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Conservation of cultural heritage — Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property

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National foreword

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Conservation des biens culturels - Modes opératoires et instruments de mesure de l'humidité de l'air et des échanges d'humidité entre l'air et les biens culturels

Erhaltung des kulturellen Erbes - Verfahren und Geräte zur Messung der Luftfeuchte und des Austausches von Feuchtigkeit zwischen Luft und Kulturgut

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Foreword

This document (EN 16242:2012) has been prepared by Technical Committee CEN/TC 346 “Conservation of cultural heritage”, the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2013, and conflicting national standards shall be withdrawn at the latest by May 2013.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

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Introduction

Humidity plays a key role in the conservation of cultural heritage because most materials and/or deterioration mechanisms are directly or indirectly affected by humidity levels or changes. This European Standard is a guide intended to assist in providing an acceptable environment for cultural heritage objects. Humidity in air, expressed in a number of ways, is an important aspect of that environment. Therefore, the control of levels and variability of humidity reduces the risk of deterioration and is an important preventive measure, minimising the need for future conservation interventions.

This European Standard is a guide to specifying adequate procedures for measuring humidity in air and the minimum characteristics of instruments for such measurements so that they are carried out to an appropriate level of accuracy. Although standards exist for measuring humidity in air in other fields like meteorology or ergonomics of thermal environments, this standard focuses on the specific requirements of cultural objects.

This document is one of the series of European Standards intended for use in the study of environments for cultural property.

1 Scope

This European Standard gives guidance and specifies procedures and instruments for the measurement of relative humidity (RH) in air, in outdoor or indoor environments. It indicates how RH can be directly measured or how it can be calculated from air temperature, wet-bulb temperature and dew-point temperature. This standard contains recommendations for accurate measurements of ambient conditions and moisture exchanges between air and cultural heritage objects. It is addressed to anyone in charge of environmental diagnosis, conservation or maintenance of buildings, collections or single objects.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15757:2010, *Conservation of Cultural Property - Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials*

EN 15758:2010, *Conservation of Cultural Property - Procedures and instruments for measuring temperatures of the air and of the surfaces of objects*

EN 60751, *Industrial platinum resistance thermometers and platinum temperature sensors (IEC 60751)*

EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025)*

ISO/IEC Guide 98-3 *Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 15758:2010 and the following apply.

3.1
absolute humidity *(AH)*

volume density of water vapour, i.e. the mass of vapour contained in the unit volume of moist air $AH = \frac{m_v}{V}$, expressed in g/m^3

Note 1 to entry: This volume density is also noted ρv (v for volume)

3.2
atmospheric (or barometric) pressure *(p)*

pressure is the force per unit area exerted by the air column above the measuring point, expressed in hPa (hectopascal)

Note 1 to entry: 1 hPa = 1 mbar (millibar)

3.3
barometer

instrument for measuring atmospheric pressure

3.4

dew-point hygrometer

instrument for measuring the temperature at which a cooled parcel of air becomes saturated with water vapour

3.5

dew-point temperature *(DP)*

temperature to which air is cooled at constant pressure and constant water vapour content in order for saturation to occur

Note 1 to entry: This is expressed in degrees Celsius (°C). [EN 15758: 2010]

3.6

dry air

atmospheric air without water vapour

3.7

dry-bulb temperature *(T, t)*

actual air temperature. In a *psychrometer*, the temperature reached by the thermometer having the dry bulb

Note 1 to entry: Capital *T* is used when the measurement is expressed in Kelvin (K); lowercase *t* when expressed in degrees Celsius (°C).

3.8

equilibrium moisture content *(EMC)*

moisture content at which a material neither loses nor gains moisture from the surrounding atmosphere at given relative humidity and temperature levels. Expressed in g/kg as the ratio of the mass of water m_w contained in the material and the dry mass m_{dm} of the same material, i.e.: $EMC = \frac{m_w}{m_{dm}}$

3.9

frost-point temperature

temperature to which moist air must be cooled, at constant pressure and humidity mixing ratio, in order that it shall be saturated with respect to ice, expressed in degrees Celsius (°C)

3.10

hygrograph

instrument for measuring relative humidity (see hygrometer) and recording over time

Note 1 to entry: Generally, a mechanically or electrically driven drum supporting a strip chart with RH graduation where an ink pen traces a time plot of the ambient humidity.

3.11

hygrometer

instrument measuring relative humidity

Note 1 to entry: It generally comprises a sensor, which is set in equilibrium with the air, and a system that transforms the signal from the sensor into humidity readings.

3.12

mixing ratio or humidity mixing ratio *(MR)*

ratio of the mass of water vapour m_v to the mass of dry air ma, i.e. $MR = \frac{m_v}{m_a}$, expressed in g/kg

3.13

moist air

mixture of dry air and water vapour

3.14
psychrometer

instrument for measuring the dry- and wet-bulb temperatures to calculate relative humidity and other related variables

Note 1 to entry: It consists of two identical thermometers, one of which is sheathed in wet wicking, and a fan to ensure their ventilation at a constant velocity in order to reach equilibrium with air. Thermometer readings are expressed in degrees Celsius (°C). Some electronic instruments provide readings of relative humidity (%), dew point (°C) and other related variables.

3.15
relative humidity *(RH)*

ratio of the actual vapour pressure of the air to the saturation vapour pressure

[SOURCE: EN 15757:2010]

3.16
measuring range

interval of values that are intended to be measured, or that are potentially measurable, or that have been measured, specified by their upper and lower limits

3.17
repeatability

ability of the measuring instrument to reproduce the same output when successively measuring the same value of the air or the surface under investigation, taken under the same conditions

Note 1 to entry: This is expressed as ± percent of the range.

[SOURCE: EN 15758:2010]

3.18
resolution

smallest difference between indications of a displaying device that can be meaningfully distinguished

3.19
response time

time interval between the instant when the parameter under investigation is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits around its final steady value

Note 1 to entry: The response time is typically expressed as the time needed to reach 63,2 % of the final value and in this case is called time constant, or 90 % or 95 % of it. The 90 % response time is 2,3 times longer than the time constant and the 95 % response time is three times longer. The response time is independent of the span of the output change.

[SOURCE: EN 15758:2010]

3.20
saturation vapour pressure $(e_{sat}(t))$

maximum pressure of the water vapour in equilibrium with plane surface of pure water, expressed in hPa (hectopascal)

3.21
sensor

device that senses either an absolute value or a change in a physical quantity and converts them into a useful signal for an information-gathering system

3.22
thermometer
instrument to measure temperature which comprises a sensor which is placed in thermal equilibrium with the air (if it measures the air temperature) or the surface, sometimes a probe that contains and protects the sensor, and a system that transforms the input from the sensor into an output expressed in degrees Celsius (°C)

[SOURCE: EN 15758:2010]

3.23
time constant
time interval between the instant when the air, or the surface temperature, is subjected to a specified abrupt change and the instant when the response reaches (1 – 1/e) x 100 = 63,2 % and remains within specified limits around its final steady value

Note 1 to entry: See also response time.

