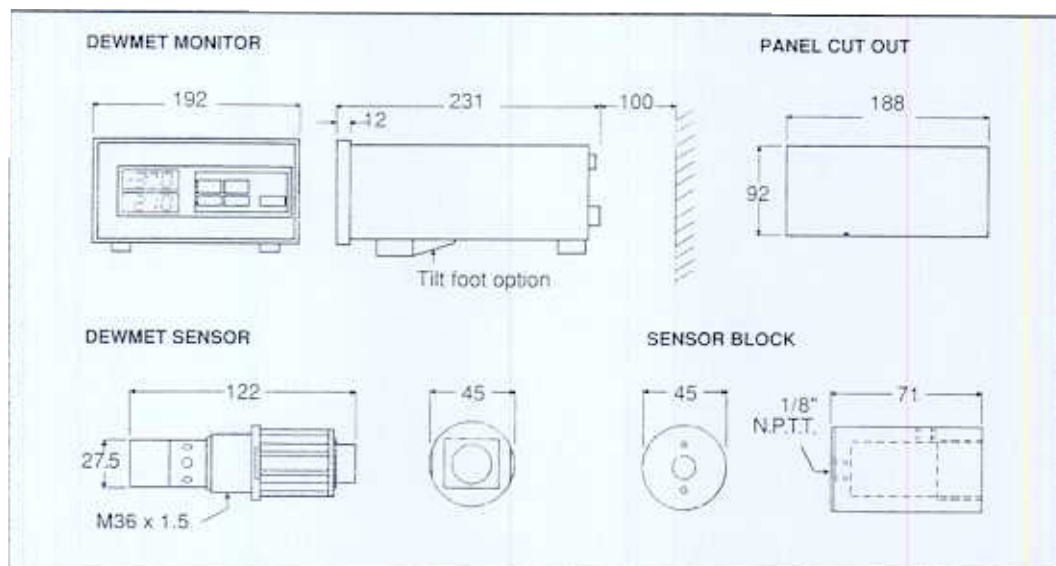


CALIBRATION
No. 0179

ISO 9002

Michell Instruments reserve the right to alter specifications and make improvements at any time and without prior notice.

your local representative:



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APPENDIX C FIRST INDUSTRIAL CONDITIONING REPORT

REPORT ON

Assessment of Instruments for use as Relative Humidity
Transfer Standards (First Conditioning Period)

Report No: VX604882

July 1999

TÜV Product Service Limited



0141
0141 SI

CAA Approved, BABT Listed, ISO 9000 Registered



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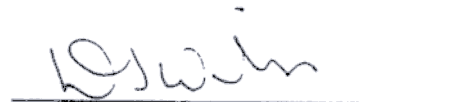
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REPORT ON: Assessment of Instruments for use as Relative Humidity
Transfer Standards

PREPARED FOR: Mark Stevens
Mass, Density and Humidity Standards
Centre for Mechanical and Acoustical Metrology
The National Physical Laboratory
Teddington
Middlesex
TW11 0LW

APPROVED BY:



DJ WILSON
Environmental Test Department Manager

DISTRIBUTION: Mr. Mark Stevens, NPL Copies 1 and 2
TÜV Product Service Ltd Copy 3
Copy No: 2



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EXECUTIVE SUMMARY

Assessment of Instruments for use as Relative Humidity Transfer Standards

Project Engineer: J Sutherland

STATUS

Security Classification	Unclassified
Order Number	S007299
Start of test	11 March 1999
Finish of test	9 April 1999

Test Item details (Table 1)

Test unit	Manufacturer	Description	Serial No	Remarks
No 1	Testo	Testo 650	00123675	Small probe 6 V DC batteries
No 2	Vaisala	HMP 233	T3630039	Mains powered
No 3	Rotronic	A1	Not serialised	9V DC battery
No 4	Novasina	MSI	9711019/2	Own power supply 7.5 V DC
No 5	Vaisala	HMP 233	T3630040	Power supply 24 V DC
No 6	Novasina	Novasina	9807008	Mains powered
No 7	Rotronic	A2	Probe only 9640010	Own power supply 9 V DC
No 8	Testo	Testo 650	000141425	Large Probe 6 V DC battery

Table 1

1.2 TEST OBJECTIVE

To assess the suitability of the RH sensors for use as transfer standards. The objective will be achieved by comparison of calibrations performed prior to and after periods of simulated use. This report details the simulated use between the initial and second calibrations.

