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Protective clothing for firefighters — Physiological impact —

Part 1: Measurement of coupled heat and moisture transfer with the sweating torso

Vêtements de protection pour sapeurs-pompiers — Impact physiologique —

Partie 1: Mesurage du transfert de masse et de la chaleur couplé de chaleur et d'humidité à l'aide du torse transpirant

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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 voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 94, *Personal safety*, Subcommittee SC 14, *Firefighters PPE*.

A list of all parts in the ISO 18640 series can be found on the ISO website.

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Introduction

The main functions of protective clothing are protection against hazards and maintenance of health and comfort for the wearer. Furthermore, protective clothing against heat and flame prevents the wearer from health risks or even life threatening heat stress in extreme environmental conditions. Today's standards provide requirements for the protective properties of protective clothing against heat and flame. However, the higher the protective properties of such clothing, the less the heat originating from the human body is dissipated. Firefighters reach metabolic rates above 500 W/m^2 during their work[5][6]. Thereof 75-85 % is released as heat[7], which has to be dissipated from the human body by thermo-regulative processes to avoid an increase in body core temperature. If heat dissipation is not restricted, the human body is able to maintain its temperature in the range of 36,5 °C to 37,5 °C (normothermia)[8]. However, in harsh environmental conditions and/or in situations of restricted heat dissipation due to protective clothing the human body is not able to maintain body core temperature within normothermia and suffers from heat stress. The working performance is gradually reduced and any further increases in body core temperature can become life threatening[16]. To reduce the risk of heat stress during high intensity physical activities, protective clothing should additionally be assessed with regard to its impact on human thermoregulation and heat stress.

Different approaches exist for the assessment of thermo-physiological impact. On the one hand, established standard parameters such as water vapour resistance, R_{et}, and thermal insulation, R_{ct}, of fabric samples are considered with regard to thermo-regulative impact. However, these parameters do not fully reflect the real impact of protective clothing; for example, moisture management properties and the combined effect of heat and moisture transfer are not considered. On the other hand, human subject trials reveal real thermo-physiological responses for a specific environmental condition and protective clothing ensemble. However, the outcome of this methodology does not only refer to the intrinsic properties of material samples but are influenced also by the design of the clothing and trapped air layers within the clothing. Furthermore, human subject trials are very time consuming and expensive, constricted by ethical guidelines and provide findings related to the collective of participants included. Thus, reproducibility between laboratories might be limited. The use of thermal manikins overcomes the limitations for human subject trials. As for human subject trials, full body manikins provide findings on ready-made protective garments including design and fit. Hence, the attribution to intrinsic material properties remains difficult.

A methodology referring to intrinsic clothing properties and taking into account combined heat and moisture transfer is the Sweating torso[9][10]. Sweating torso device is an upright standing heated cylinder, representing the surface of a human trunk, with the ability for perspiration[11]. The clothing sample is investigated by wrapping specimens around the sweating torso. Three phases are run to measure dry thermal insulation, dry and wet heat transfer and drying properties. Findings from the Sweating torso have been validated with standard methodologies, such as sweating guarded hotplate, and were shown to be highly reproducible[11]. Furthermore, validation studies have been conducted to relate human thermos-physiological measurements to Sweating torso findings under realistic environmental conditions and activities for firefighters. Based on this knowledge, guidelines are provided for intrinsic textile properties based on thermo-physiological responses. In addition to the standard procedure described above, the impact of more complex protective clothing systems including underwear, air gaps and/or design features is investigated optionally applying the same experimental protocol described in this document.

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Protective clothing for firefighters — Physiological impact —

Part 1: Measurement of coupled heat and moisture transfer with the sweating torso

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1 Scope

This document provides a test method for evaluating the physiological impact of protective fabric ensembles and potentially protective clothing ensembles in a series of simulated activities (phases) under defined ambient conditions. This standard test method characterizes the essential properties of fabric assemblies of a representative garment or clothing ensemble for thermo-physiological assessment:

— dry thermal insulation;

— cooling properties during average metabolic activity and moisture management (dry and wet heat transfer);

— drying behaviour.

Default measurements are done on fabric samples representing the garment or protective clothing combination. Optionally and in addition to the standard test method, the same testing protocol can be applied to characterise more complex protective clothing ensembles including underwear, air layer and certain design features[1]. In addition, measurements on readymade garments are possible.

