BRITISH STANDARD

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13009:2000

Hygrothermal performance of building materials and products — Determination of hygric expansion coefficient

The European Standard EN 13009:2000 has the status of a British Standard

ICS 91.100.01

National foreword

This British Standard is the official English language version of EN 13009:2000.

The UK participation in its preparation was entrusted by Technical Committee B/540, Energy performance of materials, components and buildings, to Subcommittee B/540/1, European Standards for thermal insulation, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

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Summary of pages

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Hygrothermal performance of building materials and products - Determination of hygric expansion coefficient

Performance hygrothermique des matériaux et produits pour le bâtiment - Détermination du coefficient d'expansion hydrique

Wärme- und feuchtetechnisches Verhalten von Baustoffen und Bauprodukten - Bestimmung des hygrischen Dehnkoeffizienten

This European Standard was approved by CEN on 26 November 1999.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Foreword

This European Standard has been prepared by Technical Committee CEN/TC 89, Thermal performance of buildings and building components, the Secretariat of which is held by SIS.

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of an identical text or by endorsement, at the latest by July 2000, and conflicting national standards shall be withdrawn at the latest by December 2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This document is one of a series of standards on general test methods for the thermal and moisture related properties of building materials and products.

Introduction

Many building materials exhibit expansion/contraction characteristics resulting from changes in moisture content.

This standard specifies a method of measuring the hygric expansion coefficient as a function of moisture content. This coefficient can be used in calculations of material deformations or stresses due to changes in moisture content.

Material specifications may impose additional requirements related to the test, e.g. dimensions or numbers of test specimens.

This standard is intended to be used as the reference by harmonised product specifications, as far as products do not have properties which make application of this standard difficult.

1 Scope

This standard specifies a procedure for determining the hygric expansion or contraction behaviour of building materials as a function of moisture content. It is applicable for mineral, porous hygroscopic materials. For other materials showing moisture-induced deformations, the procedure described can be applied in a suitable way taking into account their specific moisture behaviour.

This standard is relevant to material states when reversible expansion/contraction processes may be assumed, but not to states governed by irreversible processes such as shrinkage after material production or after initial drying.

2 Normative references

This standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed below. For dated references, subsequent amendments to or revisions of these publications apply to this standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN ISO 9346 Thermal insulation - Mass transfer - Physical quantities and definitions (ISO 9346:1987)

EN ISO 12570 Hygrothermal performance of building materials and products - Determination of moisture content by drying at elevated temperature (ISO/FDIS 12570:1999)

EN ISO 12571 Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties (ISO/FDIS 12571:1999)

prEN ISO 12572:2000 Hygrothermal performance of building materials and products - Determination of water vapour transmission properties (ISO/DIS 12572:1997)

3 Definitions, symbols and units

3.1 Definitions

For the purposes of this standard, the terms and definitions given in EN ISO 9346 and the following apply.

3.1.1
free water saturation
maximum water uptake under normal pressure conditions (without overpressure or vacuum)

3.1.2
reference length
the length of the specimen, between measuring points, in the dry state

3.1.3
hygric strain
ratio of measured length change to the reference length as a function of moisture content

3.1.4
hygric expansion coefficient
ratio of difference in hygric strain to difference in moisture content as a function of moisture content.

3.2 Symbols and units

Symbol	Quantity	Unit
l	length dimension of specimen along the measuring axis	M
l_0	Reference length of the dry specimen	M
Δl	length change of specimen caused by a change in moisture content	M
u	moisture content, mass by mass	kg/kg
Δu	Difference in moisture content between two successive states	kg/kg
u_f	free water saturation	kg/kg
ε_h	hygric strain	-
α_h	hygric expansion coefficient	-

4 Principle

The hygric expansion coefficient is calculated by relating the measured length change of a specimen, caused by a defined change in moisture content, to the length of the specimen in the dry state and to the difference in moisture content. The length change measurement is carried out continuously in the direction of the largest dimension of a prismatic specimen starting and ending in a state of equilibrium. The wetting or drying process is carried out in several steps of controlled moisture content change, in order to obtain the hygric expansion coefficient as a function of moisture content. Measurements are carried out under isothermal conditions to avoid superimposed temperature induced deformations.

