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# Textiles - Physiological Effects - Measurement of Thermal and Water-vapor Resistance under Steady-state Conditions (sweating guarded-hotplate test)

纺织品 生理舒适性 稳态条件下热阻和湿阻的测定（蒸发热板法）

(ISO 11092:2014, MOD)

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# Textiles - Physiological Effects - Measurement of Thermal and Water-vapor Resistance under Steady-state Conditions (sweating guarded-hotplate test)

## 1 Scope

This Standard specifies the determination methods for thermal and water-vapor resistance of physiological effects of textiles under steady-state conditions.

This Standard is applicable to all types of textile fabrics and their products. Coated fabrics, leather and multi-layer composite materials may take this as a reference.

**NOTE 1:** the application of determination techniques of this Standard is affected by the maximum determination ranges of thermal and water-vapor resistance. The two maximum values depend on the size and structural properties of the instrument (for example, the thermal and water-vapor resistance determination ranges of the instrument applicable to this Standard are generally not less than 2 $m^2$ • K/W and 700 $m^2$ • Pa/W).

**NOTE 2:** the test environment used in this Standard does not represent a specific comfort environment, nor does it provide the performance requirements for comfort.

## 2 Terms and Definitions

The following term and definitions are applicable to this document.

### 2.1 thermal resistance

***$R_{ct}$***

The ratio of the temperature difference on both sides of the specimen to the heat flow per unit area vertically passing through the specimen.

**NOTE 1:** the dry heat flow may include one or multiple forms of conduction, convection and radiation.

**NOTE 2:** thermal resistance $R_{ct}$ is expressed in the unit of ($m^2$ • K/W).

### 2.2 water-vapor resistance

***$R_{et}$***

The ratio of the water vapor pressure difference on both sides of the specimen to the evaporative heat flow per unit area vertically passing through the specimen.

$i_{mt}$: water-vapor permeability index, dimensionless.

$R_{ct0}$: an instrument constant determined for the determination of thermal resistance $R_{ct}$, expressed in $m^2 \bullet K/W$.

$R_{et0}$: an instrument constant determined for the determination of water-vapor resistance $R_{et}$, expressed in $m^2 \bullet Pa/W$.

$W_d$: water-vapor permeability, expressed in $g/(m^2 \bullet h \bullet Pa)$.

$\Phi_{Tm}$: latent heat of saturated water vapor when the surface temperature of the test plate is $T_m$, expressed in $W \bullet h/g$.

$A$: area of the test plate, expressed in $m^2$.

$T_a$: air temperature in the climate chamber, expressed in °C.

$T_m$: temperature of the test plate, expressed in °C.

$T_s$: temperature of the thermal retainer, expressed in °C.

$p_a$: water vapor pressure (when the temperature in the climate chamber is $T_a$), expressed in Pa.

$p_m$: saturated water vapor pressure (when the surface temperature of the test plate is $T_m$), expressed in Pa.

$v_a$: flow velocity of the air above the surface of the specimen under test, expressed in m/s.

$s_v$: standard deviation of air flow velocity $v_a$, expressed in m/s.

R.H.: relative humidity, expressed in %.

$H$: heating power provided to the test plate, expressed in W.

$\Delta H_c$: correction amount of heating power in thermal resistance determination.

$\Delta H_e$: correction amount of heating power in water-vapor resistance determination.

$\alpha$: slope of the correction amount curve for the calculated result of $\Delta H_c$.

$\beta$: slope of the correction amount curve for the calculated result of $\Delta H_e$.

# 4 Principle

Use the specimen to cover the test plate. The test plate, the surrounding thermal retainer, and the protective plate at the bottom can maintain a constant temperature, so that the heat of the test plate can only be dissipated through the specimen, and the air can flow parallel to the upper surface of the specimen. After the test conditions stabilize, determine the heat flow through the

specimen, so as to calculate the thermal resistance of the specimen.

The method described in this Standard is to obtain the thermal resistance value $R_{ct}$ of the determined material by subtracting the thermal resistance value of the air layer from the thermal resistance value of the determined specimen plus the air layer. Both determinations are performed under identical conditions.