Simulated use:

This falls into 2 categories:

(Test a) Variations in relative humidity at ambient temperature.

(Test b) Variations of relative humidity and temperature.

1.3 **INTRODUCTION**

TÜV Product Service Limited were contracted to carry out Environmental (Temperature / Humidity) testing of eight humidity sensors for the National Physical Laboratory (NPL) and provided the test facilities for the test programme.

The eight sensors had been calibrated by NPL before the tests commenced and were returned to NPL for re-calibration on completion of testing.

Visual inspections and operational checks before, during and after the testing were conducted by TÜV Product Service.

1.4 **BRIEF SUMMARY OF RESULTS** (Table 2)

Test Description	Results
(a) Variations in Relative Humidity at ambient temperature	At the end of the test all 8 units continued to function
(b) Variations of Relative Humidity and temperature	At the end of the test all four units subjected to this test continued to function, however unit 8 which comprised a separate sensor and indicator unit failed during the conditioning. On inspection the indicator unit was found to be faulty. To allow the test to continue the indicator unit from unit 1 which was identical to the faulty unit was substituted. During the test incorrect temperature readings were observed on unit 7, but this fault was intermittent and was not present at the end of the test.

Table 2

2.0 TEST DETAILS

2.1 Variations in Relative Humidity at ambient temperature

2.1.1 Date of Test

(Test a) 11- 22 March 1999

Sensors Tested

Sensors 1 - 8 were tested as detailed below:

2.1.3 Test Configuration

The units were powered as indicated in table 1 and functioned in the following manner.

Battery powered Instruments:

Units 1 and 8 were configured to switch pneumatically, "on" after 10 minutes and "off" after 20 minutes, throughout the test.

Unit 3 was configured to switch pneumatically on every 10 minutes throughout the test, (this unit switched itself off after approximately 2 minutes).

Mains powered Units:

Units 2, 4, 5, 6 and 7 were switched on for the duration of the test.

2.1.4 Test Equipment used (Table 3)

Instrument	Inv No	Calibration Due Date
Chamber Montford 4F ³	1147	16 May 1999
Data Acquisition system	2569	16 May 1999
Power Supply	300	Traceability unscheduled
Multimeter	3866	4 April 1999

Table 3

Test conditions

The test samples comprised of two types, those with integral display devices (units 3 and 4), and those with display devices connected via a cable, (units 1,2,5,6,7 and 8). During testing the units with remote display devices were configured with the probe inside the chamber and the display devices outside the chamber in ambient conditions.

(see Appendix I for representative arrangement).

All the instruments were powered as indicated in Table 1

A set of readings was taken before the test to confirm the operation of all the test instruments.

2.1.5 Test conditions (continued)

All units were subject to the following environmental conditions:

The temperature was maintained at +25°C, and the chamber programmed to dwell for 1.5 hours at 20%, 40%, 60% and 80% Relative Humidity in a total cycle time of 8 hours. The cycle was repeated 27 times in total, (9 days) during which time all the units were powered as detailed in 2.1.2 above. At the end of conditioning a set of readings was taken and the units were visually inspected.
(See Appendix II for a representative temperature plot).

2.1.6 Results of Test

All the units were operational at the end of test with no visible damage or degradation observed.

Variations of Relative Humidity and temperature

Date of Test

(Test b) 23 March - 9 April 1999

2.2.2 Units tested

Units 5 - 8 were tested as detailed below

Test Configuration

The units were powered as indicated in Table 1 and functioned in the following manner:

Battery powered Instruments:

Unit 8 was initially switched (Pneumatically) "on" after 10 minutes and "off" after 20 minutes, however after 1 day the batteries had run out. These were replaced and fitted incorrectly, Incident report VX604882/01 refers, the display of unit 8 failed at this time.