[SOURCE: EN 15758:2010]

3.24
time stability
rate at which characteristics change in the course of time

Note 1 to entry: It is often expressed in terms of a percent change of the response per year (% / year).

3.25
surface temperature (t_s)
temperature of a given surface of an object

Note 1 to entry: This can be measured with contact thermometers, quasi-contact total radiation thermometers or remote infrared thermometers. The surface temperature is generally different from the air temperature, and varies between different objects and different places on the same object. It is expressed in degrees Celsius (°C). In general, the measured surface temperature is not representative of the whole object.

[SOURCE: EN 15758:2010]

3.26
uncertainty (of measurement)
uncertainty is a non-negative parameter characterising the dispersion of the values attributed to a measured quantity

[SOURCE: EN 15758:2010]

3.27
wet-bulb temperature (t_w)
in a psychrometer, the temperature reached by a thermometer sheathed in wet wicking, expressed in degrees Celsius (°C)

4 Quantities characterising humidity in air

4.1 General

Air humidity is expressed in a number of ways. In this standard, we refer to four key quantities characterising humidity in air for the purposes of environmental diagnosis to preserve cultural heritage: relative humidity, humidity mixing ratio, absolute humidity and dew-point temperature.

4.2 Relative humidity

Relative humidity (RH) is responsible for, or related to, many deterioration mechanisms affecting cultural property preservation. Dry environments become dusty and electrostatic deposition is enhanced. Humid environments increase chemical reactivity of gaseous pollutants. Hygroscopic materials, such as wood, paper, textiles, leather or bone, absorb and release moisture in response to changes in RH, reaching eventually at a given temperature and RH a constant level of moisture termed Equilibrium Moisture Content (EMC). The variations in EMC produce dimensional changes of the materials, i.e. expansion when EMC is increasing and shrinkage when decreasing, which may lead to high levels of stress and physical damage as fracture and deformation. High EMC favours mould growth, as well as hydrolysis, oxidation, corrosion or other chemical reactions.

RH has a synergic effect with light, temperature, pollution and other environmental factors in accelerating fading, discoloration and embrittlement.

4.3 The humidity mixing ratio

The humidity mixing ratio (MR) is used to distinguish if water molecules are added to or removed from the atmosphere, e.g. to monitor evaporation, condensation, or mixing of two air masses. It is useful for environmental diagnostic purposes, to provide evidence of the action of heating, ventilation and air-conditioning systems (HVAC systems) or air-surface interactions. By measuring this parameter along a horizontal cross-section of a room, it is possible to reveal external air penetrating through openings, or moisture released by visitors, or when and where masonry is evaporating (higher MR close to the wall) or adsorbing moisture (lower MR to the wall).

4.4 Absolute humidity

The absolute humidity (AH) is useful in assessing the maximum quantity of water vapour that a given volume can contain at specified temperature conditions. When AH exceeds the saturation level in the air, the excess moisture will condense. From the knowledge of the volume of a closed space, it is possible to calculate how much water will condense on objects and masonry. Such information can be used to determine, e.g., the maximum allowable number of visitors in a closed room, in order to avoid high humidity levels.

4.5 Dew-point temperature

When the dew-point (DP) of the air is compared with the surface temperature (T_S) of a structure or an object, the potential risk of water vapour condensation on that surface can be evaluated, i.e. condensation occurs if T_S is below DP and does not occur if T_S is above DP.

Formulae to calculate the above quantities are reported in Annex A. Examples of environmental diagnosis using these quantities are reported in Annex B.

5 Considerations and recommendations related to measuring methods

5.1 Considerations

An accurate determination of relative humidity (RH) requires particular care because the measurement depends on the temperatures of the air and the instrument, which should be in equilibrium with each other.

Recommendations described in EN 15757 should be considered in the frame of this standard. They should also be considered in the frame of a specific monitoring campaign that contains not only the quantity but also the thermal and/or humidity fields in the surrounding environment as well as close to the object.

The locations of the measuring points should be selected in such a way that they are representative of the environment under investigation. Each room generally shows variations of temperature and RH from point to point, therefore temperature and RH of the air that interacts with the object should be measured at a close distance to the surface. RH should be measured also in free air, i.e. in a location not affected by the surface (preferably, at a one metre distance or in the middle of the room). From these two measurements, it is possible to establish whether the surface is exchanging moisture with air or not.

If the surface temperature is different from the air temperature, the air layer in contact with the surface reaches a different RH from the air around the object, which is difficult to measure. The actual RH at the interface between air and surface should be calculated from the actual surface temperature and the humidity mixing ratio of the air in the proximity, the latter to be derived from the values of air temperature and RH or wet-bulb or dew-point temperatures. In the case some parts of the building (especially external walls) have a different temperature, a number of RH measurements should be performed in order to document how RH changes over the room/building.

Measurements in locations affected by disturbing factors such as heaters, ventilation grilles, windows or doors, or surfaces having a different temperature should be avoided. The measuring instruments should be placed at the level of the object if air stratification is present.

If the instrument temperature is different from the air temperature the RH readings are affected by error. The problem of thermal inertia shall be reduced by using sensors externally connected to the measuring instrument.

Relative humidity can either be measured by means of sensors whose output is directly RH related, or calculated from measurement of the air temperature in combination with the dew-point or the wet-bulb temperature. In the latter case, atmospheric pressure shall be taken into account, in particular for measurements performed in the mountains at high altitudes.

5.2 Recommendations

In the scope of this European Standard, the following recommendations apply:

- the dew-point meter is recommended in the laboratory as a reference instrument to calibrate other hygrometers;
- the electronic psychrometer is recommended for on-site checking the calibration of other hygrometers and/or for spot measurements;
- the capacitive and/or the resistive electronic hygrometers are recommended for spot or routine measurements and/or data collection for statistical analysis;
- hair hygrometers/hygrographs should only be considered in exceptional circumstances for visual inspections.

The characteristics required for instruments or systems that measure air humidity are summarised in Table 1. This does not relate to sensors, which are considered separately. These characteristics are minimum requirements for the recommended use. Any measuring system that meets or exceeds the requirements of this European Standard can be used.

The response time of an RH hygrometer shall be considered. Meaningful results can be obtained after the sensor attains the equilibrium with the given temperature and relative humidity, which requires a time period of approximately twice the response time. If the probe is likely to be exposed to solar radiation, intense light illumination or infrared radiation from heaters, it should be shielded.

Qualified personnel should be aware of recommended measuring procedures and should use calibrated instruments that meet the characteristics set out in Table 1.