For the determination of water-vapor resistance, the porous test plate needs to be covered with a breathable but water-impermeable film. The water entering the test plate evaporates, then, passes through the film in the form of water vapor, so no liquid water contacts the specimen. After the specimen is placed on the film, determine the heat flow required to maintain a constant temperature of the test plate under a certain water evaporation rate, and calculate the water-vapor resistance of the specimen together with the water vapor pressure passing through the specimen.

The method described in this Standard is to obtain the water-vapor resistance value $R_{et}$ of the determined material by subtracting the water-vapor resistance value of the air layer from the water-vapor resistance value of the determined specimen plus the air layer. Both determinations are performed under identical conditions.

# 5 Instruments

## 5.1 Test Part with Temperature and Feed Water Control

The test plate consists of a metal plate with a thickness of about 3 mm and an area of at least 0.04 $m^2$ (for example, a square with a side length of 200 mm) fixed on a conductive metal component containing a heating wire (see Figure 1).

For the determination of water-vapor resistance, the test plate shall be porous, which shall be surrounded by a thermal retainer located within the specimen platform.

In an environment of 20 °C, by using a beam with a wavelength range of 8 μm ~ 14 μm to vertically irradiate on the surface of the metal plate and in the mode of hemispheric reflection, determine the radiation emissivity of the metal plate surface, which shall be higher than 0.35.

The surface of the electric heating wire metal component in contact with the porous plate is a groove, so that the water provided by the quantitative water supply device can enter the test plate.

The position of the test plate relative to the specimen platform shall be adjustable, so that the upper surface of the specimen placed on it can remain flush with the specimen platform.

The heat loss in the test plate or temperature test device shall be minimized, for example, by routing the traces along the inner surface of the thermal retainer as much as possible.

The temperature controller, including the temperature sensor of the test plate, shall maintain the

resistance is lower than 100 $m^2$ • Pa/W, the accuracy can be controlled at ± 0.5 °C; the error of relative humidity shall not exceed ± 3%. When the air temperature $T_a$ in the climate chamber is 20 °C, the average air flow velocity $v_a$ measured, at 15mm above the center of the test plate, shall be 1 m/s, and the error shall not exceed ± 0.05 m/s.

It is worth noting that the air flow fluctuates to a certain extent at this point. The relative variation of the air flow velocity can be expressed by the ratio $s_v/v_a$ of the standard deviation to the air flow velocity, and its value is between 0.03 and 0.07. The air flow velocity can be tested using an instrument with a time constant less than 1 s. The data collection frequency shall be no less than 10 times/min, and the total determination time shall be no less than 10 minutes.

# 6 Specimens

## 6.1 Material Thickness ≤ 5 mm

The specimen size shall completely cover the surface of the test plate and thermal retainer.

At least 3 specimens shall be taken from each sample, and the specimens shall be flat and wrinkle-free.

Before the test, the specimens shall be conditioned in the test environment specified in 7.3 or 7.4 for at least 12 hours.

## 6.2 Material Thickness > 5 mm

**6.2.1** Specimens with a thickness within this range require a special procedure to avoid heat or water vapor escaping from their edges.

In the determination of thermal resistance, if the thickness of the specimens exceeds 2 times the width $b$ of the thermal retainer, then, corrections shall be made for heat loss at the edges. The deviation of the linear relations between thermal resistance and specimen thickness is determined and corrected in accordance with the formula $[1 + (\Delta R_{ct}/R_{ctm})]$, and correction is made by determining the $R_{ct}$ value determined by stacking multiple layers of homogenous materials (for example, foam materials) (finally reaching the thickness $d$ of the specimen under test), as shown in Figure 3.

#### 7.1.3 Reference sample

By determining the reference sample with calibrated thermal resistance or water vapor resistance, the instrument can be verified. See Appendix C for the verification method.

#### 7.1.4 Verification of instrument constants

The instrument constants $R_{ct0}$ and $R_{et0}$ shall be regularly verified, and when the deviation exceeds the instrument accuracy range (see Chapter 8), adjustments shall be made. Under most circumstances, the changes in $R_{ct0}$ and $R_{et0}$ are caused by changes in the air flow velocity $v_a$ on the surface of the specimens. The air flow velocity above the surface of the specimens shall be regularly verified in accordance with the technical requirements specified in 5.3.