5 Apparatus

The test apparatus shall include the following.

a) Measuring instruments for determining specimen dimensions to an accuracy of ± 0,1 mm.

b) Measuring devices for length change measurements which do not obstruct free hygric dilatation and are not sensitive to temperature and humidity changes. These shall include length change measuring sensors with an accuracy of ± 0,001 mm, with continuous data logging during the recording of positive and negative length changes along the measuring axis of the specimen. The sensors shall be either:

- capable of maintaining defined and reproducible contact with a gauge plug attached to the end of the test specimen; or

- attached to one or two long sides of the specimen parallel to the measuring axis such that the measuring tips of the sensor are in permanent contact with the specimen over a distance between the tips (the reference length) of nearly the specimen length.

NOTE Suitable length change measuring systems include inductive movement sensors, mechanical dial gauges, optical systems with a measuring magnifier and laser optical systems (interferometry).

Systems having mechanical contact with the specimen, e.g. via plugs on the specimen, shall have good reproducibility (spherical/point contact, suitable contact force, non-corrosive plugs, etc.).

c) Measuring chamber (climatic chamber or test box or similar) capable of providing variable steps in relative humidity between about 10 % relative humidity and about 95 % relative humidity at constant temperature (e.g. 20 °C or 23 °C), maintaining constant conditions in each step within ± 2 % relative humidity and ± 1 K. If test boxes or desiccators with saturated aqueous solutions are used (see EN ISO 12571), they should be placed in a constant-temperature chamber with the specified temperature conditions.

d) Balance capable of weighing test specimens and water supply equipment to an accuracy of ± 0,01 % of their mass.

e) Ventilated oven for specimen drying at elevated temperatures with specifications according to EN ISO 12570.

f) Desiccator with desiccant so that dried specimens may be cooled down to test temperature while maintaining dry conditions (desiccants according to prEN ISO 12572:2000).

g) Suitable and regularly calibrated sensors for temperature and humidity control within the measuring chamber, possibly with a continuous recording system.

h) Hypodermic syringe of suitable volume for water supply.

6 Test specimens

6.1 General

Test specimens shall be representative of the material, taking account of any guidance given in material standards. If the material to be tested is suspected of being anisotropic, two sets of test specimens shall be cut so that measurements can be made in different anisotropic directions.

6.2 Dimensions of test specimens

The test specimens shall be prisms with their largest dimension used as the measuring axis. Test specimen dimensions shall be in accordance with material standards, where possible.

NOTE Suitable dimensions include 40 mm × 40 mm × 160 mm, 20 mm × 20 mm × 160 mm, 40 mm × 10 mm × 200 mm, 20 mm × 10 mm × 200 mm, or similar. The ratio of length to cross sectional dimensions should be as large as possible in order to reach moisture equilibrium after drying or wetting steps as quickly as possible, whilst ensuring that the specimen remains representative of the material structure.

6.3 Number of test specimens

A minimum of three specimens shall be tested.

6.4 Preparation of test specimens

Preparation methods shall not change the original structure of material. The surfaces of the test prisms shall be plane and rectangular. Two gauge plugs shall be attached either to the opposite faces of the specimen at either end of the long axis or, if necessary, towards the opposite ends of the long side (see figure 1 types A or B). The effects of cutting or attaching of gauge plugs or sensor fixings shall not change the structure or expansion behaviour of the specimens. The masses of plugs, adhesives and fixings, which shall not be made of hygroscopic materials, shall be determined by weighing the specimens before and after attachment in order to enable weight corrections according to 7.2.11.

