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**Oblačila - Fiziološki učinki - Merjenje odpornosti proti vodni pari s pomočjo lutke za potenje**

Clothing - physiological effects - Measurement of water vapour resistance by means of a sweating manikin

Bekleidung - Physiologische Wirkungen - Messung des Wasserdampfdurchgangswiderstandes mittels einer schwitzenden Prüfpuppe



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# Clothing - physiological effects - Measurement of water vapour resistance by means of a sweating manikin

Bekleidung - Physiologische Wirkungen - Messung des Wasserdampfdurchgangswiderstandes mittels einer schwitzenden Prüfpuppe

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

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## European foreword

This document (prEN 17528:2020) has been prepared by Technical Committee CEN/TC 248 “Textiles and Textile Products”, the secretariat of which is held by BSI.

This document is currently submitted to the CEN Enquiry.

# Introduction

The type of clothing worn by people directly affects the heat exchange between the human body and the environment. The heat transfer is both sensible (conduction, convection, and radiation) and latent (evaporation). The water vapour resistance of a clothing ensemble is dependent upon the designs and materials used in the component garments, the amount of body surface area covered by the clothing, the distribution of the layers over the body, looseness or tightness of fit, and the increased surface area for heat loss. Water vapour resistance measurements made on fabrics alone do not take these factors into account. Measurements of the resistance to evaporative heat loss provided by clothing can be used with thermal insulation values (EN ISO 15831:2004) to determine the comfort or stress of people in different environments.

# 1 Scope

This document describes the requirements of the sweating manikin and the test procedure used to measure the water vapour resistance of a clothing ensemble, as it becomes effective for the wearer in practical use in a defined environment, with the wearer either standing or moving. This water vapour resistance, among other parameters, can be used to determine the effect of clothing on the physiology of the wearer in specific climate/activity scenarios.

# 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 11092, *Textiles — Physiological effects — Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test) (ISO 11092)*

EN ISO 15831:2004, *Clothing — Physiological effects — Measurement of thermal insulation by means of a thermal manikin (ISO 15831:2004)*

# 3 Terms and definitions

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



ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/



**3.1**
**clothing ensemble**
group of garments worn together on the body at the same time

**3.2**
**water vapour resistance of clothing**
water-vapour pressure difference between the manikin's skin surface and ambient atmosphere divided by the resulting evaporative heat flux per unit area in the direction of the gradient of water-vapour pressure

**3.3**
**total water vapour resistance of clothing**
$\mathbf{R_{et,M}}$
total water-vapour resistance from manikin's surface to ambient atmosphere, including clothing and boundary air layer, under defined conditions measured with a stationary manikin

Note 1 to entry: $R_{et,M}$ is expressed in square metres pascal per watt.

**3.4**
**resultant total water vapour resistance of clothing**
$\mathbf{R_{etr,M}}$
total water-vapour resistance from manikin's surface to ambient atmosphere, including clothing and boundary air layer, under defined conditions measured with a manikin moving its legs and arms

Note 1 to entry: $R_{etr,M}$ is expressed in square metres pascal per watt.

**3.5**
**air water vapour resistance**
$\mathbf{R_{ea, M}}$
water-vapour resistance of the boundary (surface) air layer around the sweating nude manikin, under defined conditions measured with a stationary manikin

Note 1 to entry: $R_{ea, M}$ is expressed in square metres pascal per watt.

**3.6**
**resultant air water vapour resistance**
$\mathbf{R_{ear, M}}$
water-vapour resistance of the boundary (surface) air layer around the sweating nude manikin, under defined conditions measured with a manikin moving its legs and arms

Note 1 to entry: $R_{ear, M}$ is expressed in square metres pascal per watt.

**3.7**
**basic water vapour resistance of clothing**
$\mathbf{R_{ecl, M}}$
water-vapour resistance from manikin's surface to the outer clothing surface (including enclosed air layers), under defined conditions measured with a stationary manikin

Note 1 to entry: $R_{ecl, M}$ is expressed in square metres pascal per watt.



**3.8**
**resultant basic water vapour resistance of clothing**
$\mathbf{R_{eclr, M}}$
water-vapour resistance from manikin's surface to the outer clothing surface (including enclosed air layers), under defined conditions measured with a manikin moving its legs and arms



Note 1 to entry: $R_{eclr, M}$ is expressed in square metres pascal per watt.

