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Textiles — Physiological effects — Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)

Textiles — Effets physiologiques — Mesurage de la résistance thermique et de la résistance à la vapeur d'eau en régime stationnaire (essai de la plaque chaude gardée transpirante)

Reference number
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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 38, *Textiles.*

This second edition cancels and replaces the first edition (ISO 11092:1993), which has been technically revised. It also incorporates Amendment 1 to ISO 11092:1993 (ISO 11092:1993/Amd.1:2012).

Introduction

This International Standard is the first of a number of standard test methods in the field of clothing comfort.

The physical properties of textile materials which contribute to physiological comfort involve a complex combination of heat and mass transfer. Each may occur separately or simultaneously. They are time-dependent, and may be considered in steady-state or transient conditions.

Thermal resistance is the net result of the combination of radiant, conductive and convective heat transfer, and its value depends on the contribution of each to the total heat transfer. Although it is an intrinsic property of the textile material, its measured value may change through the conditions of test due to the interaction of parameters such as radiant heat transfer with the surroundings.

Several methods exist which may be used to measure heat and moisture properties of textiles, each of which is specific to one or the other and relies on certain assumptions for its interpretation.

The sweating guarded-hotplate (often referred to as the “skin model”) described in this International Standard is intended to simulate the heat and mass transfer processes which occur next to human skin. Measurements involving one or both processes may be carried out either separately or simultaneously using a variety of environmental conditions, involving combinations of temperature, relative humidity, air speed, and in the liquid or gaseous phase. Hence transport properties measured with this apparatus can be made to simulate different wear and environmental situations in both transient and steady-states. In this International Standard only steady-state conditions are selected.

Textiles — Physiological effects — Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)

1 Scope

This International Standard specifies methods for the measurement of the thermal resistance and water-vapour resistance, under steady-state conditions, of e.g. fabrics, films, coatings, foams and leather, including multilayer assemblies, for use in clothing, quilts, sleeping bags, upholstery and similar textile or textile-like products.

The application of this measurement technique is restricted to a maximum thermal resistance and water-vapour resistance which depend on the dimensions and construction of the apparatus used (e.g. 2 $m^2 \cdot K/W$ and 700 $m^2 \cdot Pa/W$ respectively, for the minimum specifications of the equipment referred to in this International Standard).

The test conditions used in this International Standard are not intended to represent specific comfort situations, and performance specifications in relation to physiological comfort are not stated.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
thermal resistance
R_{ct}
temperature difference between the two faces of a material divided by the resultant heat flux per unit area in the direction of the gradient

Note 1 to entry: It is a quantity specific to textile materials or composites which determines the dry heat flux across a given area in response to a steady applied temperature gradient. The dry heat flux may consist of one or more conductive, convective and radiant components.

Note 2 to entry: Thermal resistance is expressed in square metres kelvin per watt.

2.2
water-vapour resistance
R_{et}
water-vapour pressure difference between the two faces of a material divided by the resultant evaporative heat flux per unit area in the direction of the gradient

Note 1 to entry: It is a quantity specific to textile materials or composites which determines the "latent" evaporative heat flux across a given area in response to a steady applied water-vapour pressure gradient. The evaporative heat flux may consist of both diffusive and convective components.

Note 2 to entry: Water-vapour resistance is expressed in square metres pascal per watt.

2.3
water-vapour permeability index
i_{mt}
ratio of thermal and water-vapour resistances in accordance with Formula (1):

$$i_{mt} = S \cdot \frac{R_{ct}}{R_{et}} \tag{1}$$

where S equals 60 Pa/K

Note 1 to entry: The water-vapour permeability index is dimensionless, and has values between 0 and 1. A value of 0 implies that the material is water-vapour impermeable, that is, it has infinite water-vapour resistance, and a material with a value of 1 has both the thermal resistance and water-vapour resistance of an air layer of the same thickness.