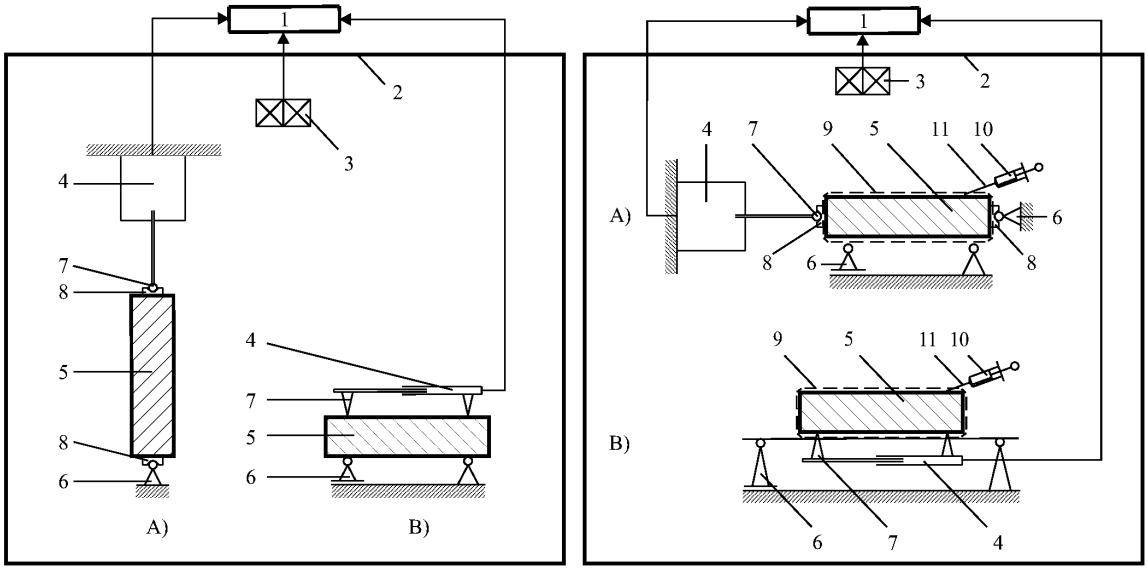
Measures shall be taken to achieve approximately symmetric and uniform moisture distribution within the specimen after supplying water according to 7.2.6, so as to obtain one-dimensional hygric dilatations without appreciable bending of the specimen.

NOTE Suitable measures to achieve approximately symmetric and uniform moisture distribution within the specimen can be e.g.:

- for bulky, nearly even-sided cross-sections: sawing a groove almost half as deep as the specimen along the middle of the upper long surface of the specimen;

- for bulky, cross sections without even sides: sawing two symmetric sloped grooves along the two opposite smaller long surfaces of the specimen with a depth of about a quarter of the specimen dimension in that direction;

- for flat cross sections: forming two lateral grooves, to retain the water, with non-obstructive mastics bulges at the bottom of the two opposite smaller long surfaces of the specimen.



a) Hygroscopic moisture range b) Super-hygroscopic moisture range

Key

Type A) Measurement of length changes between two plugs being attached to the facing surfaces of the specimen

Type B) Measurement of length changes between two measuring tips being in contact with one specimen side (directly or via plugs)

1 Data logging system
2 Measuring chamber (with high relative humidity for measurements in case b)
3 Sensors for temperature and humidity control
4 Length change measuring system, e.g. dial gauge, inductive sensor
5 Specimen
6 Non-obstructive specimen suspension,
vertical or horizontal for both types A and B in case a,
horizontal for both types A and B in case b
7 Measuring tips, e.g. sphere (type A) or tapered pin (type B, penetrating the foil in case b)
8 Plugs, e.g. with tapered hole for sphere contact (type A)
9 Vapour tight foil around the specimen surfaces
10 Hypodermic syringe
11 Needle penetrating foil for water supply

Figure 1 - Schematic representation of two types of measuring set-ups A) and B) for hygric length change measurements both for the hygroscopic (a) and the super-hygroscopic moisture range (b) of a material

6.5 Conditioning of test specimens

The specimens shall be immersed in water under normal pressure conditions and at the test temperature (see 7.1) until free water saturation is reached (for the criterion see 7.2.10). The water shall cover the specimens by not more than 10 mm.