Table 1 — Minimum requirements for measuring instruments

	Dew-point hygrometer [a]	**Electronic psychrometer**	**Capacitive electronic hygrometer**	**Resistive electronic hygrometer**	**Hair hygrometer**
Accuracy level	1: very high	2: high	3: medium	3: medium	4: low
Measuring range	-20° to 50 °C	5 % - 95 % +10 to 50 °C	5 % - 95 % -10° to 50 °C	5 % - 95 % -10° to 50 °C	35 % - 95 % -10° to 50 °C
Uncertainty [b]	0,5 °C	2 %	3 %	3 %	10 %
Repeatability	0,2 °C	1 %	2 %	2 %	5 %
Resolution	0,1 °C	1 %	1 %	1 %	2,5 %
Instrument time constant (63 %) in still air	not relevant	required: ≤ 2 min desirable [c] : ≤ 1 min	required: ≤ 5 min desirable: ≤ 2 min	required: ≤ 5 min desirable: ≤ 2 min	10 min
Stability	≤ 0,2°C/year	≤ 2 %/year	≤ 2 %/year	≤ 2 %/year	5 %/month
Periodic checking and maintenance [d]	6 months	Calibration: 1 year; Wick: daily, or when the instrument is used	1 year	1 year	3 months
Recommended use	laboratory calibration	1) checking calibration of other hygrometers 2) spot field measurements	spot or routine measurements; data collection for statistical analysis	spot or routine measurements; data collection for statistical analysis	only in exceptional circumstances for visual inspection

[a] The specifications apply to chilled-mirror dew-point meters. Other hygrometers exist, based on temperature and (capacitive or resistive) RH sensors that calculate and provide dew-point values, and for this reason are improperly called “dew-point meters”. For them, reference should be made to the related “Capacitive” or “Resistive” electronic hygrometer in this Table

[b] Uncertainly includes everything under the condition of use, stated by the supplier/manufacturer, i.e. display resolution and short-term repeatability, calibration, periodical service, air quality, etc. See ISO/IEC Guide 98-3:

[c] The ‘desirable’ response time would be of a considerable benefit for spot readings or continuous monitoring of short-term effects

[d] In case of polluted air or marine environments the intervals will have to be shorter.

6 Main features of the hygrometers

6.1 Chilled-mirror dew-point hygrometer

Operating principle: This hygrometer is based on the detection of the temperature of a cooled mirror at the point at which condensation forms. The temperature of a mirror is controlled by an electronic feedback to maintain a dynamic equilibrium between evaporation and condensation, thus closely following the dew-point temperature changes.

NOTE The chilled-mirror hygrometer is more accurate than other hygrometers because the measurement is based on only one temperature sensor, and temperature sensors are more accurate than humidity sensors. Other commercially available instruments exist under the name “dew-point hygrometer” but are based on a combination of temperature and

RH sensors (generally capacitive or resistive RH sensors) and from these inputs they calculate the dew-point values. These instruments are common capacitive or resistive hygrometers but able to calculate one or more hygrometric variables, including the dew-point.

Recommended use: The instrument provides the most accurate humidity measurements. It is convenient for laboratory tests and calibrations; it is a stable and reliable instrument and covers a very wide RH range. For this reason, it can be used as a reference instrument for the calibration of other hygrometers.

The laboratory calibration is made under stationary conditions is controlled microclimate cells. The time required by the instrument to reach equilibrium is not relevant and is in any case much shorter than the time required for reaching the equilibrium in the cell.

It can be also used to detect the frost point.

Its use requires well-trained personnel.

Main limitations and key factors:

- The instrument operates in the full RH range, from about 0 % to 100 %.
- It is rarely used for on-site monitoring because of its size.
- The high precision requires periodic control and cleaning of the optical components.

6.2 Electronic psychrometer

Operating principle: The psychrometer consists of two thermometers and a fan to ensure their ventilation at a sufficient velocity. The first thermometer is an ordinary thermometer measuring air temperature. This is referred to as ‘dry-bulb’ temperature as opposed to ‘wet-bulb’ temperature indicated by the second thermometer. The latter has a bulb sheathed with a wet wicking, i.e. a piece of wet cloth transporting distilled water from a reservoir to the sensor by capillarity. Evaporation from the wet bulb lowers its temperature, i.e. the wet-bulb thermometer becomes colder than the dry-bulb thermometer, and the temperature difference is proportional to the degree of saturation of humid air.

NOTE The psychrometer is more accurate than other hygrometers because the measurement is based on two temperature sensors, and temperature sensors are more accurate than humidity sensors. However, it is less accurate than the chilled-mirror hygrometer because of the small uncertainty related to the airflow speed.

Recommended use: When appropriately used, this instrument provides accurate humidity measurements.

It can also be used for a simple on-site check of other hygrometers. In such a case, and whenever accurate RH determinations are needed, the RH should be calculated with the formula including the barometric pressure (Annex A, formula A.4).

If used for routine measurements, the psychrometer requires periodic checking and maintenance. Its use requires trained personnel.

Main limitations: At low RH, the wicking may freeze at ambient temperature up to 10° C. When the ambient temperature drops below 0° C, water in the reservoir freezes.

The water reservoir capacity imposes a limit on the duration of unattended monitoring.

The wicking should be clean and the airflow velocity should be periodically checked.

In small, closed environments (e.g. showcases, small cavities), the forced air flow and the wicking evaporation may slightly change the microclimate.

Precise relative humidity values should be calculated with formulae that include barometric pressure (Annex A). Barometric pressure should be independently measured when it departs too much from the sea level pressure (e.g. in mountain sites). The change of barometric pressure with altitude and a graphical example of the related error is reported in Annex C.2. However, in non-elevated locations, under usual barometric pressure variability, in the absence of barometric readings, the common practice is to substitute 1000 hPa to the pressure that causes an error in the order of ± 2 %.

Key factors:

- The instrument operates in a wide RH range from 20 % to 100 %.
- Air flow speed should be kept constant in the range from 2,5 m/s to 6 m/s. The fan should be operated well in advance so that the both sensors and the wet wicking reach an equilibrium. This performance is adequately provided by an electronic psychrometer with an electrically-driven fan. The previous mechanical psychrometer with spring-operated fan changes the ventilation speed with the spring winding and might provide incorrect readings. The use of mechanical instruments is not recommended.
- Temperature sensors should conform to the EN 60751 and have a resolution equal to or lower than 0,1°C; temperature sensors shall be calibrated and, when both are dry, they should read the same temperature.
- Temperature sensors should be shielded against radiation with a metal shield.
- Wet wicking should be clean; this is particularly relevant in coastal (sea spray) or polluted areas.
- The water reservoir should be clean and filled with pure, distilled water.

6.3 Electronic hygrometer with a capacitive sensor

Operating principle: The sensor is made of a polymeric material that reaches equilibrium with the ambient relative humidity; the equilibrium moisture content influences the capacitance dielectric constant as a consequence of the absorbed water vapour.

Recommended use: Except in the case of extreme environmental conditions and under normal use, the sensor is generally stable and accurate and may provide long-term monitoring on site. The small sensor size allows its use in small volumes. It is easy to use and flexible.

Main limitations and key factors:

- The sensor operates in the RH range from 15 % to 95 %.
- The sensors are normally protected with a shield, often made of plastic material, that will induce a thermal inertia. This might lead to large errors in cases of rapid changes of temperature or humidity (Annex C.3). The problem of thermal inertia shall be reduced by using sensors externally connected to the measuring instrument.
- For outdoor measurements, the humidity sensor should be shielded against radiation with a metallic shield.
- The sensor can be contaminated after long-term exposure in polluted environments.