This test method is intended to be used to measure and describe the behaviour of fabric assemblies of a garment or clothing ensemble in response to a simulated series of activities under controlled laboratory conditions, with the results used to optimize garment combinations and material selection. Furthermore, this document together ISO 18640-2, is intended to be used to describe the thermo-physiological impact of protective clothing but not the risk for heat stress under actual fire conditions. The results of this test can be used as elements of a risk assessment with respect to thermo-physiological load.

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.

ISO 3696, *Water for analytical laboratory use — Specification and test methods*

3 Terms and definitions

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

1) A study conducted by Empa (Swiss Federal Laboratories for Materials Science and Technology, Switzerland) showed good correlation between results of standard torso tests (without underwear and air layers on fabrics) to tests on fabrics with underwear, tests on fabrics with underwear and air layers and test on readymade garments (with underwear and with or without air layers) of the same material composition. Due to the added thermal insulation values of the additional layers direct comparison of results between different measurement configurations is not possible, however.

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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 http://www.electropedia.org/

3.1
cooling delay
CD
time delay until the effect of evaporation cooling will be detected in an experimental phase with simulated activity and sweating

Note 1 to entry: The cooling delay is given in minutes.

3.2
evaporated sweat water
fraction of supplied sweat water which is evaporated in active phase with sweating

3.3
experimental phase
part of an experiment with a defined sweat rate and surface temperature or heating power; an experiment can consist of multiple phases

Note 1 to entry: Each phase simulates a specific situation with defined temperature or heating power and sweat rate settings. A standard experiment consists of three phases.

3.4
initial cooling
IC
rate at which temperature changes after cooling delay CD in an experimental phase simulating activity with sweating

Note 1 to entry: The initial cooling is given in degrees (°C) per hour.

3.5
moisture uptake
amount of moisture stored in clothing system determined by torso weight

Note 1 to entry: The moisture uptake is given in grams.

3.6
post cooling
PC
end of cooling period in an experimental phase without sweating and heating power corresponding to a human being at rest following a simulated activity

Note 1 to entry: The evaporation of stored moisture will extract energy from the sweating torso which can be detected in a decrease of the surface temperature.

Note 2 to entry: The post cooling is given in minutes.

3.7
phase profile
series of experimental phases which define the experiment

3.8
sustained cooling
SC
rate at which temperature changes towards the end of an experimental phase simulating activity with sweating (steady state of cooling)

Note 1 to entry: The sustained cooling is given in degrees (°C) per hour.

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3.9
spacer
air layer
frame or setup to add a defined air layer between torso surface and protective garment to be tested

Note 1 to entry: Simulation of air layers which are typically observed in real use. An air layer influences overall thermal resistance and moisture transport. A spacer may be used to simulate a defined air layer.

3.10
sweat water
supply of water used to simulate sweating

3.10.1
gravimetric system to deliver sweat water
control of sweat water delivery using a tank on a balance with a defined height difference to the sweat nozzles to deliver the set amount of water by opening and closing valves in a calibrated interval

Note 1 to entry: Other ways of sweat water deliver may be used as long as the requirements of this document are fulfilled.

3.11
thermal resistance
$R_{ct\ (torso)}$
calculated at steady state from the difference between torso surface temperature and ambient temperature, the surface area of the device and the heating power needed to maintain the temperature difference

Note 1 to entry: The thermal insulation is given in $m^2 \cdot K/W$.

3.11.1
correction value for $R_{ct\ (torso)}$
$R_{ct0\ (torso)}$
thermal resistance measurement without a sample on the sweating torso to determine a system specific correction value for the thermal resistance $R_{ct\ (torso)}$

Note 1 to entry: Thermal resistance as defined above depends on the geometry of the apparatus, convective conditions (wind or still air) and ambient conditions. $R_{ct0\ (torso)}$ is a cumulative measure of this and might differ slightly from device to device and installation to installation. By taking it into account differences in results from different installations can be reduced.

