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Clothing — Physiological effects — Measurement of thermal insulation by means of a thermal manikin

Vêtements — Effets physiologiques — Mesurage de l'isolation thermique à l'aide d'un mannequin thermique

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Foreword

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ISO 15831 was prepared by Technical Committee ISO/TC 38, *Textiles*.

Clothing — Physiological effects — Measurement of thermal insulation by means of a thermal manikin

1 Scope

This International Standard describes the requirements of the thermal manikin and the test procedure used to measure the thermal insulation of a clothing ensemble, as it becomes effective for the wearer in practical use in a relatively calm environment, with the wearer either standing or moving.

NOTE This thermal insulation, among other parameters, can be used to determine the physiological effect of clothing on the wearer in specific climate/activity scenarios.

2 Terms and definitions

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

2.1
clothing ensemble
group of garments worn together on the body at the same time

2.2
thermal insulation of clothing
temperature difference between the wearer's skin surface and ambient atmosphere divided by the resulting dry heat flow per unit area in the direction of the temperature gradient where the dry heat flow consists of conductive, convective and radiant components

NOTE Depending on the end use of the clothing, different thermal insulation values can apply.

2.2.1
total thermal insulation of clothing
I_t
total thermal insulation from skin to ambient atmosphere, including clothing and boundary air layer, under defined conditions measured with a stationary manikin

2.2.2
resultant total thermal insulation of clothing
I_{tr}
total thermal insulation from skin to ambient atmosphere, including clothing and boundary air layer, under defined conditions measured with a manikin moving its legs and arms

3 Symbols and units

a_i	surface area of the body segment i of the manikin	m^2
A	total body surface area of the manikin	m^2
f_i	fraction of the total manikin surface area represented by the surface area of segment i	
H_c	total heating power supplied to the manikin	W
H_{ci}	heating power supplied to the body segment i of the manikin	W
I_t	total thermal insulation of the clothing ensemble with the manikin stationary	$\frac{m^2K}{W}$
I_{tr}	resultant total thermal insulation of the clothing ensemble with the manikin moving	$\frac{m^2K}{W}$
RH	relative humidity of the air within the climatic chamber	%
T_a	air temperature within the climatic chamber	°C
T_s	mean skin surface temperature of the manikin	°C
T_{si}	skin surface temperature of the body segment i of the manikin	°C
v_a	air speed in the climatic chamber	m/s

4 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 I_{tr}, 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 a dry 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 nude manikin's body surface area, the clothing ensemble's thermal insulation can be calculated, considering the temperature difference 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 insulation values obtained include the thermal insulation 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.

5 Apparatus

5.1 Manikin

5.1.1 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 fingers extended to allow gloves to be worn), legs and feet. The manikin shall consist of at least 15 body segments, each independently controlled with regard to surface temperature and monitored for heat flow. These 15 body segments shall be arranged as shown in Figure 1. If the manikin consists of more than 20 body segments, in the evaluation of the measured data, adjacent segments shall be combined using Equation (3), in order to approximate the segment arrangement shown in Figure 1.