6.4 Electronic hygrometer with a resistive sensor

Operating principle: The sensor is a hydrophilic material that quickly reaches equilibrium with the ambient relative humidity; its equilibrium moisture content determines its electrical resistance.

Recommended use: Except in the case of extreme environmental conditions and under normal use, the sensor is generally stable and accurate and may provide long-term monitoring on site. The small sensor size allows its use in small volumes. It is easy to use and flexible.

Main limitations and key factors: See capacitive sensors. In addition, if the sensor is an electrolyte, it may be damaged after a long period at very high humidity or in wetting conditions.

6.5 Hair hygrometer/hygrograph

Operating principle: This instrument uses a human or animal hair as an RH sensor. This sensor is used either in non-recording instruments (e.g. pointer hygrometer) or in recording instruments (e.g. hygrograph, or thermo-hygrograph when a temperature sensor is associated). In order to record the humidity over time, a mechanically- or electrically-driven drum supports a strip chart with RH graduation where an ink pen traces the time plot of the ambient humidity.

Recommended use: The hair hygrometer/hygrograph is unsuitable as a standard instrument for measuring humidity. Other types of environmental monitoring equipment are cheaper and proven as more reliable. Purchase of hair hygrometers/hygrographs should only be considered in exceptional circumstances for visual inspections.

Main limitations: The hygrograph provides an ink graph on a strip chart useful for visual inspection. It does not provide readings in digital form useful for a statistical analysis, e.g. to calculate averages and departures, range, percentile distribution and define and/or control the historical climate (EN 15757:2010), or assess climate classes in museums.

The instrument needs continuous maintenance and frequent calibration. The equipment can be prone to large measurement error.

Key factors:

- The hair response is usually limited to the RH range from 35 % to 95 %.
- The hair response is not linear (deviation of up to 20 % were observed). The departure from linearity is highest when it is wet. However, a dry hair is less sensitive so needs to be hydrated. Hair hydration is part of the regular maintenance with a frequency that depends on the dryness of the room.
- The hair response can be affected by a large hysteresis, up to 20 % (Annex C2).
- The hair is affected by ageing, absorption of gases and deposition of particles. It needs periodical cleaning carried out by well-trained personnel. Maintenance frequency depends on air pollution and dustiness, e.g. once every 6 months in air not contaminated by dust, pollutants or marine aerosols, one month in polluted air.
- Calibration checks should be periodically carried out, at least at one or two measurement points, by comparison with a primary instrument. Calibration frequency depends on air dryness and pollution, e.g. once every 6 months in average-to-humid environments and unpolluted air; in polluted, marine or arid environments once a month.
- The friction of the pen against the paper and the dimensional changes of the strip chart may add a further error (up to 10 %).

7 Instrument calibration

Instruments should be calibrated periodically so that they achieve a high level of accuracy in measuring humidity in order to control the indoor climate for conservation purposes.

In order to achieve this objective one of the following conditions shall be met:

- all measuring instruments shall be provided with a calibration certificate issued by an accredited laboratory in compliance with EN ISO/IEC 17025, or

- at least one reference instrument shall be provided with a calibration certificate issued by an accredited laboratory in compliance with EN ISO/IEC 17025. Such an instrument will be used for checking the calibration of other instruments by comparison.

In this case, the class of accuracy of the reference instrument shall be higher than that of the instrument being checked.

The calibration of instruments should be checked frequently. If it is found to have slipped beyond the manufacturers specification, the instrument should be recalibrated.

The calibration certificate shall report, for each humidity value, the correction to the readings of the instrument under calibration and the associated uncertainty in agreement with the ISO/IEC Guide 98-3.

NOTE 1 It is recommended to perform spot checks of readings, but this is not a calibration.

NOTE 2 In the field it is possible to check the quality of the readings of one instrument by comparison with another recently calibrated instrument, although this does not substitute a calibration.

Annex A
(informative)

Formulae for calculating relative humidity and related variables

The following formulae (after Camuffo, 1998) enable the calculation of relative humidity and other related quantities from three basic parameters, including atmospheric pressure *p*. In the case of approximate calculations and in the absence of a barometric reading, *p* can be substituted with 1013 hPa.

A.1 Instruments: Psychrometer, barometer – Parameters: air temperature *t (°C),* wet bulb air temperature *t*w *(°C)*, *p (hPa)*

Water vapour pressure *e* (A.1)

$$e = 6.112\times\left(10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)\right)(hPa)$$

Mixing ratio (A.2)

$$MR = 3801.5\times\frac{10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)}{p-6.112\times\left(10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)\right)}\quad(g/kg)$$

Absolute humidity (A.3)

$$AH = 1344.6\times\frac{10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)}{273.15+t}\quad(g/m^3)$$

Percent relative humidity (A.4)

$$RH = 100\times\frac{10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)}{10^{\frac{7.65t}{243.12+t}}}\quad(\%)$$

Dew-point temperature (A.5)

$$DP = \frac{243.12\times\ln\left(10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)\right)}{17.62-\ln\left(10^{\frac{7.65t_W}{243.12+t_W}} - 1.068\times10^{-4}\,p(t-t_W)\right)}\quad(°C)$$

A.2 Instruments: RH hygrometer, thermometer, barometer - Parameters: *t, RH, p*

Water vapour pressure (A.6)

$$e = 0.06112 \times 10^{\frac{7.65t}{243.12+t}} \times RH \quad (hPa)$$

Mixing ratio (A.7)

$$MR = 38.015 \times \frac{10^{\frac{7.65t}{243.12+t}} \times RH}{p - \left(0.06112 \times 10^{\frac{7.65t}{243.12+t}} \times RH\right)} \quad (g/kg)$$

Absolute humidity (A.8)

$$AH = 13.44 \times \frac{10^{\frac{7.65t}{243.12+t}}}{273.15 + t} \times RH \quad (g/m^3)$$

(A.9)

Dew-point temperature

$$DP = \frac{243.12 \times \ln\left(10^{\frac{7.65t}{243.12+t}} \times \frac{RH}{100}\right)}{17.62 - \ln\left(10^{\frac{7.65t}{243.12+t}} \times \frac{RH}{100}\right)} \quad (°C)$$

A.3 Instruments: Dew-point hygrometer, thermometer, barometer - Parameters: *t,: t_d*, *p*

The symbol $\mathbf{t_d}$ *is used to express the value of the DP when measured in °C.*

Water vapour pressure (A.10)

$$e = 6.112 \times 10^{\frac{7.65 t_d}{243.12 + t_d}} \quad (hPa)$$

Mixing ratio (A.11)

$$MR = 3801.5 \times \frac{10^{\frac{7.65 t_d}{243.12 + t_d}}}{p - 6.112 \times 10^{\frac{7.65 t_d}{243.12 + t_d}}} \quad (g/kg)$$

Absolute humidity (A.12)

$$AH = 1344.6 \times \frac{10^{\frac{7.65 t_d}{243.12 + t_d}}}{273.15 + t} \quad (hPa)$$