Units 1 and 8 were identical apart from the probe, therefore when the display on unit 8 failed, the faulty display was substituted with the display from unit 1, but was only switched on (and off) for a brief period once a day to check operation.

Mains powered Units:

Units 5, 6 and 7 were switched on for the duration of the test.

Test Equipment used (Table 4)

Instrument	Inv No	Calibration Due Date
Chamber Montford 4F ³	1147	16 May 1999
Chamber Pern	2444	23 April 1999
Data Acquisition system	2569	16 May 1999
Power Supply	300	Traceability unscheduled
Multimeter	3866	4 April 1999

Table 4

2.2.5 Test conditions

Units 5, 6, 7 and 8 were installed into a humidity chamber. The units were powered as indicated in Table 1 and a set of readings was taken to check functionality. The units were subjected to 9 days of test cycling, each temperature and humidity cycle comprised of the humidity cycle (Test a) repeated at 3 temperature levels which were: 25°C or 30°C (dependant on the humidity range of the test chamber), 40°C and 60°C.

(See Appendix I for representative arrangement).

2.2.5 Test conditions (continued)

Readings were taken daily and at the end of testing to confirm the operation of the test units.

The 9 cycles were completed in 2 test periods one of 6 days and one of 3 days with the test units stored at ambient between the 2 periods. (See Appendix II for a representative temperature plot).

2.2.6 Results of Test

After 1 day of testing the batteries in unit 8 were exhausted, however when replaced the batteries were incorrectly fitted.

When the batteries were correctly positioned the display failed to work. Incident Report VX604882/01 refers.

After 3 cycles it was observed that the temperature indication on unit 7 was incorrect. Incident Report VX604882/02 refers.

After 6 cycles the temperature readout on unit 7 recovered.

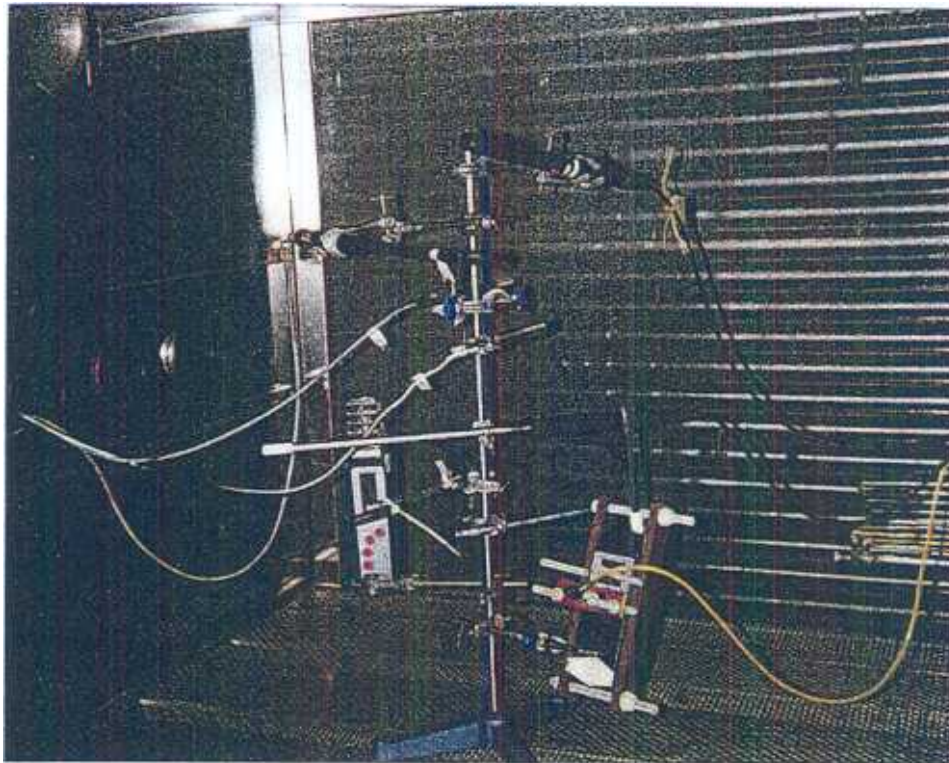
At the conclusion of the test the 4 units (one with a substituted display) were all operational and no visible signs of damage or degradation were observed.