7 Procedure

7.1 Test conditions

Measurements shall be carried out under isothermal conditions; (20 ± 1) °C or (23 ± 1) °C should be used unless otherwise specified.

Length change measurements shall be carried out in steps between the dry state and free water saturation of the material, covering the following moisture ranges.

a) The hygroscopic moisture range

Approximately evenly distributed steps in relative humidity (not more than four steps are necessary) should be chosen from the dry state up to about 95 % relative humidity. Unless otherwise specified, the following steps in relative humidity should be used: dry state (≤ 10), (30 ± 2), (50 ± 2), (80 ± 2), (93 ± 2) % relative humidity.

NOTE If materials are expected to undergo structural changes at very low moisture contents, the lowest relative humidity step should be chosen appropriately.

b) The super-hygroscopic moisture range

From the final equilibrium moisture content in the hygroscopic range at e.g. (93 ± 2) % relative humidity, up to free water saturation (u_f) of the specimens, two further steps of increasing moisture content are sufficient in most cases. Unless otherwise specified, the following moisture content steps should be used:
approximately 0,5 u_f , and (0,95 to 1,0) u_f.

7.2 Test procedure

7.2.1 Remove specimens from water immersion after free water saturation is reached (for the criterion see 7.2.10). Carefully remove water adhering to the specimen surface (using a moist sponge), then weigh the specimen in the wet state. Determine the water content of free saturation, u_f, by weighing the specimen again after drying according to EN ISO 12570. Measure the reference length l_0 in the dry state.

7.2.2 Weigh the dried specimen immediately before installation in the measuring chamber. Bring the length change sensor into contact with the gauge plugs (see figure 1 a)) and set it to zero. Expansion shall not be obstructed and the whole specimen surface shall be in contact with the air in the chamber. While maintaining constant temperature conditions, set the relative humidity to the first level of the hygroscopic moisture range according to 7.1 a).

7.2.3 After expansion has ceased (for the criterion see 7.2.10) remove the specimen from the chamber, determine its mass and re-install it in the measuring device within the chamber at the same humidity level as before until length change equilibrium at this level is reached again.

7.2.4 Repeat the procedure in 7.2.3 for each level of relative humidity specified in 7.1 a).

7.2.5 After the last step in the hygroscopic moisture range weigh the specimen then wrap and seal it in vapour tight foil to avoid evaporation during the second part of the test procedure according to 7.1 b), the super-hygroscopic moisture range. Suspend the sealed specimen horizontally by a suitable device within the measuring chamber, maintaining constant temperature as before, in such a way as not to obstruct free expansion. Bring the length change sensor into contact with the gauge plugs (allowing the measuring tips of the sensor to penetrate the foil and have reliable contact with the test material, ensuring that the vapour tightness is maintained; see figure 1 b)) and set it to zero.

7.2.6 By means of a hypodermic syringe penetrate the foil at appropriate locations and introduce a predetermined (see 7.1 b)) amount of water to the specimen. The water should be distributed evenly in order to reach a symmetric water uptake according to 6.4. The needle hole should be closed by a drop of sealant.

Measure the length change after water has distributed within the whole specimen and the expansion process has ceased. Determine the mass of injected water by weighing the syringe before and after injection.

7.2.7 Repeat the procedure in 7.2.6 for each level of moisture content specified in 7.1 b).

7.2.8 After the final step in moisture content has been completed, remove the specimen from the chamber and determine its mass. Then remove the foil, sealants etc. and determine their mass for purposes according to 7.2.11.

7.2.9 If required or recommended, e.g. because of significant differences for adsorption /desorption moisture contents, the procedure can be repeated starting from the state reached in 7.2.7 and making measurements in environments of decreasing relative humidity, in accordance with 7.2.2 to 7.2.4.