Percent relative humidity (A.13)

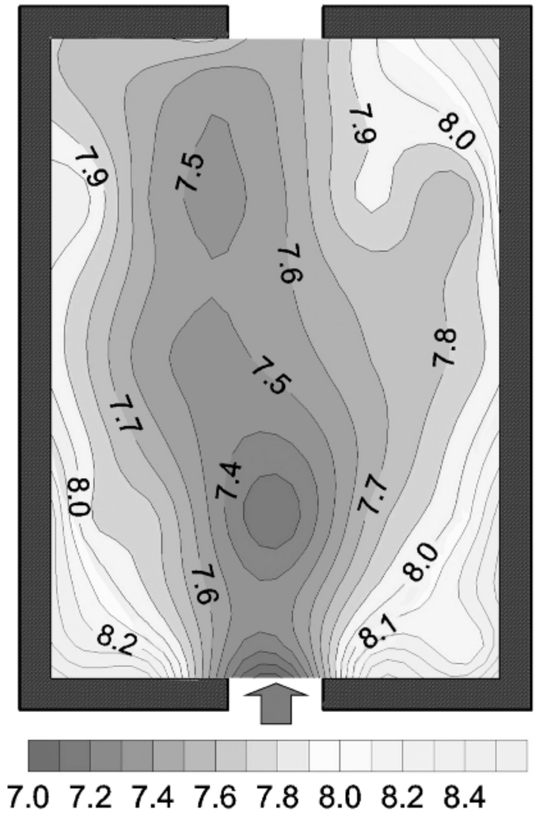
$$RH = 100 \times 10^{\frac{7.65 t_d}{243.12 + t_d} - \frac{7.65 t}{243.12 + t}}$$

Annex B
(informative)

Examples for indoor climate measurements

B.1 Recognising the penetration and spread of external air across a room

The humidity mixing ratio is used as a tracer to recognise the penetration of external air, its path and diffusion. Figure B.1 shows the distribution of MR in a horizontal cross section of a room in a museum, sampled 1 m above the floor. The distribution is obtained from a number of psychrometric, or temperature and RH measurements made at regular distances along a grid on a horizontal plane at some distance from the floor. The MR is then calculated at each sampling point and the lines having equal levels are then drawn with a graphic computer programme. The mapping shows that some drier air is penetrating through the door and crossing the room, with some internal spread.



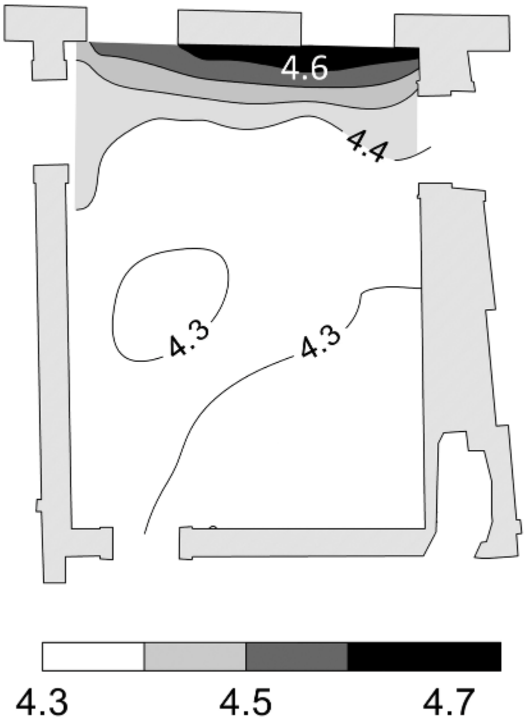
Key

Numbers and scale refer to mixing ratio (g/kg)

Figure B.1 — Penetration and spread of external air shown with a map of mixing ratio

B.2 Recognising if wall dampness is associated to condensation or evaporation

In this room of a historic palace, the external wall was cold and damp, the origin of water was unclear, and the question was whether the problem was condensation on a cold wall, or evaporation from a damp wall. In the former case, some wall heating would be beneficial, in the latter, dangerous, as it could enhance the salt efflorescence. Using the same technique as for Clause B.1, a gradient of MR is evident in front of the cold wall (Figure B.2). The maximum level of MR is found at the interface with the cold wall, showing that the air is locally enriched with moisture escaping from the wall by evaporation. The wall was damp due to the penetration of rainwater through permeable external plaster



Key

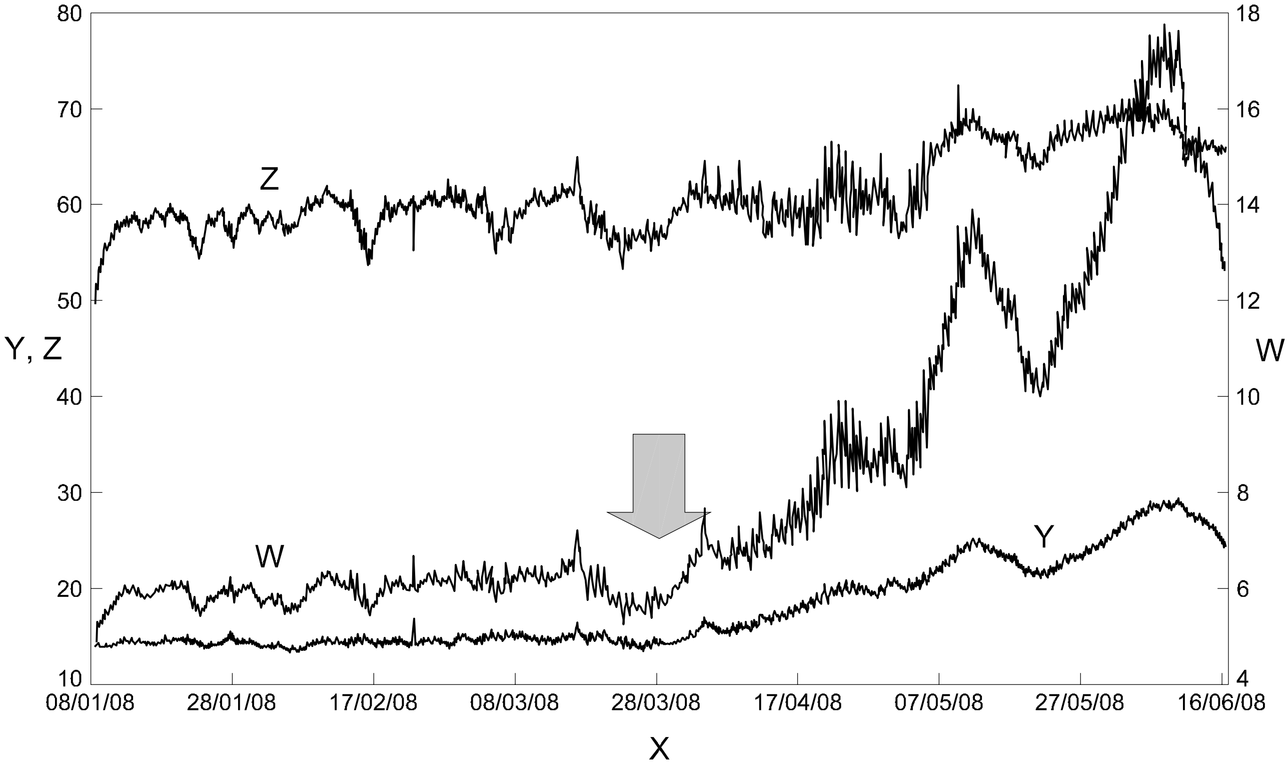
Numbers and scale refer to mixing ratio (g/kg)

Figure B.2 — Evaporation from a wall shown with a map of mixing ratio

In general, a gradient in the mixing ratio near a wall is an index of condensation or evaporation, if the MR close to the wall is lower or higher, respectively. The difference between the indoor and the outdoor MR values indicates that some moisture is released or absorbed inside the room.