2.4
water-vapour permeability
W_d
characteristic of a textile material or composite depending on water-vapour resistance and temperature in accordance with Formula (2):

$$W_d = \frac{1}{R_{et} \cdot \phi T_m} \quad (2)$$

where ϕT_m is the latent heat of vaporization of water at the temperature T_m of the measuring unit, equals, for example, 0,672 W·h/g at T_m = 35 °C

Note 1 to entry: Water-vapour permeability is expressed in grams per square metre hour pascal.

3 Symbols and units

R_{ct}	is the thermal resistance, in square metres kelvin per watt
R_{et}	is the water-vapour resistance, in square metres pascal per watt
i_{mt}	is the water-vapour permeability index, dimensionless
R_{ct0}	is the apparatus constant, in square metres kelvin per watt, for the measurement of thermal resistance R_{ct}
R_{et0}	is the apparatus constant, in square metres pascal per watt, for the measurement of water vapour resistance R_{et}
W_d	is the water-vapour permeability, in grams per square meter hour pascal
ϕT_m	is the latent heat of vaporization of water at the temperature T_m, in watt hours per gram
A	is the area of the measuring unit, in square metres
T_a	is the air temperature in the test enclosure, in degrees Celsius
T_m	is the temperature of the measuring unit, in degrees Celsius
T_s	is the temperature of the thermal guard, in degrees Celsius
p_a	is the water-vapour partial pressure, in pascals, of the air in the test enclosure at temperature T_a
p_m	is the saturation water-vapour partial pressure, in pascals, at the surface of the measuring unit at temperature T_m
v_a	is the speed of air above the surface of the test specimen, in metres per second
S_v	is the standard deviation of air speed v, in metres per second
R.H.	is the relative humidity, in percent
H	is the heating power supplied to the measuring unit, in watts

ΔH_c is the correction term for heating power for the measurement of thermal resistance R_{ct}

ΔH_e is the correction term for heating power for the measurement of water-vapour resistance R_{et}

α is the slope of the correction line for the calculation of ΔH_c

β is the slope of the correction line for the calculation of ΔH_e

4 Principle

The specimen to be tested is placed on an electrically heated plate with conditioned air ducted to flow across and parallel to its upper surface as specified in this International Standard.

For the determination of thermal resistance, the heat flux through the test specimen is measured after steady-state conditions have been reached.

The technique described in this International Standard enables the thermal resistance R_{ct} of a material to be determined by subtracting the thermal resistance of the boundary air layer above the surface of the test apparatus from that of a test specimen plus boundary air layer, both measured under the same conditions.

For the determination of water-vapour resistance, an electrically heated porous plate is covered by a water-vapour permeable but liquid-water impermeable membrane. Water fed to the heated plate evaporates and passes through the membrane as vapour, so that no liquid water contacts the test specimen. With the test specimen placed on the membrane, the heat flux required to maintain a constant temperature at the plate is a measure of the rate of water evaporation, and from this the water-vapour resistance of the test specimen is determined.

The technique described in this International Standard enables the water-vapour resistance R_{et} of a material to be determined by subtracting the water-vapour resistance of the boundary air layer above the surface of the test apparatus from that of a test specimen plus boundary air layer, both measured under the same conditions.

5 Apparatus

5.1 Measuring unit, with temperature and water supply control, consisting of a metal plate approximately 3 mm thick with a minimum area of 0,04 m^2 (e.g. a square with each side 200 mm in length, l) fixed to a conductive metal block containing an electrical heating element [see Figure 1, items (1) and (6)]. For the measurement of water-vapour resistance, the metal plate (1) must be porous. It is surrounded by a thermal guard [item (8) of Figure 2] which is in turn located within an opening in a measuring table (11).

The coefficient of radiant emissivity of the plate surface (1) shall be greater than 0,35, measured at 20 °C between the wavelengths 8 µm to 14 µm, with the primary beam perpendicular to the plate surface and the reflection hemispherical.

Channels are machined into the face of the heating element block (6) where it contacts the porous plate to enable water to be fed from a dosing device (5).