3.12
torso balance
device used to measure torso weight

3.13
torso surface temperature
average temperature on the surface of the measurement area of the torso

3.14
torso weight
overall weight of the sweating torso and test object during a test

3.15
total sweat water
amount of water supplied to torso surface during an active phase with sweating

3.16
wicking layer
thin hydrophilic textile layer with defined moisture transport and thermal properties used for homogeneous sweat water distribution

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3.17
wind speed
ambient velocity of air flow around the torso during an experiment

Note 1 to entry: To avoid undefined boundary air layers due to random air exchange in the chamber and the temperature difference between torso surface and climatic chamber a fan system is used. The fan system consists of ventilators to achieve a set homogeneous wind speed at the torso surface of 1 m/s (turbulence level of up to 25 % measured with a hot-wire anemometer).

4 Symbols and abbreviations

CD	Cooling delay, in minutes
HDPE	High Density Polyethylene
IC	Initial cooling in °C/h
PC	Post cooling, in minutes
PTFE	Polytetrafluoroethylene
$R_{ct\ (torso)}$	Thermal resistance in m²·K/W
$R_{ct0\ (torso)}$	Correction value for $R_{ct\ (torso)}$
RH	Relative humidity
SC	Sustained cooling, in °C/h
THS	Thermal Human Simulator

5 Apparatus

The sweating torso is an upright standing cylindrical test apparatus, simulating the human trunk with thermal guards on the upper and lower end (see Figure 1). The apparatus is equipped with heating foils, sweating nozzles, a multi-layer shell (simulation of the skin layers) and electronics to control the valves and sensors.

The whole measurement system (see Figure 1) consists of the sweating torso (key element 1) on a balance (key element 2) positioned in a climatic chamber. A fan system (key element 3) is used to set the wind speed. The control system (key element 4) power supplies, controllers, and computer with data acquisition) can be placed either inside or outside the chamber. A sweat water tank positioned outside the climatic chamber placed on a balance (key element 5) provides the water to the sweating nozzles. The water supply is controlled by valves.

NOTE The design and control system of the sweating torso has been validated in numerous research projects with respect to different types of clothing systems for the assessment of coupled heat and mass transfer (see Annex E).

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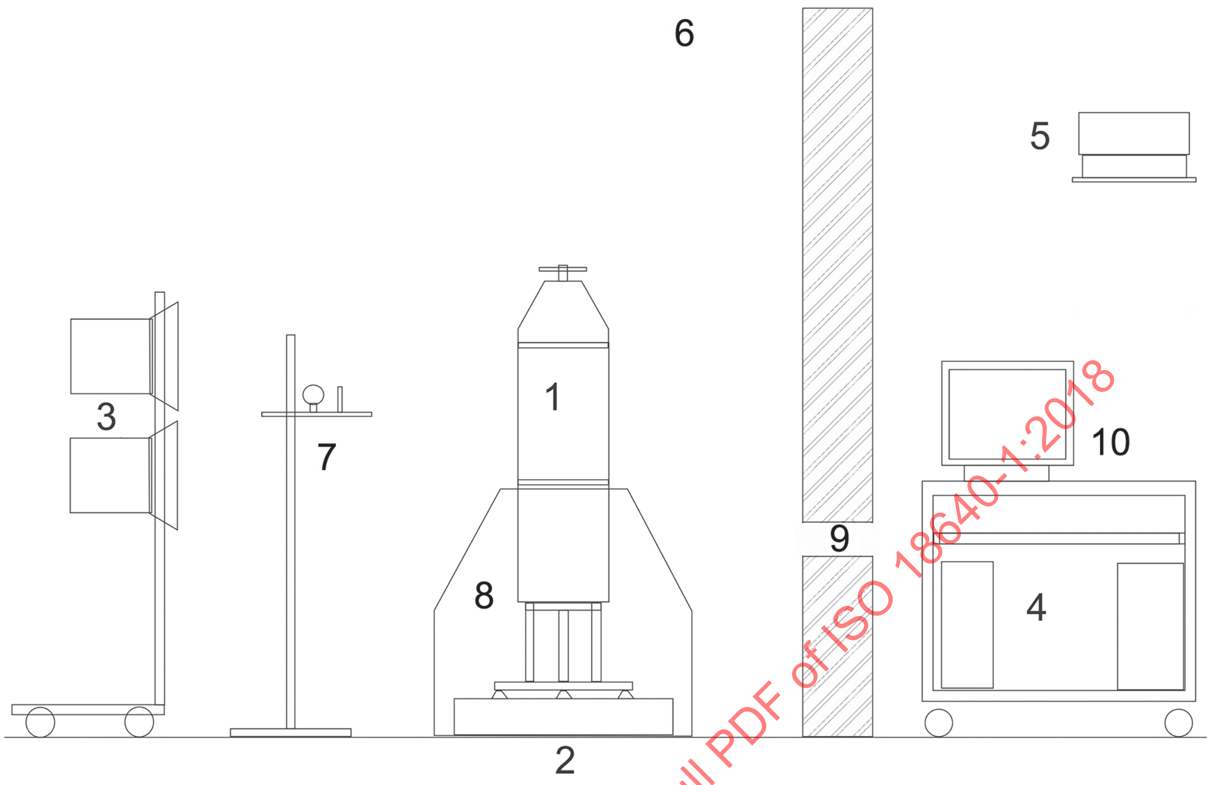