The air flow (velocity and degree of fluctuations) above the surface of the specimens affects the resistance of the air layer attached to the specimen surface, thus, affecting the test results.

### 7.2 Placement of Specimens on the Test Plate

**7.2.1** The placement direction of the specimens is related to the direction of air flow and shall be specified and explained in the test report.

The specimens shall be placed flat on the test plate, with the side normally in contact with human skin facing the test plate. The same goes for multiple-layer fabrics. The specimens shall be free of blisters and wrinkles, so as to avoid the generation of undesirable air layers between the specimens and the test plate, and between each layer of multi-layer fabrics. Waterproof tape or a lightweight metal frame can be used to fix the edges of the specimens to keep them flat.

**NOTE:** for specimens that are prone to expansion, refer to Appendix D for the placement.

**7.2.2** Typically, the specimens are tested without tension and without air gaps between each layer of multi-layer specimens. If the test is conducted under tension or pressure or with an air gap, this shall be stated in the test report.

**7.2.3** When the thickness of the specimen exceeds 3 mm, the height of the test plate shall be adjusted, so that the upper surface of the specimen is flush with the specimen platform.

### 7.3 Determination of Thermal Resistance $R_{ct}$

**7.3.1** Adjust the surface temperature $T_m$ of the test plate to 35 °C, the air temperature $T_a$ in the climate chamber to 20 °C, the relative humidity to 65% and the air flow velocity to 1 m/s. The deviations of the above values shall be within the range required by Chapter 5.

If necessary, other temperature $T_a$, relative humidity *R.H.* and air flow velocity $v_a$ may also be used, but the specific test conditions shall be stated in the test report, and the differences between the results obtained under these conditions and the environment specified in this Standard shall be explained.

After placing the specimens on the test plate, and $T_m$, $T_a$, *R.H.* and *H* reach stability, record their

values.

**7.3.2** In accordance with Formula (5), calculate the thermal resistance:

$$R_{ct} = \frac{(T_m - T_a) \times A}{H - \Delta H_c} - R_{ct0} \qquad \cdots\cdots (5)$$

Calculate the arithmetic mean of the thermal resistance $R_{ct}$ of the specimens under test as the test result of the sample. The result shall retain 3 significant figures.

### 7.4 Determination of water vapor resistance $R_{et}$

**7.4.1** To determine the water vapor resistance, a film that is permeable to water vapor but impermeable to water shall be placed on the test plate described in 7.1.2.

**7.4.2** Adjust the surface temperature $T_m$ of the test plate to 35 °C, the air temperature $T_a$ to 35 °C, the relative humidity to 40% and the air flow velocity to 1 m/s. The deviations of the above values shall be within the range required by Chapter 5. These isothermal conditions are intended to prevent water vapor from condensing within the specimens.

If necessary, other relative humidity *R.H.* and air flow velocity $v_a$ may be used, but the specific test conditions shall be stated in the test report, and the differences between the results obtained under these conditions and the environment specified in this Standard shall be explained. If the air temperature $T_a$ is changed, and the surface temperature of the test plate and the air temperature are not isothermal conditions, it does not fall within the scope of application of this Standard.

After placing the specimens on the test plate, and the determined values $T_m$, $T_a$, *R.H.* and $H$ reach stability, record their values.

**7.4.3** In accordance with Formula (6), calculate the water vapor resistance:

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

Calculate the arithmetic mean of the water vapor resistance $R_{et}$ of the specimens under test as the test result of the sample. The result shall retain 3 significant figures.

## 8 Result Accuracy

### 8.1 Repeatability

When determining the thermal resistance $R_{ct}$ of single-layer fabric specimens, if the thermal resistance of the specimens is not higher than $50 \times 10^{-3}$ m$^2$ • K/W, then, its repeatability error is $3.0 \times 10^{-3}$ m$^2$ • K/W; when the $R_{ct}$ value exceeds $50 \times 10^{-3}$ m$^2$ • K/W, its repeatability error is 7%.