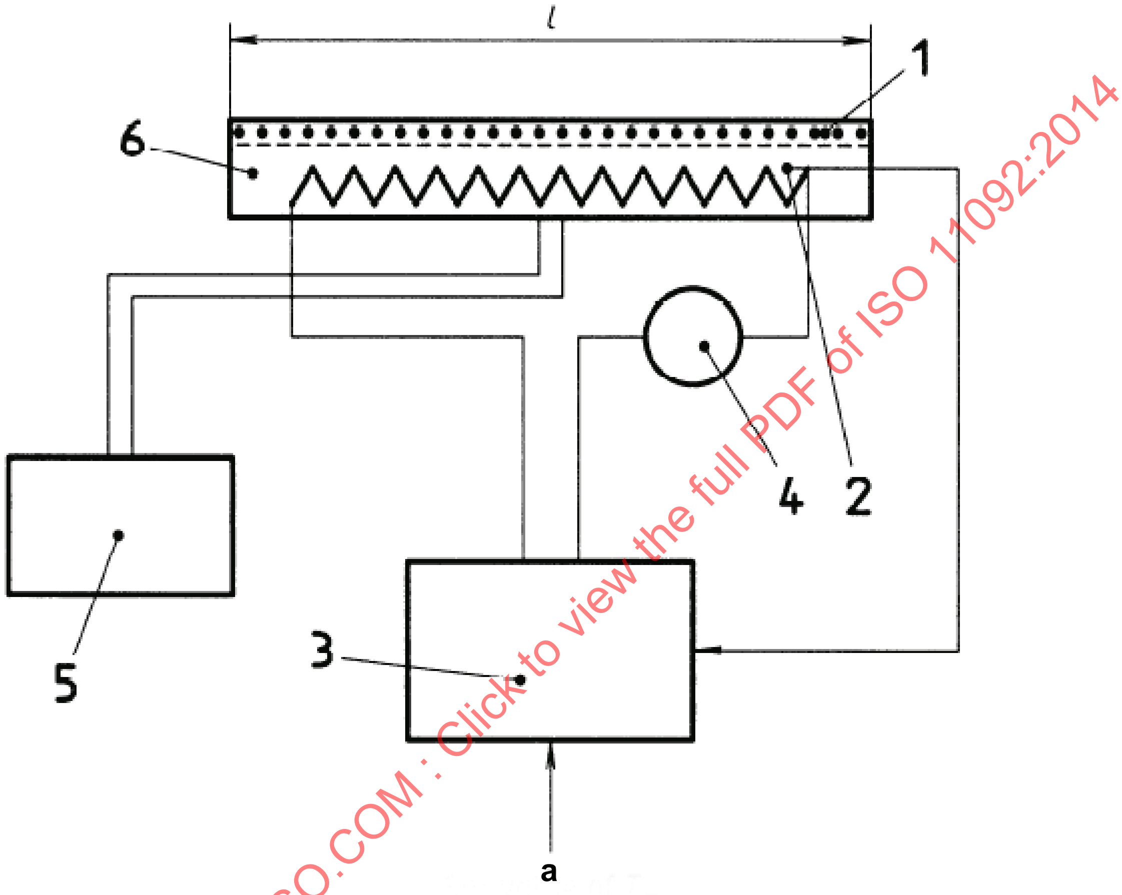
The position of the measuring unit with respect to the measuring table shall be adjustable, so that the upper surface of test specimens placed on it can be made coplanar with the measuring table.

Heat losses from the wiring to the measuring unit or to its temperature measuring device should be minimized, e.g. by leading as much wiring as possible along the inner face of the thermal guard (8).

The temperature controller (3), including the temperature sensor of the measuring unit (2), shall maintain the temperature T_m of the measuring unit (7) constant to within ± 0,1 K. The heating power H shall be measurable by means of a suitable device (4) to within ± 2 % over the whole of its usable range.

Water is supplied to the surface of the porous metal plate (1) by a dosing device (5) such as a motor-driven burette. The dosing device is activated by a switch which senses when the level of water in the plate falls more than approximately 1,0 mm below the plate surface, in order to maintain a constant rate of evaporation. The level switch is mechanically connected to the measuring unit.