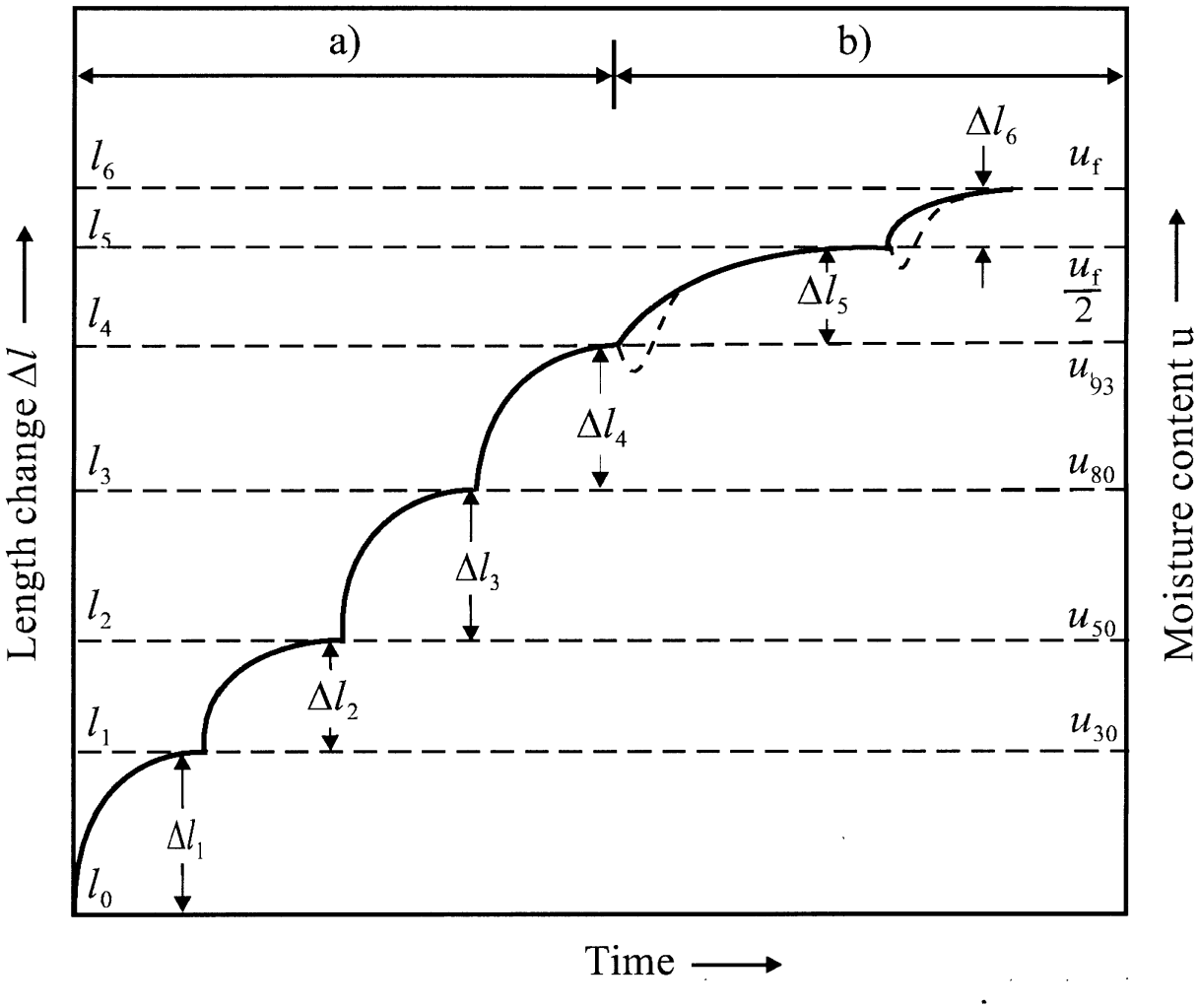
7.2.10 Criteria for equilibrium:

a) free water saturation of the specimen by complete immersion to water is assumed to be reached when the mass change of the specimen over a period of 24 h is less than 0,1 % of its mass. For materials with a slow moisture uptake, an appropriate longer time interval for the final 0,1 % mass change shall be taken,