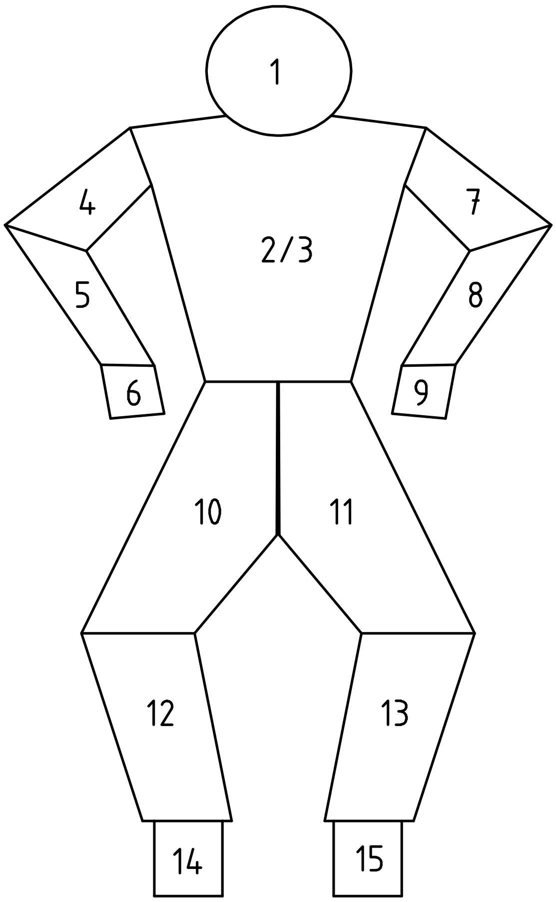

Figure 1 — Schematic arrangement of the manikin's body segments

The body height of the 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 I_t the manikin's arms and legs shall be movable, with joints at the shoulder, hip and knee. For the measurement of the clothing ensemble's resultant total thermal insulation, I_{tr}, 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.

5.1.2 Surface temperature

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

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.

5.1.3 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 Controlled climatic chamber

5.2.1 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 variations within 0,5 m of the manikin's surface shall not exceed the following:

a) air temperature ± 1,0 °C;

b) relative humidity ± 10 %;

c) air speed ± 50 % of the mean value;

d) temperature of the walls, floor and ceiling shall not differ more than 1 K from the mean air temperature.

In the chamber, temporal variations during the test period shall not exceed the following:

e) air temperature ± 0,5 °C;

f) relative humidity ± 10 %;

g) air speed ± 20 % of the mean value for data averaged over 3 min.

5.2.2 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.

5.2.3 Relative humidity sensor

Any humidity sensing device with an accuracy of at least ± 5 % 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 5.2.1 are met.

5.2.4 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.

6 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 and put back on the manikin between each single measurement.

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

Garments should not normally be laundered or dry cleaned prior to testing, because different procedures may affect the results. However, if garments are cleaned the cleaning shall be in accordance with the care label, and the specific care procedures applied shall be stated in the test report.

Prior to testing, the garments shall be conditioned either at (20 ± 5) °C and (50 ± 20) % RH or at the test climate set in the climatic chamber for at least 12 h.

7 Test procedure

The manikin is dressed with the clothing ensemble to be tested, with each garment arranged on the appropriate part of its body as in practical use.

For the measurement of the total thermal insulation, I_t, the manikin is kept stationary, standing with its legs straight, and the arms hanging straight at its sides.

For the measurement of the resultant total thermal insulation, I_{tr}, the legs and arms of the manikin are mechanically moved, with the frequency and stride length specified in 5.1.1.

The skin surface temperature, T_{si}, at each of the manikin's body segments, is set and, during the test period, maintained at (34 ± 0,2) °C.

The air temperature in the climatic chamber, T_a, is set to at least 12 K below the manikin's mean skin temperature, T_s, and/or to a value ensuring a minimum heat flux of 20 W/m^2 at each segment of the manikin.

The relative humidity in the climatic chamber is set between 30 % and 70 %, preferably 50 %.

The air speed v_a in the climatic chamber is set to (0,4 ± 0,1) m/s.

After starting the test, allow the system to reach steady-state conditions, i.e., the skin surface temperatures, T_{si}, of the manikin's body segments and the power input to the segments during a time period of 10 min remain constant within ± 0,2 °C and ± 2 %, respectively.

After the system has reached steady-state conditions, record the manikin's skin surface temperatures, T_{si}, the air temperature, T_a, in the climatic chamber and the power input, H_{ci}, to the manikin's body segments at least every minute during the measurement period. The average of these measurements taken over a period of at least 20 min will be sufficient to determine the clothing ensemble's thermal insulation.

At least two independent tests per clothing ensemble shall be conducted. If the difference in the results between these two tests exceeds 4 %, at least one more test shall be carried out.

The thermal insulation value(s) of the clothing ensemble given in the test report shall be the arithmetic mean of the single test results.

8 Recalibration of the manikin system

In order to verify that the manikin system is functioning correctly, at regular time intervals an in-house “control” clothing ensemble whose thermal insulation is known, shall be tested. If this insulation value does not lie within ± 4 %, the manikin system shall be recalibrated.