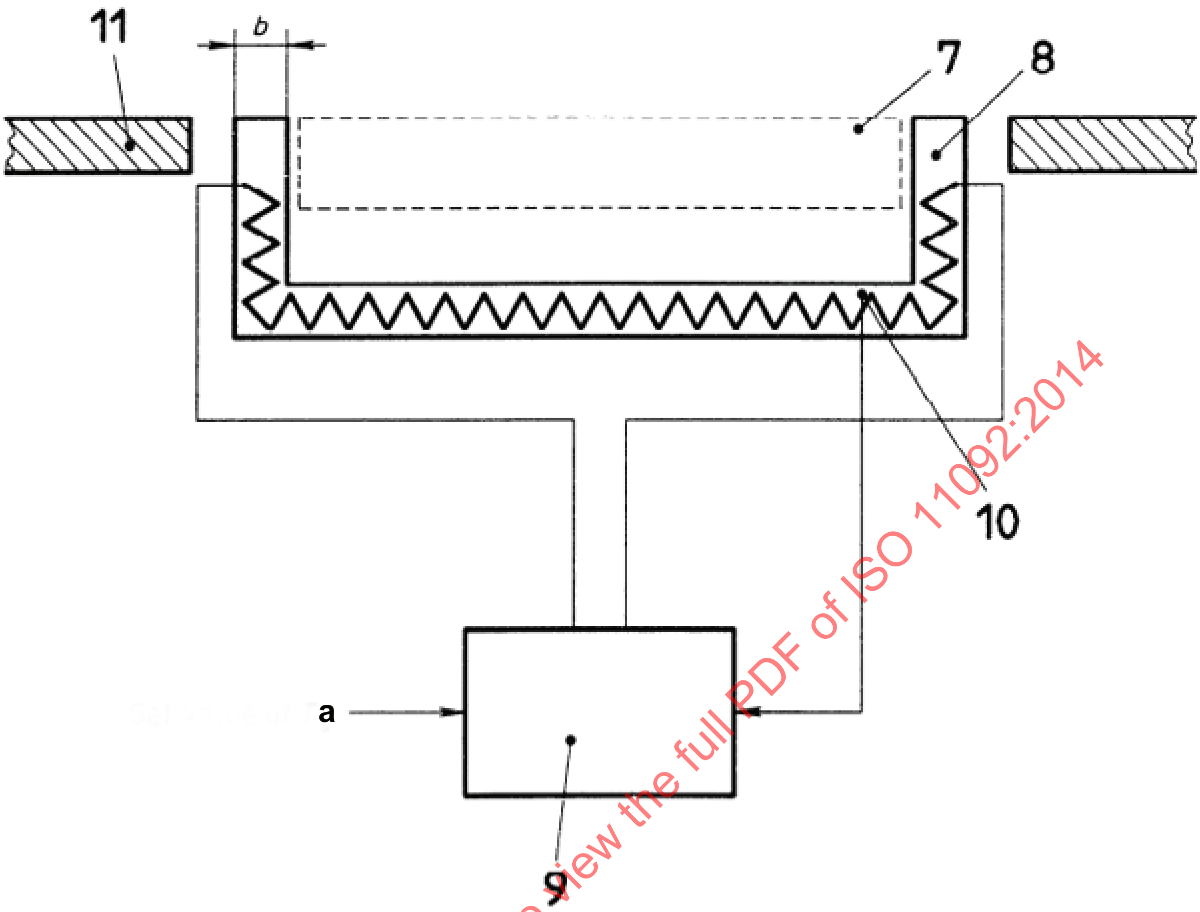
Before entering the measuring unit, the water shall be preheated to the temperature of the measuring unit. This can be achieved by passing it through tubes in the thermal guard before it enters the measuring unit.



Key

1 metal plate
2 temperature sensor
3 temperature controller
4 heating-power measuring device
5 water-dosing device
6 metal block with heating element
a Set value of T_m.

Figure 1 — Measuring unit with temperature and water supply control



Key

7 measuring unit according to 5.1

8 thermal guard

9 temperature controller

10 temperature sensor

11 measuring table

a Set value of T_s.