**3.9**
**effective water vapour resistance of clothing**
$\mathbf{R_{ecle, M}}$
increase in water-vapour resistance provided to a sweating manikin by a clothing ensemble compared to the water-vapour resistance of the sweating nude manikin, under defined conditions measured with a stationary manikin

Note 1 to entry: $R_{ecle, M}$ is expressed in square metres pascal per watt.

**3.10**
**resultant effective water vapour resistance of clothing**
$\mathbf{R_{ecler, M}}$
increase in water-vapour resistance provided to a sweating manikin by a clothing ensemble compared to the water-vapour resistance of the sweating nude manikin, under defined conditions measured with a manikin moving its legs and arms

Note 1 to entry: $R_{ecler, M}$ is expressed in square metres pascal per watt.

**3.11**
**clothing area factor**
**$f_{cl}$**
ratio of the outer surface of the clothed manikin to the surface area of the nude manikin

Note 1 to entry: $f_{cl}$ is dimensionless and is always higher or equal to 1.

## 4 Symbols and abbreviated terms

| | | |
|---|---|---|
| $A_w$ | total wet body surface area of the manikin | $m^2$ |
| $a_i$ | surface area of the body segment *i* of the manikin | $m^2$ |
| $f_i$ | fraction of the total manikin surface area represented by the surface area of segment *i* | |
| $H_e$ | total heating power supplied to the manikin | W |
| $H_{ei}$ | heating power supplied to the body segment i of the manikin | W |
| *RH* | relative humidity of the air within the climatic chamber | % |
| $T_a$ | air temperature within the climatic chamber | °C |
| $T_s$ | mean surface temperature of the manikin | °C |
| $T_{si}$ | surface temperature of the body segment i of the manikin | °C |
| $p_a$ | water vapour pressure of the air within the climatic chamber | Pa |
| $p_s$ | water vapour pressure at the manikin's sweating surface | Pa |
| $p_{si}$ | water vapour pressure at the body segment i of the manikin's sweating surface | Pa |
| $v_a$ | air speed in the climatic chamber | m/s |



## 5 Measurement and test methods

### 5.1 Principle

The components of the clothing ensemble to be tested are placed on the manikin in the same arrangement as in practical use.

The manikin in the shape and size of an adult human body and, for the measurement of $R_{etr, M}$, with movable legs and arms, is internally heated to a constant skin surface temperature, uniform over its body. The manikin is placed in a climatic chamber where defined air temperature and air speed can be set, and air humidity controlled.

There will be an evaporative heat flow from the manikin's skin surface area through the clothing into the ambient air, which is measured after steady-state conditions have been reached. From this heat flow, related to the sweating nude manikin's body surface area, the clothing ensemble's water vapour resistance can be calculated, considering the difference of water-vapour partial pressure between the manikin's skin surface and the ambient air.

The measurement is performed with the manikin stationary and/or moving its legs and arms, with a defined number of movements per minute and a defined stride length. The water-vapour resistance values obtained include the water-vapour resistance provided by the clothing and the adhering air layer around the body. They apply only to the particular clothing ensemble, as tested, and to the specific conditions of the test, particularly with respect to the air movement around the manikin.

NOTE: The principles described in this document can also be applied for other kinds of manikins (e.g. child manikin, female manikin, partial manikin, for example hand, torso, foot).

## 5.2 Apparatus

### 5.2.1 Standard Manikin

#### 5.2.1.1 Size and shape

The manikin, made from metal or plastic, shall be constructed to simulate the body of an adult human, i.e. it shall consist of an anatomically formed head, chest, abdomen, back, buttocks, arms, hands (preferably with individual fingers extended to allow gloves to be worn), legs and feet.

NOTE: Experience shows that at least 15 body segments provide reasonable homogenous surface temperature, allow monitor heat flux and provide information about local differences.

The body height of the standard manikin shall be (1,70 ± 0,15) m, with a body surface area of (1,7 ± 0,3) m$^2$.

The manikin's body proportions should correspond to those required for standard sizes of garments, because deviations in fit will affect the results.

For the measurement of $R_{etr,M}$ the manikin's arms and legs shall be movable, with joints at least at the shoulder and hip. For the measurement of the clothing ensemble's resultant total water-vapour resistance, $R_{etr,M}$, the manikin, mechanically driven, shall perform (45 ± 2) double steps per min, and (45 ± 2) double arm movements per min cross walking. The stride length, measured from toe to toe, shall be (63 ± 10) cm, and the length of the arm movements, measured between the wrists at the base of the thumbs, (53 ± 10) cm.