Key

1	torso	6	climatic chamber
2	torso balance	7	environmental sensors
3	fan system	8	frame to minimize influence of wind
4	control system	9	wall of climatic chamber with opening for cables
5	sweat water balance	10	computer, monitor and printer

Figure 1 — Example of torso system

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5.1 Sweating torso

5.1.1 General

The sweating torso was designed to simulate the human trunk. The cylinder shall consist of an aluminium tube a layer each of HDPE-[2)] and PTFE which has an outer diameter of (30,0 ± 0,25) cm (circumference of ~94,25 cm) and a length of (46,0 ± 0,25) cm .Heating foils are situated inside the aluminium tube. On the lower and upper end of the upright standing cylinder there are thermal guards with individually controlled heating. There are temperature sensors in the aluminium part (Pt-100 sensors or equivalent) as well as on the surface of the measurement cylinder (Ni wires or equivalent).

The electronic components to control the valves for the 54 sweating nozzles can be situated in the lower guard (see Figure A.1) or in an electronic box outside the torso. Transducers converting the resistance values of the temperature sensors may also be located here. Also data acquisition and temperature controlling electronics or parts of these may be placed in the cavity of the guards. Care has to be taken that the heating power of these components shall not disturb temperature control of lower guards and, hence, affect measures obtained from main cylinder.

2) HDPE: High density Polyethylene. E.g. PAS-PE3, thermal conductivity: (0,41 ± 0,02) W/(m·K); thermal capacity: (2,0 ± 0,3) kJ/(kg·K).

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The compartment between cylinder and guards shall be separated by thermally insulating discs (thermal conductivity less than 0,35 [W/m·K]) to limit heat exchange between the measurement cylinder and the guards. A more detailed technical description is given in Annex A.

The mass of cylinder, thermal guards and equipment shall be designed to have a mass of ~(82,5 ± 2,5) kg.

5.1.2 Heated cylinder

The central part of the torso is the area where the measurement takes place (surface area: ~0,433 5 m^2). The internal aluminium tube is covered by layers of synthetic material with similar thermal properties as the human skin (6 mm HDPE and PTFE foil, see Annex A).

5.1.3 Thermal guard sections

There is a thermal guard on each end of the measurement cylinder made of aluminium of the same diameter as the measurement cylinder. These two segments are controlled and heated separately to ensure that there is no parasitic heat flow from or to the measurement cylinder which is supported by the insulating discs between the sections. In addition, the space in the lower guard can be used to incorporate the electronics to register temperatures and to control the valves.

The upper guard has a conical end and is smaller compared to the lower guard to allow donning of readymade garments to the device.

5.1.4 Heating and temperature control

Heating elements shall be provided for each segment of the torso. Power supplies and means to regulate the temperature and heating power of each segment are needed. The power supplies shall be able to provide an output power of at least 500 W for the measurement cylinder and 240 W for each of the guards.

5.1.5 Temperature measurement

Temperature sensors (Pt100 or equivalent) in the aluminium part of the torso and nickel wires (or equivalent) for integral assessment of the surface temperature are used to control and monitor the temperature in the individual segments of the torso device. Optionally additional sensors placed close to the outer layers can be used for Thermal Human Simulator (THS) measurements according to ISO 18640-2. Temperature sensors shall have an accuracy of at least 0,1 °C in the range from 15 °C to 50 °C. See A.7 for more details.

5.1.6 Simulation of perspiration

Hardware to control sweat water supply is needed. This can be a gravimetric sweat water control system (see 5.5.1) or any other system capable to fulfil the requirements of 5.5. Temperature of the water coming out of the nozzles shall be within 0,5 °C of the temperature of the measurement cylinder.