Figure 2 — Thermal guard with temperature control

5.2 Thermal guard with temperature control [item (8) of Figure 2], consisting of a material with high thermal conductivity, typically metal, and containing electrical heating elements.

Its purpose is to prevent heat leakage from the sides and bottom of the measuring unit (7).

The width *b* of the thermal guard (see Figure 2) should be a minimum of 15 mm. The gap between the upper surface of the thermal guard and the metal plate of the measuring unit shall not exceed 1,5 mm.

The thermal guard may be fitted with a porous plate and water-dosing system similar to that of the measuring unit to form a moisture guard.

The thermal guard temperature T_s measured by the temperature sensor (10) shall by means of the controller (9), be maintained at the same temperature as the measuring unit T_m to within ± 0,1 K.

5.3 Test enclosure, into which is built the measuring unit and thermal guard, and in which the ambient air temperature and humidity are controlled.

The conditioned air shall be ducted so that it flows across and parallel to the upper surface of the measuring unit and thermal guard. The height of the duct above the measuring table shall not be less than 50 mm.

The drift of the temperature T_a of this air flow shall not exceed ± 0,1 K for the duration of a test. For the measurement of thermal resistance and water vapour resistance values below 100 m^2·Pa/W, an accuracy of ± 0,5 K is sufficient.

The drift of the relative humidity R.H. of this air flow shall not exceed ± 3 % R.H. for the duration of a test.

This air flow is measured at a point 15 mm above the measuring table over the centre of the uncovered measuring unit and at an air temperature T_a of 20 °C. The air speed v_a measured at this point shall have a mean value of 1 m/s, with the drift not exceeding ± 0,05 m/s for the duration of a test.

It is important that at this point the air flow shall have a certain degree of turbulence, expressed by the related variation in air speed s_v/v_a of between 0,03 and 0,07, measured at approximately 6 s intervals over a time period of at least 10 min with an instrument which has a time constant of less than 1 s.

6 Test specimens

6.1 Materials ≤ 5 mm thick

Test specimens shall completely cover the surfaces of the measuring unit and thermal guard.

From each material to be tested, a minimum of three test specimens shall be cut and tested.

Before testing, specimens shall be conditioned for a minimum of 12 h at the temperature and humidity specified in either 7.3 or 7.4 as appropriate.

6.2 Materials > 5 mm thick

6.2.1 Specimens falling into this category require a special test procedure to avoid loss of heat or water vapour from their edges.

In the measurement of thermal resistance, corrections for thermal edge losses are necessary if the specimen thickness is greater than approximately twice the width *b* of the thermal guard (see Figure 2). The deviation from the linear relationship between thermal resistance and specimen thickness can be determined and corrected by the factor $[1+ (\Delta R_{ct}/R_{ct\ measured})]$ using the measurement of the R_{ct} values for several thicknesses of a homogeneous material such as foam, up to a total thickness *d* of at least that of the specimen to be tested (see Figure 3).