NOTE Drawing a graph of mass increase is helpful in those cases.

b) hygric expansion is assumed to have ceased when a graph of continuously recorded values has reached the asymptotic final value or at least approximately 97 % of the expected asymptotic final value of length change related to the starting value of the specific measuring step (see figure 2). Take the asymptotic final value as the measured result.

NOTE In many cases the asymptote is reached clearly (a horizontal line in the measuring plot) so that it is obvious that the real final value of the length change measurement has been achieved. If an asymptote is not reached clearly within an appropriate time, the asymptotic final value can be obtained by fitting the measured data by means of a suitable approximation formula.



NOTE Irregularities at the starting points for the super-hygroscopic moisture content steps can result from specimen deflections because of non-symmetric water supply at one side of the specimen.

Figure 2 - Schematic plot of measuring results for hygric length changes due to moisture content steps of a specimen during tests within the hygroscopic (a) and the super-hygroscopic moisture range (b) of a material

7.2.11 The masses of plugs, adhesives, foil, sealant drops etc. shall be recorded with the weighing results throughout this procedure and subtracted afterwards in order to obtain the mass of the specimen.

7.2.12 All measuring equipment shall be calibrated regularly to minimise device errors; calibration of the length change sensors shall be carried out before and after a measuring series.

8 Calculation and expression of results

The hygric expansion coefficient as a function of moisture content of the material can be determined from the measured length changes and changes in moisture content according to the following steps:

a) Calculate the hygric strain values, $(\varepsilon_h)_i$, after each measuring step, i, according to equation (1)

$$\left(\varepsilon_h\right)_i = \frac{l_i - l_0}{l_0} = \frac{\Sigma \Delta l_i}{l_0} \qquad (1)$$

where

l_i is the measured length after measuring step i;
Δl_i is the measured length change per measuring step i;
$\sum \Delta l_i$ is the accumulated measured length change after measuring step i.

Plot the values of $(\varepsilon_h)_i$ against the moisture content u_i after each measuring step and draw the curve relating all $(\varepsilon_h)_i$ to u_i (see figure 3, upper diagram).

b) Calculate the values of the hygric expansion coefficient, α_h, from the gradient of the curve relating ε_h to u according to

$$\alpha_h = \frac{d\varepsilon_h}{du} \approx \frac{\Delta \varepsilon_h}{\Delta u} \qquad (2)$$

where

$\Delta \varepsilon_h$ is the difference in hygric strain between two successive measuring steps;
Δu is the difference in equilibrium moisture content between two successive measuring steps.

The quotient $(\Delta \varepsilon_h)_i$ / $(\Delta u)_i$ for each step may be taken as a single value of the hygric expansion coefficient at the mean value $\overline{u}_i$ for each $(\Delta u)_i$ according to equations (3) to (5)

$$\left(\Delta \varepsilon_h\right)_i = \left(\varepsilon_h\right)_i - \left(\varepsilon_h\right)_{i-1} \qquad (3)$$

$$\left(\Delta u\right)_i = u_i - u_{i-1} \qquad (4)$$

$$\overline{u}_i = \frac{u_i + u_{i-1}}{2} \qquad (5)$$

where

$\overline{u}_i$ is the calculated mean moisture content for each measuring step i;
u_{i-1} is the equilibrium moisture content before the actual measuring step i;
u_i is the equilibrium moisture content after the actual measuring step i.

Draw the graph for the hygric expansion coefficient α_h = f (u) as the final result within the range of $0 < u < u_f$ (see figure 3, lower diagram).