#### 5.2.1.2 Sweat generation



The manikin shall have the ability to evaporate water from its surface. Sweating can be simulated either by a tight fitting water saturated textile skin body suit, for example high absorptive cotton or a tight fitting water-fed capillary body suit (cotton or other appropriate textile) worn over the thermal manikin. The entire surface of the manikin shall be heated and saturated before the start of the test.

It shall be guaranteed that all parts of the manikin skin do not dry out during the test. This can be checked by monitoring the stability of the heating power supply for individual zones.

If a water-fed capillary system is used for sweat generation, each manikin’s segment should be controlled individually regarding the sweating rate.

#### 5.2.1.3 Surface temperature

The manikin shall be constructed so as to maintain the same average constant temperature $T_s$ of (34,0 ± 0,2) °C measured at all segment surfaces.

The surface temperatures of the manikin shall be measured by at least one appropriate temperature sensor (e.g. thermocouples, thermistors, resistance temperature devices) per body segment. The sensors shall not protrude more than 0,5 mm from the manikin's surface and shall be well bonded, both mechanically and thermally, to the manikin's surface. Lead wires shall be bonded to the surface, or preferably pass through the interior of the manikin.

When calculating the mean skin surface temperature of the manikin's body, each sensor temperature shall be area-weighted, considering the portion of the body surface area covered by the sensor.

#### 5.2.1.4 Heating equipment and power measurement

Each body segment of the manikin shall be equipped with an independently controlled heating system, whose capacity is sufficiently high to guarantee a constant surface temperature of (34,0 ± 0,2) °C in the nude manikin at each body segment.

The dry heat flow from the manikin's body through the clothing can be determined by measuring the heating power necessary to maintain a constant surface temperature, supplied to each of the manikin's body segments during the test period.

The power measuring equipment shall be capable of giving an accurate average over the test period. Its accuracy shall be within ± 2 % of the value for the average power supplied to each body segment of the manikin during the test period.

### 5.2.2 Controlled climatic chamber

#### 5.2.2.1 General

The manikin shall be placed in a controlled climatic chamber, at least 2 m × 2 m × 2 m (length × width × height). The air flow in the chamber may be horizontal or vertical.

In the chamber, spatial uniformity shall be verified by recording values for the test conditions (see 5.4) at heights of 0,1, 1,1, and 1,7 m above the manikin sole height at the location occupied by the manikin. The temperature of the walls, floor and ceiling shall not differ more than 1 °C from the mean air temperature.

#### 5.2.2.2 Air temperature sensor(s)



To monitor the air temperature in the chamber during the test, a single sensor with an overall accuracy of ± 0,15 °C and a time constant not exceeding 1 min may be used. However, multiple sensors are preferable.



The temperature sensor(s) shall be placed at a distance of (0,5 ± 0,1) m from the manikin. If a single sensor is used, it shall be at least 1,0 m above the floor of the chamber. If multiple sensors are used, they shall be spaced at equal height intervals, and their readings averaged.

#### 5.2.2.3 Relative humidity sensor

Any humidity sensing device with an accuracy of at least ± 2 % relative humidity and a repeatability of ± 3 % is acceptable. Only one location in the chamber needs to be monitored during the test to ensure that the temporal uniformity requirements mentioned in 5.2.2.1 are met.

#### 5.2.2.4 Air speed sensor

For measuring the air speed in the climatic chamber an omni-directional anemometer with ± 0,05 m/s accuracy shall be used. Measurements shall be averaged for at least 3 min at locations spaced at equal height intervals, (0,5 ± 0,1) m in front of the manikin. If it is demonstrated that the air speed does not vary temporally by more than ± 0,1 m/s, then it is not necessary to monitor air speed during a test.

## 5.3 Selection and preparation of test garments

It is desirable to independently test three different specimens of the clothing ensemble. However, if only one specimen is available, it shall be removed from the manikin after each test, dried and conditioned as specified below before retesting.

The garments tested shall be an appropriate fit to the manikin.

Prior to testing, the garments shall be conditioned either at (34 ± 5) °C and (40 ± 20) % RH or at the test climate set in the climatic chamber for at least 12 h.