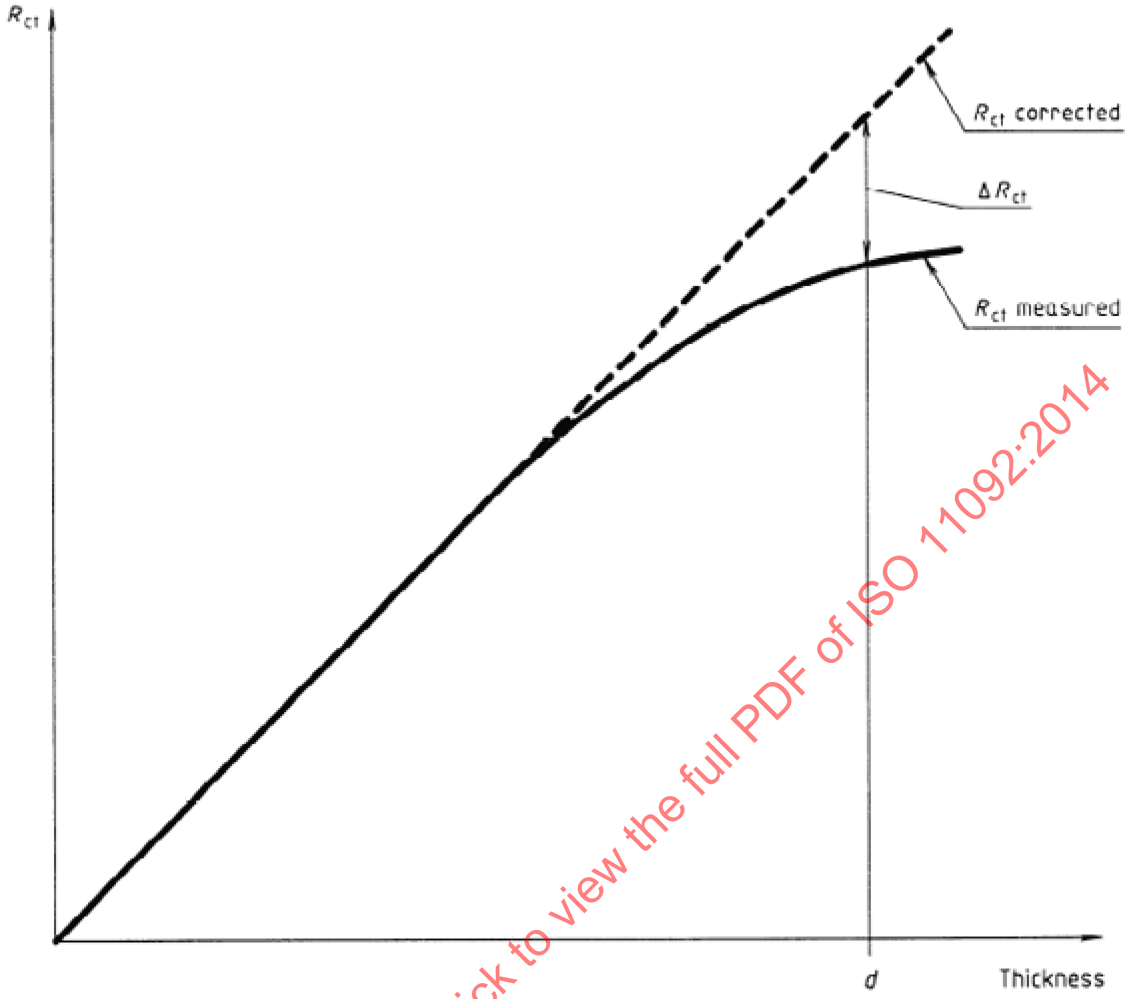


Figure 3 — Corrections for thermal edge losses during the measurement of thermal resistance

6.2.2 If the thermal guard is not fitted with a porous plate and water-dosing system similar to that of the measuring unit, for the measurement of water-vapour resistance the vertical sides of the cut specimens shall be surrounded by a water-vapour impermeable frame of approximately the same height as that of the free-standing specimen. The inner dimensions of the frame shall be the same on all sides as those of the porous plate of the measuring unit.

6.2.3 Before testing, specimens shall be conditioned for a minimum of 24 h at the temperature and humidity specified in either 7.3 or 7.4 as appropriate.

6.2.4 Specimens containing loose filling materials or having uneven thickness, such as quilts and sleeping bags, require a special mounting procedure as described in Annex A.

7 Test procedure

7.1 Determination of apparatus constants

In the values for thermal and water-vapour resistance measured with the device described in this International Standard, constants intrinsic to the apparatus are included. These constants comprise the resistance within the measuring unit itself, plus that of the boundary air layer adhering to the surface of the test specimen. The latter is dependent on the speed and degree of turbulence of the air flowing over the test specimen.

These apparatus constants, R_{ct0} and R_{et0}, are determined as “bare plate” values, and it is essential that the upper surface of the measuring unit is coplanar with the measuring table.