APPENDIX I

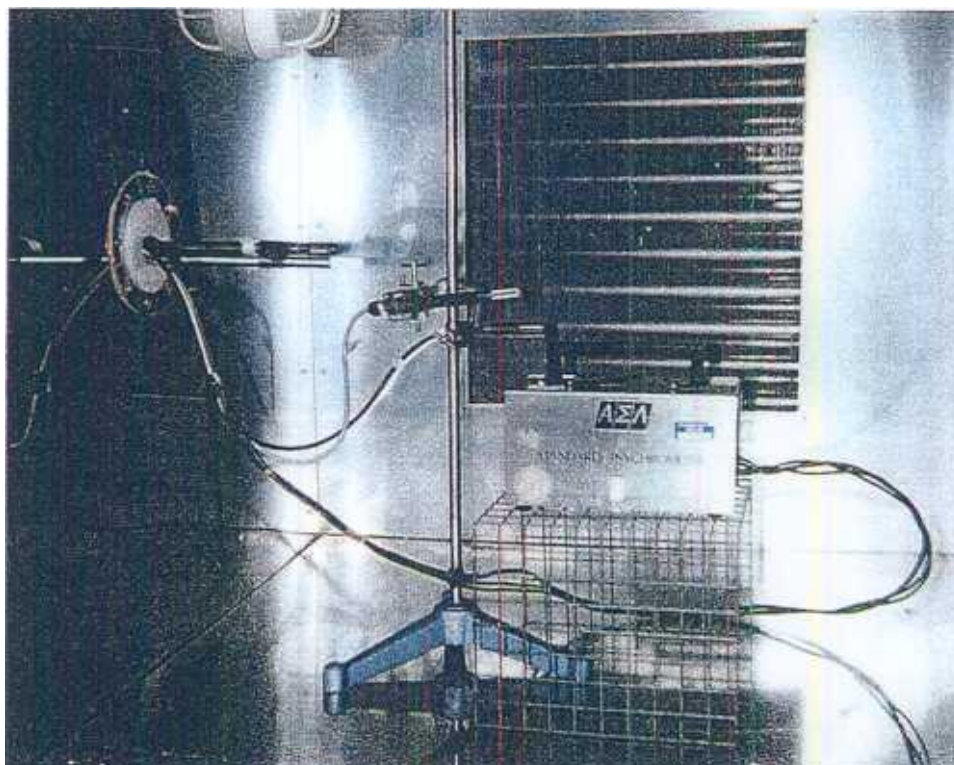
Representative Test Photographs

One page

Test Photographs



Set-up Test (a)



Set-up Test (b)