9 Calculation of test results

9.1 General

The thermal insulation of the clothing ensemble tested can be calculated either by adding the area-weighted local thermal insulation at the manikin's different body segments (serial model) or by using the total heat flow from the manikin's body (parallel model). For a given clothing ensemble the results will differ significantly between the two calculation models. The specific type of garment/s and the activity/climate conditions under which it/they is/are worn will determine which of these models is used to assess the physiological effect of the clothing ensemble on its wearer.

In application standards when physiological demands on a particular clothing ensemble are specified, it is usual for a statement to be included to direct the user as to whether the application relates to the serial or parallel model in order to obtain its appropriate thermal insulation.

The serial and parallel calculation models are defined respectively in 9.2 and 9.3. The test report shall state the model on which the insulation values are based.

9.2 Serial model — Surface area weighted thermal insulation

The total thermal insulation, I_t, or the resultant total thermal insulation, I_{tr}, is calculated on the test results gained with the manikin respectively either stationary or moving its legs and arms, using Equation (1).

$$I_t \text{ or } I_{tr} = \sum_i f_i \times \left[\frac{(T_{si} - T_a) \times a_i}{H_{ci}} \right] \quad \text{in square metre kelvins per watt} \qquad (1)$$

$$\text{where } f_i = \frac{a_i}{A} \qquad (2)$$

9.3 Parallel model — Surface area averaged thermal insulation

The total thermal insulation, I_t, or the resultant total thermal insulation, I_{tr}, is calculated on the test results gained with the manikin respectively either stationary or moving its legs and arms, using Equation (3).

$$I_t \text{ or } I_{tr} = \frac{(T_s - T_a) \times A}{H_c} \quad \text{in square metre kelvins per watt} \qquad (3)$$

where

$$T_s = \sum_i f_i \times T_{si} \text{ in degrees centigrade} \quad (4)$$

$$H_c = \sum_i H_{ci} \text{ in watts} \quad (5)$$

10 Precision of results

In a round-robin test using one clothing ensemble tested with three repetitive measurements in seven laboratories with different manikins, the following precision (coefficient of variation) of the total thermal insulation and resultant total thermal insulation, respectively, has been found:

a) Repeatability

Serial model: I_t: 2,6 %

I_{tr}: 0,8 %

Parallel model: I_t: 2,4 %

I_{tr}: 1,9 %

b) Reproducibility

Serial model: I_t: 6,8 %

I_{tr}: 7,9 %

Parallel model: I_t: 5,3 %

I_{tr}: 5,9 %

11 Test report

The test report shall include at least the following information.

a) reference to this International Standard, i.e. ISO 15831;

b) description of the test sample including washing or dry cleaning procedures, if applied;

c) arrangement of the garments on the manikin (e.g. was the shirt-tail tucked in? were there any zippers, and, if so, were they closed?);

d) number of test specimens per clothing ensemble and number of individual measurements on each test specimen;

e) air temperature, T_a, relative humidity, RH, and air speed, v_a, in the climatic chamber during the measurement period;

f) arithmetic mean of the clothing ensemble's total thermal insulation, I_t, and/or resultant total thermal insulation, I_{tr}, with reference to the calculation model (serial or parallel) on which the values are based;

g) details of deviations from this International Standard;

h) date of test.

Annex A
(informative)

Calculation of test results

A.1 General

Usually, the thermal insulation values measured with a thermal manikin are used to assess the physiological effects of clothing. This assessment is based on different physiological models, depending on the end-use of the clothing. Partly, these models are defined in specific standards of application and use different thermal insulation values gained with the manikin, i.e. total thermal insulation or effective thermal insulation or basic thermal insulation. The latter are described in A.2, e.g. for a given clothing ensemble, the difference between the basic and effective thermal insulation can amount to up to 20 %.

A.2 Calculation methods

In order to measure the resultant thermal insulation of the boundary air layer, I_a or I_{ar}, conduct a test with the nude manikin, respectively in a stationary or moving condition. The nude manikin should preferably be tested at the beginning and end of each series of clothing tests to assure correct system functions.