7.1.1 Determination of R_{ct0}

For the determination of R_{ct0} set the temperature of the measuring unit T_m at 35 °C and the air temperature T_a at 20 °C with a relative humidity R.H. of 65 %. Set the air speed v_a to 1 m/s. Any deviations from these values shall be within the limits stated in Clause 5. Wait until the measured quantities (T_m, T_a, R.H., H) reach steady-state before recording their values.

The bare plate resistance R_{ct0} is determined from Formula (3).

$$R_{ct0} = \frac{(T_m - T_a)\cdot A}{H - \Delta H_c} \tag{3}$$

ΔH_c is a correction term and is determined as described in Annex B.

7.1.2 Determination of R_{et0}

7.1.2.1 During the determination of R_{et0}, the surface of the porous plate is kept constantly moist by means of a water-dosing device (see 5.1). A smooth, water-vapour permeable but liquid-water impermeable cellophane membrane of thickness 10 µm - 50 µm shall be fitted over the porous plate.

The cellophane membrane shall be moistened with distilled water and fixed to the measuring plate by appropriate means so that it remains completely free of wrinkles.

The water supplied to the measuring plate shall be distilled, preferably double-distilled, and reboiled prior to use so that it is free of gas in order to prevent the formation of gas bubbles beneath the membrane.

7.1.2.2 Set the temperature of both the measuring unit T_m and the air temperature T_a at 35 °C. Set the air speed v_a to 1 m/s.

The relative humidity R.H. of the air shall be kept constant at 40 %. corresponding to a water-vapour partial pressure p_a of 2,250 Pa. The water-vapour partial pressure p_m directly at the surface of the measuring unit can be assumed equal to the saturation vapour pressure at the temperature of this surface, i.e. 5,620 Pa, without compromising the accuracy of the test.

Any deviations from the above values of T_m, T_a, v_a and R.H. shall be within the limits stated in Clause 5. Wait until the measured quantities (T_m, T_a, R.H., H) reach steady-state before recording their values.

7.1.2.3 The bare plate resistance R_{et0} is determined from Formula (4).

$$R_{et0} = \frac{(p_m - p_a)\cdot A}{H - \Delta H_e} \tag{4}$$

ΔH_e is a correction term and is determined as described in Annex B.

7.1.3 Reference material

A useful cross-check of the apparatus can be obtained by measuring a precalibrated thermal resistance material, e.g. a reference material for thermal conductivity[1)].

1) Obtainable from the website (https://irmm.jrc.ec.europa.eu/Pages/rmcatalogue.aspx); Order No. IRMM-440 A to D.

7.1.4 Recalibration

Check the apparatus constants R_{ct0} and R_{et0} at regular intervals. Where deviations greater than the accuracy of the measuring device occur (see Clause 8), an adjustment shall be made. In most cases a change in R_{ct0} or R_{et0} is caused by a deviation in the speed of the air v_a over the surface of the test specimen. Air speed should be checked at regular intervals by the technique described in 5.3.

The air flow (both speed and degree of turbulence) over the surface of the test specimen influences the resistance of the boundary layer which adheres to the outer surface of the specimen, and thus influences the test result.

7.2 Assembly of test specimens on the measuring unit

7.2.1 Where appropriate, the orientation of the test specimens with respect to the air flow shall be defined and described in the test report.

The test specimens shall be placed so that they lie flat across the measuring unit, with the side normally facing the human body towards the measuring unit. In the case of multiple layers, specimens shall be arranged and stacked on the measuring unit as on the human body. Water-vapour impermeable adhesive tape or a light metal frame may be used around the edges of the test specimen to keep it flat.

Bubbles and wrinkles in the test specimen, or air gaps between the specimen and measuring unit or between the components of multilayer specimens, shall be prevented provided they are not specific to the surface profile of the specimens.

NOTE Guidance on the test specimen assembly for materials prone to swelling is given in Annex C.

7.2.2 Normally, test specimens are measured free from stretch or loading and, in the case of multiple layers, without air gaps between layers. However, if a test is carried out under extension or applied pressure or with air gaps, this shall be mentioned in the test report.