B.3 External dampness entering a room shown with a mixing ratio plot

Figure B.3 shows the microclimate inside a room. At a first sight, neither the plot of temperature T, nor the plot of RH point out anything relevant. On the other hand, the plot of MR, calculated from the temperature and relative humidity measurements shown that MR was initially more or less constant, and then it started to increase after a certain date (see arrow). The increase of MR means that the indoor air is enriched in moisture and the day indicated with the arrow had an intense rainfall. The wall absorbed some rainwater and part of it migrated indoors in enriching the air with moisture released by evaporation. The variability in the subsequent days was due to wind increasing air infiltration into the room (major oscillations) and the operation of a de-humidifier (short-term fluctuations).



Key

X = date (dd/mm/yy)

Y = temperature (°C)

Z = relative humidity (%)

W = mixing ratio (g/kg)

Figure B.3 — Moisture enrichment from damp wall after rainfall

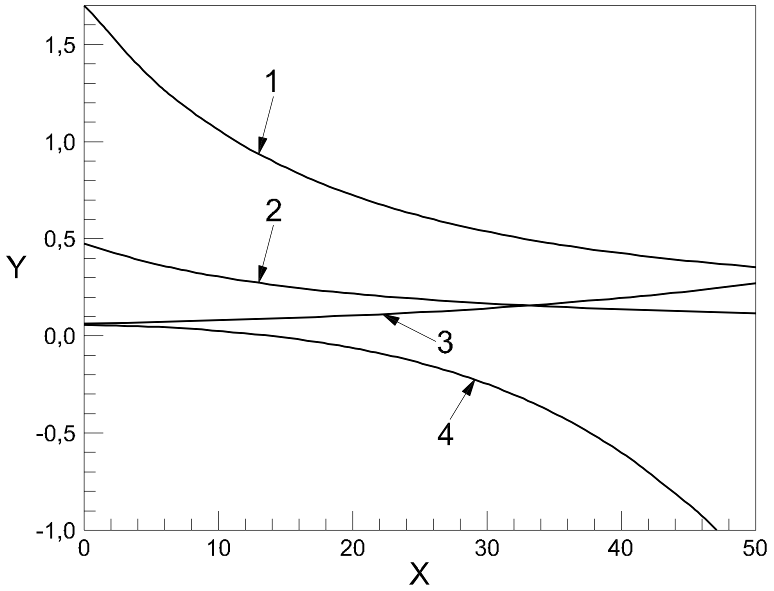
Annex C
(informative)

Instrumental errors

C.1 Psychrometer: errors in the various hygrometric variables generated by an error of 0,1° C in a temperature reading

In a psychrometer, all the hygrometric variables are derived from two temperature readings, i.e. the dry-bulb and the wet-bulb temperatures. An error in one of them, or in both, reflects an error in the calculated values. The uncertainty due to a difference in the response between the two thermometers is as significant as the absolute error in the temperature measurement. For this reason, a key precaution is to ensure that both thermometers give exactly the same readings when both bulbs are dry.

Figure C.1 illustrates an example of the propagation of errors when a difference of 0,1° C is found between the two thermometers, or when the dry-bulb or the wet-bulb temperature reading is under- or over-estimated by 0,1° C, in the case of ambient temperature between 0° C and 50° C, and RH = 50 %.



Key

Y errors in relative humidity (%), mixing ratio (g/kg), absolute humidity (g/cm), dew point temperature (°C)

X temperature (°C)

1 relative humidity (%)

2 dew point (°C)

3 mixing ratio (g/kg)

4 absolute humidity (g/m)

Figure C.1 — An example of error in the hygrometric variables when a psychrometer reading fails by -0,1°C, at ambient RH = 50 %

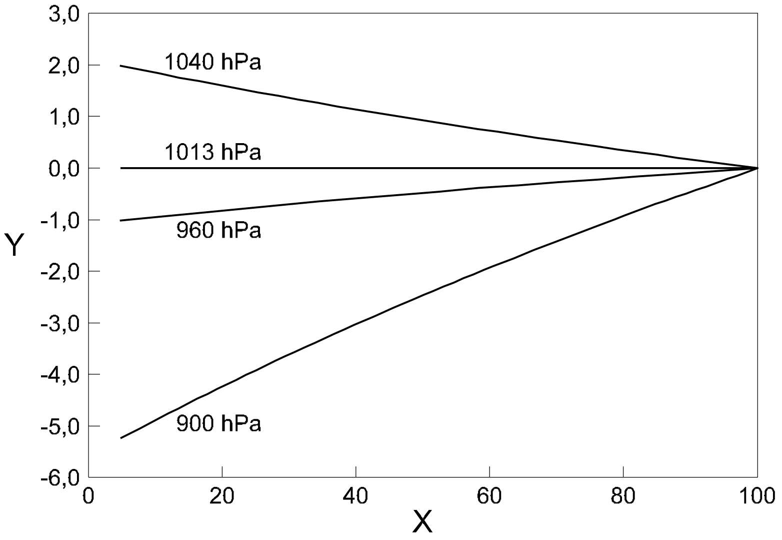
C.2 Psychrometer: error in determining the relative humidity due to pressure change

The formulae used to calculate the relative humidity involve the atmospheric pressure. At sea level, the barometric pressure generally lies in the range 960 hPa to 1040 hPa, depending on the general circulation. However, the barometric pressure decreases very much with the altitude, as shown in Table C.1, and this fact cannot be neglected in the mountain sites.

Table C.1 — Change of barometric pressure with altitude in the Standard Atmosphere

Altitude (m)	0	500	1000	1500	2000	2500	3000	3500
Pressure (hpa)	1013	955	899	846	795	747	701	658

An example of the error arising from neglecting the influence of barometric pressure (as happens with the psychrometric diagrams drawn for the sea level, or with the electronic psychrometers that calculate the hygrometric variables but do not include a barometric sensor), is reported in Figure C.2 for some selected barometric pressure values.