# Appendix B

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**Determination of Correction Value for Heating Power**

**B.1** During the determination of thermal resistance and water vapor resistance, the temperatures of the test plate and the thermal retainer (guard plate) are set to the same value, but the tolerances in 5.1 and 5.2 will, in practice, result in a significant temperature difference between the test plate and the thermal retainer. Under this circumstance, the heating power provided to the test plate is not equal to the heat flow through the specimens. During the determination of thermal resistance and water vapor resistance, the heating power shall be corrected, and the correction amounts are respectively represented by $\Delta H_c$ and $\Delta H_e$.

**B.2** The correction value $\Delta H_c$ of heating power is linearly related to the temperature difference between the test plate and the thermal retainer, and calculated in accordance with Formula (B.1):

$$\Delta H_c = \alpha \cdot (T_m - T_s) \qquad \cdots\cdots (B.1)$$

The slope $\alpha$ can be determined through the following mode: select a material with high thermal insulation properties (for example, a foam material with a thickness of at least 4 mm), cut it to a size large enough to completely cover the test plate and the thermal retainer; set the ambient temperature to 20 °C, and the test plate temperature to 35 °C. Adjust the temperature controller of the thermal retainer, so that the temperature of the thermal retainer gradually changes between 34 °C ~ 36 °C with a gradient of 0.2 °C. After each set value reaches stability, record the heating power provided to the test plate.

A straight line can be drawn from the linear relations between this heating power and the temperature difference between the test plate and the thermal retainer, and its slope is $\alpha$.

**B.3** The correction value $\Delta H_e$ of heating power is calculated in accordance with Formula (B.2):

$$\Delta H_e = \beta \cdot (T_m - T_s) \qquad \cdots\cdots (B.2)$$

The slope $\beta$ can be determined through the following mode: the test plate is covered with the film described in 7.1.2 and the water is supplied by a water pumping device. Choose an air-impermeable material (for example, PET mylar) and a material with high insulation properties (for example, a foam material with a thickness of at least 4 mm), cut it to a size large enough to completely cover the test plate and the thermal retainer. Set the ambient temperature to 35 °C, the relative humidity to 40%, and the temperature of the thermal retainer to 35 °C.

The temperature of the test plate increases with a gradient of 0.2 °C relative to the temperature of the thermal retainer. When each setpoint reaches stability, record the heating power provided to the test plate.

A straight lien can be drawn from the linear relations between this heating power and the

# Appendix C

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**Instrument Verification**

## C.1 Verification of Thermal Resistance

**C.1.1** The verification of the thermal resistance of the instrument shall be carried out using a calibrated reference sample.

**C.1.2** The determined thermal resistance value and linearity value of the instrument shall be verified at the same time.

**C.1.3** In accordance with the standard conditions, respectively determine the total thermal resistance of the empty plate and 1 ~ 4-layer reference sample, and respectively record them as $R_{ct1}$, $R_{ct2}$, $R_{ct3}$, $R_{ct4}$.

**C.1.4** When verifying the instrument, the instrument shall reach the following requirements:

a) The total thermal resistance shall be linearly related to the number of test layers of the reference sample;

b) The slope of the curve shall not exceed ± 10% of the slope of the standard curve;

c) Any single test value cannot exceed ± 10% of the standard value.

**C.1.5** If the instrument fails to meet any of the above requirements, the instrument shall be adjusted, until the above requirements are satisfied.

**C.1.6** When the instrument is reused after repair or a long-term suspension, the instrument shall be verified and satisfy the above requirements before being put into use.

**C.1.7** If the instrument cannot be adjusted to satisfy the above requirements, and if the actual deviation is linear, the test results can be corrected, but it shall be stated in the report; if the actual deviation is non-linear (irregular), then, the instrument can no longer be used.

**C.1.8** If all interested parties agree, a single-layer reference sample can only be used for verification, but this shall be indicated.

## C.2 Verification of Water Vapor Resistance

The verification of water vapor resistance of the instrument is the same as the verification procedures and requirements of thermal resistance in C.1.

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