7.2.3 With test specimens thicker than 3 mm, the measuring unit shall be lowered so that the outer surface of the specimen is flush with the measuring table.

7.3 Measurement of thermal resistance R_{ct}

7.3.1 Set the temperature of the measuring unit T_m at 35 °C and the air temperature T_a at 20 °C with a relative humidity R.H. of 65 %. Set the air speed v_a at 1 m/s. Any deviations from these values shall be within the limits stated in Clause 5.

Other conditions of air temperature T_a, relative humidity R.H. and air speed v_a may be used. The test report shall describe the alternative conditions and shall include a statement to the effect that the results differ from those of tests carried out under the conditions stated in this International Standard.

After placing the test specimen on the measuring unit, wait until the measured quantities (T_m, T_a, R.H., H) reach steady-state before recording their values.

7.3.2 Calculate the thermal resistance R_{ct} from Formula (5):

$$R_{ct} = \frac{(T_m - T_a)\cdot A}{H - \Delta H_c} - R_{ct0} \tag{5}$$

where the symbols and units are defined in Clause 3.

Calculate the thermal resistance R_{ct} of the material being tested as the arithmetic mean of the individual measurements.

7.4 Measurement of water-vapour resistance R_{et}

7.4.1 For the measurement of water-vapour resistance, a water-vapour permeable but liquid-water impermeable cellophane membrane shall be fitted over the surface of the measuring unit as described in 7.1.2.

7.4.2 Set the temperature of both the measuring unit T_m and the air T_a to 35 °C with a relative humidity R.H. of 40 %. Hold the air speed v_a at 1 m/s. Any deviations from these values shall be within the limits stated in Clause 5.

These isothermal conditions prevent water-vapour condensation within the test specimen.

Other conditions of relative humidity and air speed v_a may be used. The test report shall describe the alternative conditions and shall include a statement to the effect that the results may differ from those of tests carried out under the conditions stated in this International Standard.

If the air temperature T_a is changed, the test is non-isothermal and this International Standard no longer applies.

After placing the test specimen on the measuring unit, wait until the measured quantities (T_m, T_a, R.H., H) have reached steady-state before recording their values.

7.4.3 Calculate the water-vapour resistance R_{et} from Formula (6):

$$R_{et} = \frac{(p_m - p_a) \cdot A}{H - \Delta H_e} - R_{et0} \qquad (6)$$

where the symbols and units are defined in Clause 3.

Calculate the water-vapour resistance R_{et} of the material being tested as the arithmetic mean of the individual measurements.

8 Precision of results

8.1 Repeatability

For thermal resistance R_{ct}, the precision of repeated measurements on the same specimens with values up to 50×10^{-3} m²·K/W has been found to be $3,0 \times 10^{-3}$ m²·K/W, as measured on single layers of fabrics. With R_{ct} values higher than 50×10^{-3} m²·K/W, the precision has been found to be 7 %, as measured on foams.

For water-vapour resistance R_{et}, the precision of repeated measurements on the same specimens with values up to 10 m²·Pa/W has been found to be 0,3 m²·Pa/W, as measured on single layers of fabrics.

With R_{et} values higher than 10 m²·Pa/W, the precision has been found to be 7 %, as measured on foams.

8.2 Reproducibility

In an interlaboratory trial using three specimens of a foam material of 3 mm, 6 mm and 12 mm thickness tested in four laboratories, an average standard deviation of $6,5 \times 10^{-3}$ m²·K/W for thermal resistance R_{ct} and of 0,67 m²·Pa/W for water-vapour resistance R_{et} was found.

9 Test report

The test report shall include at least the following information:

a) reference to this International Standard;

b) complete description of the material to be tested;

c) arrangement of test specimens according to 7.2;

d) number of test specimens per material to be tested and number of individual measurements on each test specimen;

e) test climate;

f) arithmetic mean value of the thermal resistance;

and/or

g) arithmetic mean value of the water-vapour resistance;

h) details of deviations from this International Standard;

i) date of test.