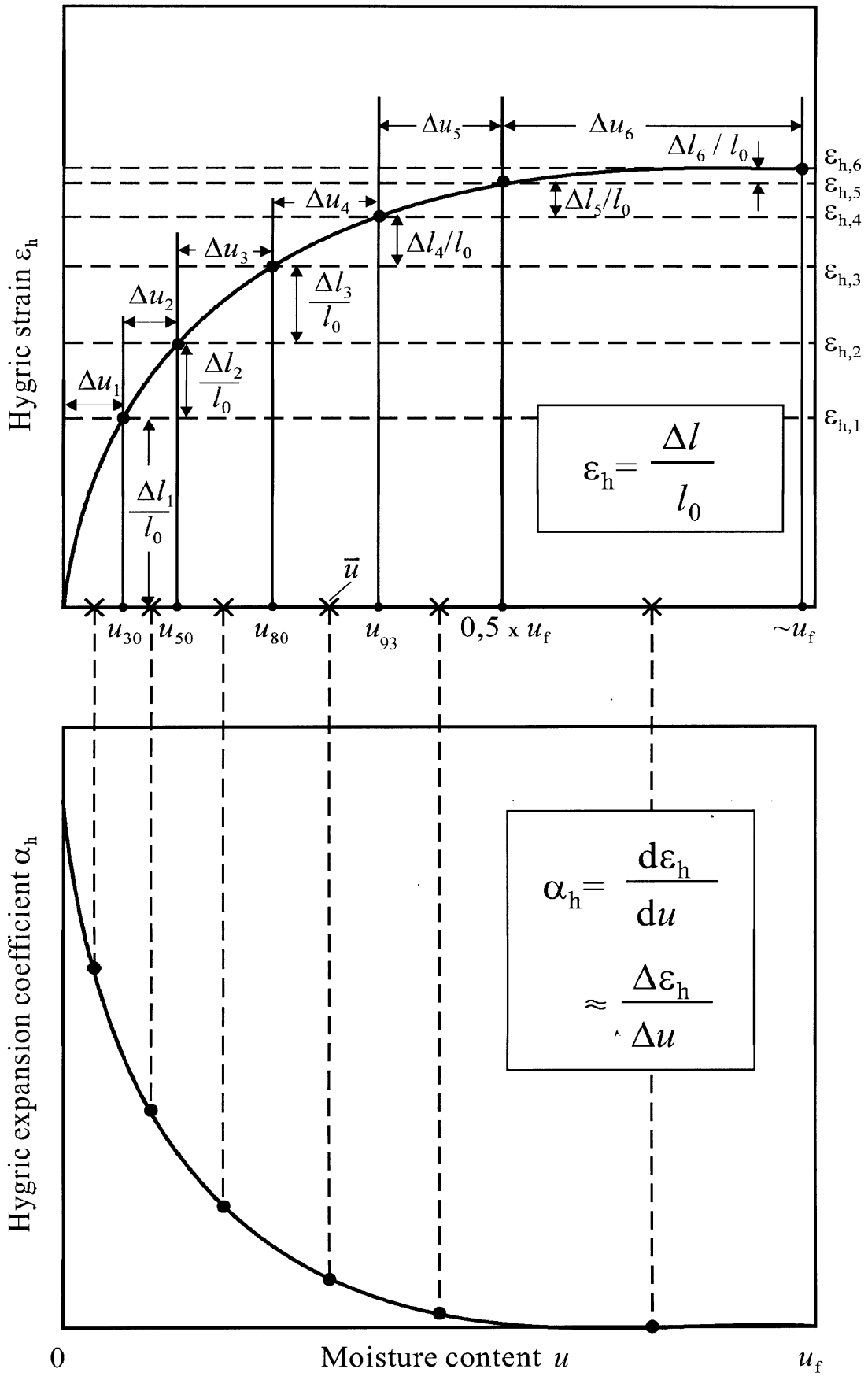


Figure 3 - Schematic derivation of the hygric expansion coefficient as a function of moisture content from measured hygric strain and moisture content changes

9 Accuracy

a) The length measurement (l_0) depends on the type of instrument and device accuracy as specified in 5a).