Key

X relative humidity (%)

Y error in relative humidity readings (%)

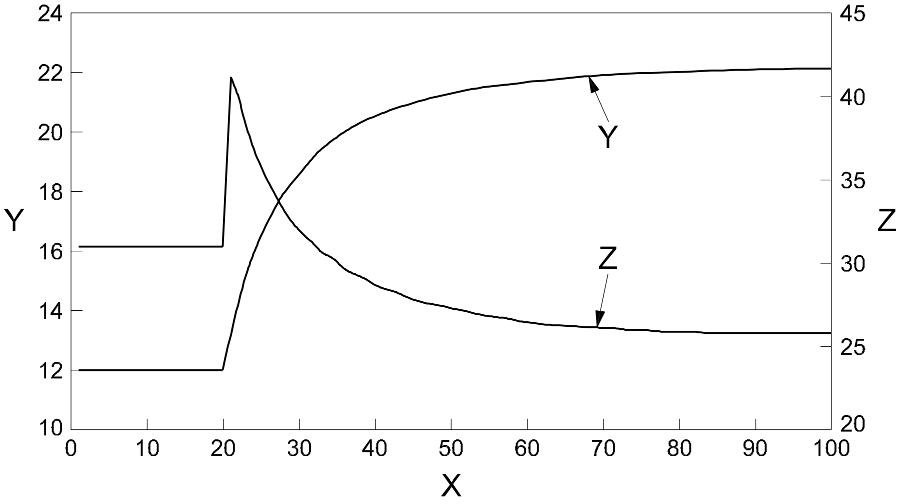
Lines correspond to some selected barometric pressure values, indicated in hPa

Figure C.2 — Error arising from neglecting the influence of barometric pressure for some selected barometric pressure values

C.3 Error due to a thermal inertia of a case, a probe or a shield

In some instruments, the sensor quickly responds to temperature and humidity variations. However, the sensor is not in free air, but is fixed to a support, a probe, or is protected by a shield or is placed inside a case. These devices have a longer time response to temperature changes, especially when they are made of plastics. Therefore, the sensor is conditioned by the RH of its microenvironment, which is determined by the moisture content in the air and the temperature inside the case, which can be different from that in the free air. This means that that the RH measurement will be incorrect whenever fast temperature changes occur. If the temperature fluctuates continually, the measurement of RH will be continually affected, and in some cases, when both the temperature and MR change, the error can be very large and apparently unpredictable, as illustrated in Figure C.3 for a compact data logger with the temperature and RH sensor having a protection in plastics material.

In Figure C.3 at the instant X = 20 min, the temperature has a sudden rise from the initial level to the final level, and the RH too has a sudden drop from the initial level to the final one. However, the plot of the temperature and RH outputs of the instrument, respectively indicated Y and Z in the figure, shows that the temperature reading Y increases slowly and gradually from the initial level to approach asymptotically the final higher level. On the other hand, the RH reading Z increases immediately with an overshoot peak as a result of cooling the air within the case, and then decreases following the gradual heating of the case, until it reaches the final equilibrium when the temperature of the protection in plastics has reached its equilibrium with the environment.



Key

X time (min)

Y temperature (°C)

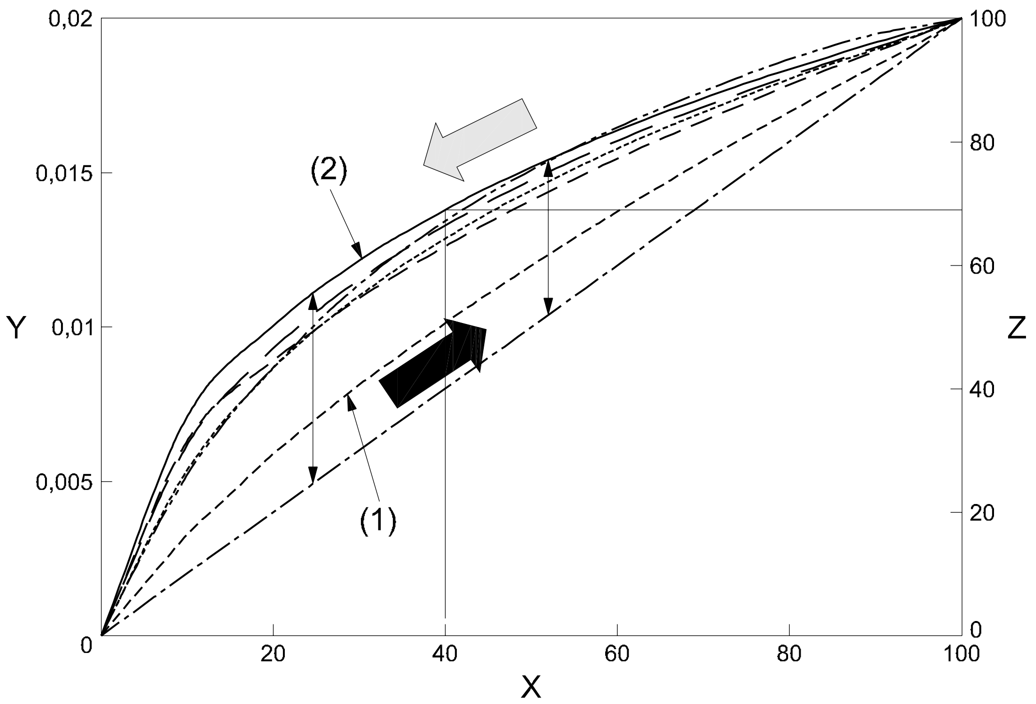
Z relative humidity (%)

Figure C.3 — Temperature and RH output distortion as a consequence of a sudden change in ambient temperature and thermal inertia of the protective support

C.4 Typical non-linearity and hysteresis of the hair hygrometer

C.4.1 Hair non-linearity and hysteresis

The hair response is not linear and is affected by hysteresis. The effect of past humidity exposure on calibration curve of a hair is represented in Figure C.4. In the practice, the dehydrated hair branch (lower branch, from dry to wet) is avoided and only the hydrated hair branch (upper lines) is used. The hydrated hair branch may have several values, depending on the hydration and contamination. In the interval 35-90 % the same reading may be obtained for different actual RH values in the environment, 15 % of the full scale. Deviations from linearity of the hair are very large, and may reach 30 % at the middle of the range.



Key

X relative humidity (%) in the calibration chamber (input)

Y hair elongation (%)

Z relative humidity (%) reading (output)

(1) Dotted line: the response of a de-hydrated hair

(2) Continuous lines: the response of a hydrated hair

The vertical arrow indicates the uncertainty in readings.