Serial model — Surface area weighted thermal insulation

$$I_a \text{ or } I_{ar} = \sum_i f_i \left[\frac{(T_{si} - T_a) \times a_i}{H_{ci}} \right] \quad \text{(A.1)}$$

$$f_i = \frac{a_i}{A}$$

Parallel model — Surface area averaged thermal insulation

$$I_a \text{ or } I_{ar} = \frac{\left[\left(\sum_i f_i \times T_{si} \right) - T_a \right] \times A}{\sum_i H_{ci}} \quad \text{(A.2)}$$

$$f_i = \frac{a_i}{A}$$

To calculate the thermal insulation of the boundary air layer, I_a or I_{ar}, use Equation (A.1) or (A.2) on the test results obtained with the nude manikin.

To calculate the basic thermal insulation, I_{cl} or I_{clr}, use Equation (A.3).

$$I_{cl} = I_t - \frac{I_a}{f_{cl}} \quad \text{(A.3 a)}$$

or

$$I_{clr} = I_{tr} - \frac{I_{ar}}{f_{cl}} \quad \text{(A.3 b)}$$

To calculate the effective thermal insulation, I_{cle} or I_{cler}, use Equation (A.4).

$$I_{cle} = I_t - I_a \tag{A.4.a}$$

or

$$I_{cler} = I_{tr} - I_{ar} \tag{A4. b}$$

where

I_t is the total thermal insulation of the clothing ensemble with the manikin stationary, in square metre kelvins per watt;

I_{tr} is the resultant total thermal insulation of the clothing ensemble with the manikin moving, in square metre kelvins per watt;

I_a is the total thermal insulation of the boundary air layer with the manikin stationary, in square metre kelvins per watt;

I_{ar} is the resultant total thermal insulation of the boundary air layer with the manikin moving, in square metre kelvins per watt;

I_{cl} is the basic thermal insulation of the clothing ensemble with the manikin stationary, in square metre kelvins per watt;

I_{clr} is the resultant basic thermal insulation of the clothing ensemble with the manikin moving, in square metre kelvins per watt;

I_{cle} is the effective thermal insulation of the clothing ensemble with the manikin stationary, in square metre kelvins per watt;

I_{cler} is the resultant effective thermal insulation of the clothing ensemble with the manikin moving, in square metre kelvins per watt;

T_{si} is the local surface temperature of section i of the manikin, in degrees centigrade;

T_a is the air temperature within the testing chamber, in degrees centigrade;

a_i is the surface area of section i of the manikin, in square metres;

H_{ci} is the local heat loss from section i of the manikin, in watts;

A is the total body surface area of the nude manikin, in square metres;

f_i is the area factor of section i of the nude manikin;

f_{cl} is the clothing area factor.

A.3 Determination of the clothing area factor

The surface area of the clothed manikin, A_{cl}, is greater than the surface area of the nude manikin, A. This relation (A.5) is called the clothing area factor f_{cl}.

$$f_{cl} = \frac{A_{cl}}{A} \tag{A.5}$$

The value of f_{cl} can be measured by a photographic method. Pictures of the projected area of the nude manikin are compared with pictures of the projected area of the clothed manikin from the same directions. Pictures of the projected area are taken from six directions; two altitudes: 0° (horizontal) and 60° and in three azimuth angels at each altitude: 0° (front), 45° and 90° (profile). The clothing area factor for each direction is then estimated by Equation (A.6).

$$f_{cli} = \frac{A_{cli}}{A_i} \tag{A.6}$$

where

A_{cl} is the total body surface area of the clothed manikin, in square metres;

A_{cli} is the projected surface area in direction i of the clothed manikin, in square metres;

A_i is the projected surface area in direction i of the nude manikin, in square metres;

f_{cli} is the area factor of section i of the clothed manikin.

Then the clothing area factor is calculated by Equation (A.7).

$$f_{cl} = \frac{\sum_{i=1}^{6} f_{cli}}{6} \tag{A.7}$$

where i designates the direction considered.

It is very important that the position and posture (stationary) of the manikin in relation to the camera is exactly the same when clothed as when nude.

On the other hand, f_{cl} could be determined as described in ISO 9920.

Bibliography

[1] ISO 9920, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble*

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