EXAMPLE A device accuracy of ± 0,1 mm and a reference length l_0 = 100 mm will lead to a measuring a relative accuracy for l_0 of:
$\Delta(l_0)/l_0 = \pm$ 0,1 mm/100 mm = ±0,1 %
where $\Delta(l_0)$ is the error in l_0.

b) The length change measurement (Δl) depends on the type of sensor and device accuracy as specified in 5b) and any superimposed thermal expansion or contraction due to the thermal expansion coefficient α_T of the material and deviations in chamber temperature as specified in 5c).

EXAMPLE A sensor accuracy of ± 0,001 mm and a temperature variation of ±1K with $\alpha_T = 10 \times 10^{-6}$ K^{-1} and l_0 = 100 mm will lead to a relative accuracy for a measured result Δl = 0,02 mm per moisture content step of:

$\Delta(\Delta l)/\Delta l = (\pm$ 0,001 mm ± 1 K×10 × 10^{-6} K^{-1}×100 mm)/0,02 mm = ± 10 %.

where $\Delta(\Delta l)$ is the error in Δl.

c) The moisture content measurement (u), depends on the type of balance and device accuracy as specified in 5d). The difference in moisture content between two measuring steps related to the dry mass of the specimen $\Delta u = (m_2\text{-}m_1)/m_0$ is determined by measuring the specimen mass three times, m_2, m_1, m_0. The measuring error from the balance accuracy is included each time. That leads to a relative error estimation for Δu, e.g. with a balance accuracy of ± 0,01 %, due to equation (6).

$$\Delta(\Delta u)/\Delta u = \pm 0{,}0001\left[2m_2^2 + 2m_1^2 - 2m_1 m_2\right]^{1/2} / m_0 \qquad (6)$$

where $\Delta(\Delta u)$ is the error in Δu.

d) A total measurement error analysis for the determined hygric expansion coefficient may be made by evaluating $\alpha_h = \Delta l / (l_0 \times \Delta u)$ for each moisture content step according to the law of error propagation. That leads to an estimation of the relative accuracy according to equation (7)

$$\frac{\Delta\alpha_h}{\alpha_h} = \pm\left[\left(\frac{\Delta(l_0)}{l_0}\right)^2 + \left(\frac{\Delta(\Delta l)}{\Delta l}\right)^2 + \left(\frac{\Delta(\Delta u)}{\Delta u}\right)^2\right]^{1/2} \qquad (7)$$

e) Further influences:

Handling errors, e.g. caused by sorption/desorption effects during weighing of non-sealed specimens outside of the chamber, can be approximated to about ± 1 % of the weight, if no values due to laboratory experience are available.

Reproducibility errors from personnel handling will need to be estimated according to laboratory experience, as no statistical values are available.

If the asymptotic final value of length change for a measuring step is not reached completely and has to be approximated (see 7.2.10 b)), an additional error for Δl can arise which has to be evaluated for the special case and should not exceed a value of 3 %.

10 Test report

The test report shall contain the following:

a) reference to this standard;

b) product identification:
- product name, factory, manufacturer or supplier;
- type of product;
- production code number;
- the form in which the product arrived at the laboratory, packaging, date of delivery;
- other information if necessary.

c) preparation of test specimens:
- number of specimens;
- date, place and method of preparation;
- details of any curing processes, pre-conditioning;
- other details of relevance to the test result.

d) test procedure:
- measuring device and test configuration;
- information on controlled test environment and test conditions;
- date of the start and duration of the test;
- any factors that may have influenced the results.

e) results:
- table of measured individual specimen values and mean values (reference length, free water saturation, steps of relative humidity, moisture content, length change, hygric strain and hygric expansion coefficient);
- graph showing mean value curve of hygric expansion coefficient;
- estimate of accuracy.

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