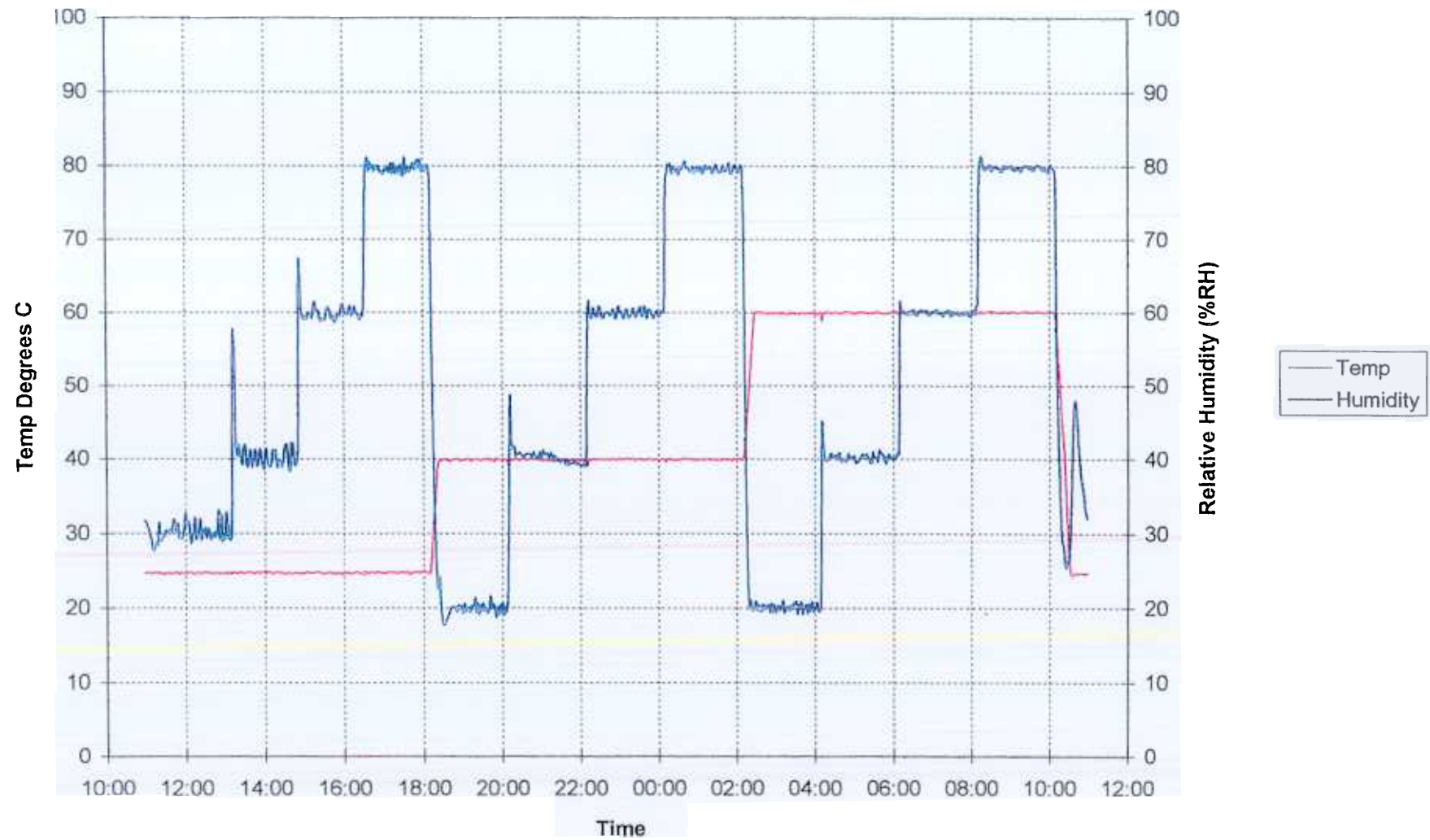
APPENDIX I

Temperature Charts

Two pages

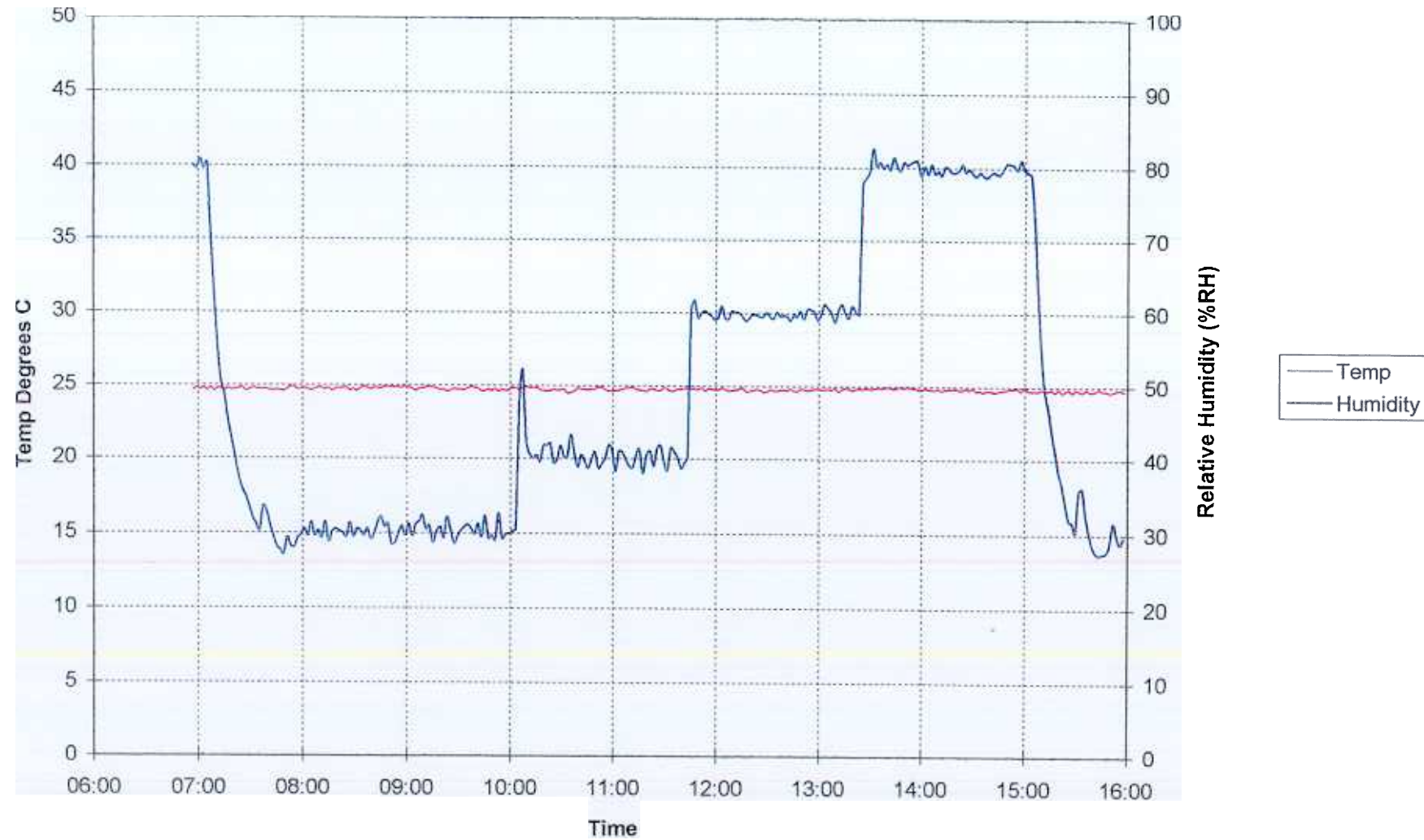
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finish time = 11:00 08/04/1999

Montford 4f3



start time = 07:00:00 12/03/1999
finish time = 16:00 12/03/1999

Montford 4f3



A P P E N D

Incident Reports

Two pages

INCIDENT REPORT

Job Title:	NPL	Report Serial No:	VX604882/01
		Date:	25 March 1999
Equipment:	Testo 650	Serial No:	000141425
Test Spec:	Not specified	CI No:	N/A

Description of Incident

There was no display on the Testo 650, 4 new AA batteries were fitted, a burning smell came from the instrument.

Operating Conditions: The Unit was at laboratory ambient conditions, the probe was in the test chamber at +25°C, 40% RH.

Probable Cause: Batteries fitted incorrectly.

Originator: J Sutherland Checked By: R Harris

Person notified:	Mark Stevens (Customer)	By Project Engineer:	R Harris	Date:	25 March 1999
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Local Corrective Action:	Testo 650 Serial No 00123675 used for continued test, defective Testo 650 returned to Mark Stevens for repair.	Inspected:	R Harris
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Authorised:	Mark Stevens (Customer)	Actioned:	J Sutherland	Date:	25 March 1999
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Testing to Continue:	Yes	Authorised:	Mark Stevens (Customer)	Date:	25 March 1999
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Note to Customer: Please complete this report by typing your comments on the reverse of this form, then sign and return to TÜV Product Service for inclusion in the final report..

REPORT ON

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July 1999

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