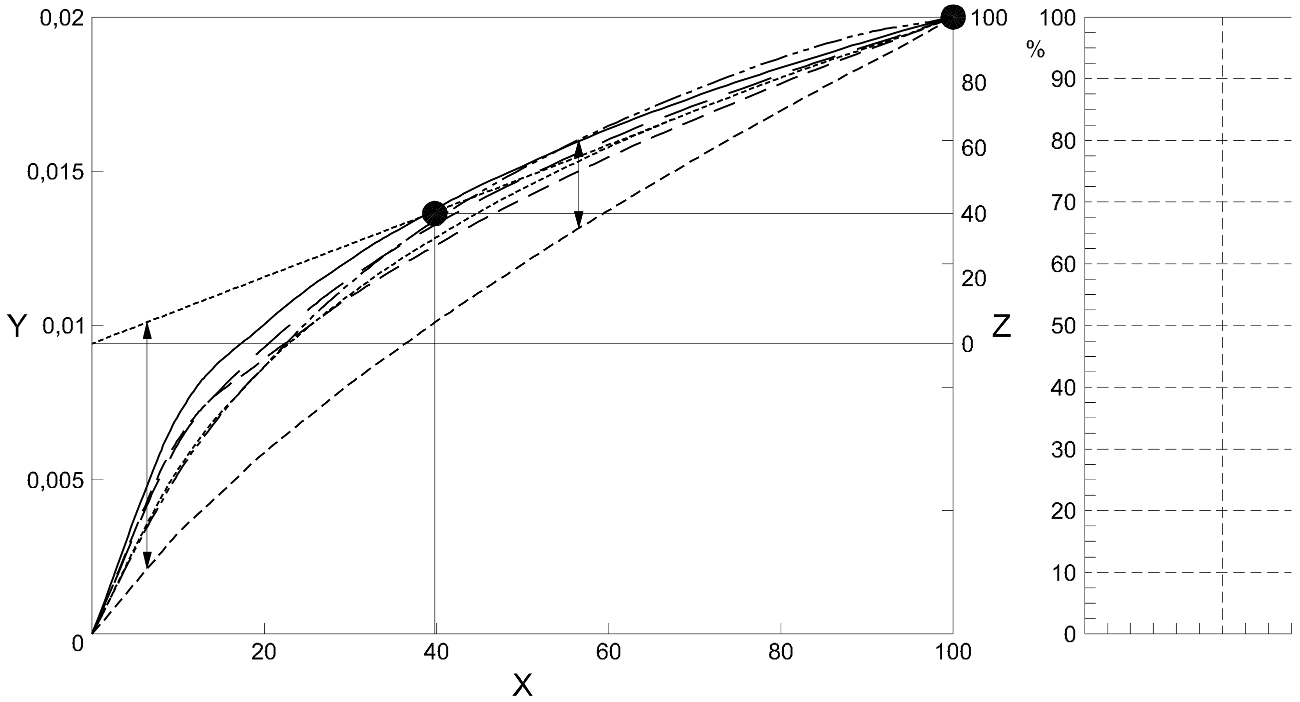
Black thick arrow: the part of the hysteresis cycle when wetting.

Grey thick arrow: the part of the hysteresis cycle when drying.

Figure C.4 — Deviations from linearity of the hair sensor

C.4.2 Linear and non-linear scales

A further problem is the linearisation of the output. In some instruments, the way to get a linear but compressed scale is to calibrate the hair at 100 % and mid-range, e.g. 40 %, and then make reference to the best-fit interpolation, as shown in Figure C.5. Uncertainty is reduced at mid and high RH levels but is very high at low RH levels. Low RH levels are quite rare outdoors but very frequent in heated rooms and very dangerous for the conservation of objects containing organic hygroscopic materials like wood. The calibration scale is arbitrary and thus does not follow a true calibration for the whole range.



Key

X relative humidity (%) in the calibration chamber (input)

Y hair elongation (%)

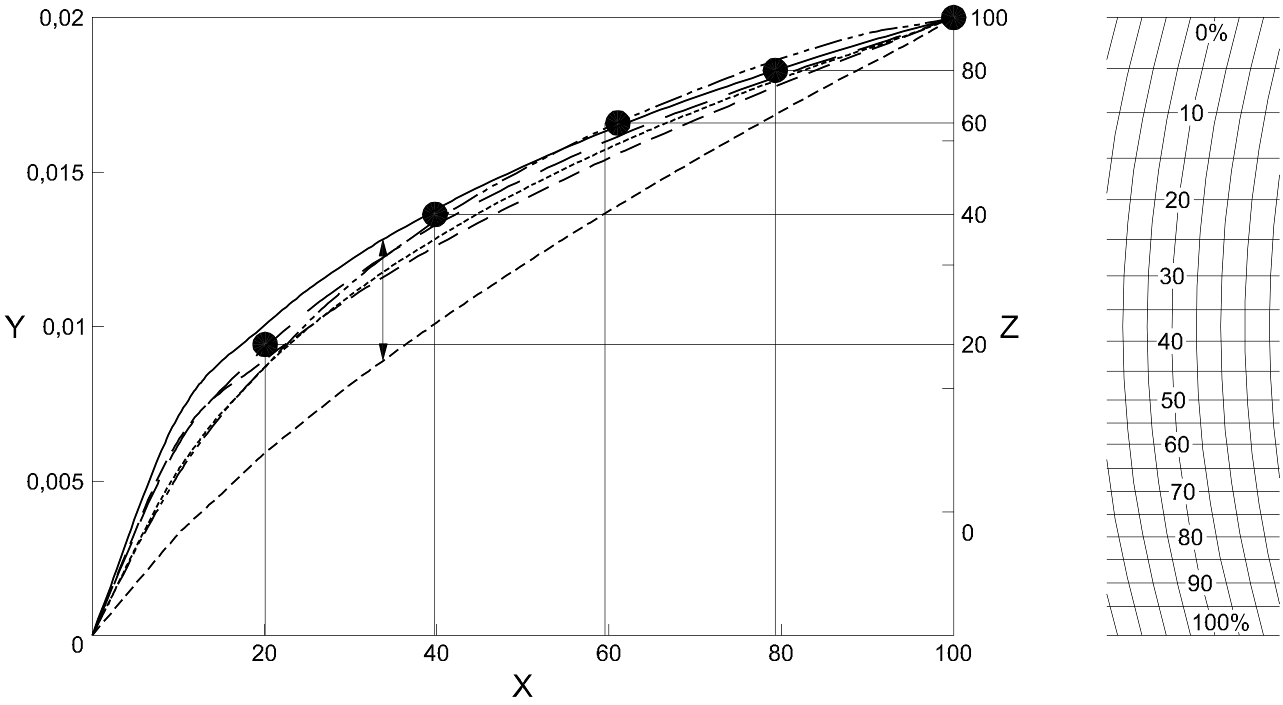
Z relative humidity (%) reading (output) after calibration made with some selected reference points (black dots)

Symbols as in Figure C.4.

To the right: The linear RH scale on a strip chart recorder.

Figure C.5 — Linear calibration of an hair sensor (left) and linear-scale strip chart (right)

In some instruments, the scale is non-linear, and follows the curvature with variable resolution (see Figure C.6.) Sometimes this is an adapted diagram, not following a true calibration for the whole range.



Key

X relative humidity (%) in the calibration chamber (input)

Y hair elongation (%)

Z relative humidity (%) reading (output) after calibration made with some selected reference points (black dots)

Symbols as in Figure C.4.

To the right: The non-linear RH scale on a strip chart recorder.

Figure C.6 — Non-linear calibration of an hair sensor (left) and non-linear-scale strip chart (right)

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