NOTE The inner diameter and length of the tubes from the water storage to the nozzles will influence the amount of water delivered.

5.1.7 Wicking layer

A thin hydrophilic textile layer with defined moisture transport and thermal properties shall be used for homogeneous moisture distribution on the torso surface. The wicking layer shall be applied for all measurements and fulfil the requirements according to Table 1. This shall provide a sufficiently even sweat water distribution also when testing combinations with hydrophobic inner surfaces[16].

NOTE 1 The human skin has 50 to 250 sweat glands per cm^2 varying for body areas[14] while torso contains 0,01 sweating nozzles per cm^2 only. The use of a wicking layer with good, symmetrical wicking properties and insignificant added thermal insulation will ensure even spread of the moisture.

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Table 1 — Requirements for wicking layer

Property	Standard	Value/range	unit
Thickness	ISO 5084	0,8 ± 0,15	mm
Weight (gsm)	ISO 3801	200 ± 10	g/m^2
Wetting time (MMT top/bottom)	AATCC 195	<3,5 (class fast)	s
Max. wetted radius (MMT top/bottom)		>20 (class large)	mm
Thermal insulation Rct	ISO 11092	0,01 ± 0,005	$m^2{\cdot}K/W$

NOTE 2 Textiles are subjected to aging and will potentially change

5.1.8 Balance torso weight

A scale with computer interface and a range of at least 100 kg with a minimum precision of 1 g is used to monitor the weight course of the torso and specimen during experiments.

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5.2 Computer, control system and data acquisition

5.2.1 General

A control system consisting of the electronics to control temperature, power supplies, computer and data acquisition is used to control an experiment.

5.2.2 Computer and measurement software

To control the measurement a computer with appropriate software is used. Temperature and heating power control can be achieved by dedicated controllers or software control of the power supplies.

The balances used to assess the torso weight and potentially register sweat water output are attached over a software compatible interface to the computer.

A data acquisition system attached to the computer shall be used to measure and register all sensor data and control sweat rate.

5.2.3 Control system

Power supplies and electronics are needed to control the temperature and heating power of the three sections of the torso system and the sweat rate of the measurement section.

5.2.4 Data acquisition

Data acquisition shall provide enough channels to register all temperature signals, heating powers, and mass readings (as a means to control the sweat rate).

5.2.5 Measurement control options

The torso can be controlled with the following mechanisms:

— Defined surface temperature: The surface temperature of the three segments of the torso will be set to a defined value. This allows, for example, the calculation of thermal insulation in steady state condition of phase 1 of a standard measurement.

— Defined heating power: The heating power of the measurement cylinder is set to a defined value. The surface temperature of the guards is set corresponding to the temperature of the measurement cylinder (guard function). This setting is used to simulate different activity levels in phases 2 and 3 of standard measurement.

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— Defined sweat rate: Torso sweating is controlled by releasing a defined amount of purified water (see 5.5) per time unit Sweating is usually combined with constant heating power for a static simulation of an activity (e.g. phase 2 of a standard measurement).

NOTE Torso parameters can also be controlled by THS (Thermal Human Simulator) where a thermo-physiological model is coupled to the torso as described in ISO 18640-2.

5.3 Climatic chamber

5.3.1 General

Measurements take place in controlled climatic conditions. The climatic chamber shall fulfil the following requirements:

— Minimal size of 2,5 m × 2 m × 2 m (length × width × height). Torso and fan system shall have a minimal distance of 0,5 m to the walls;

— Temperature range of 15 °C to 50 °C (with an accuracy of ±0,5 °C); temperature of the walls, floor and ceiling shall not differ more than 1 °C from the mean air temperature in the chamber;

— Relative ambient humidity range between 25 % RH and 75 % RH (with an accuracy of ±5 %).

— The air flow from ventilation of the chamber shall not be higher than 0,25 m/s (averaged over 3 minutes) independent of the direction. Measure the contribution of the chamber ventilation system to the wind speed while the fan system is turned off.

Ambient conditions shall be registered during experiments.

5.3.2 Climatic chamber sensors

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

Any humidity sensing device with an accuracy of at least ±5 % relative humidity and a repeatability of ±3 % is acceptable.

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 around the torso.

5.4 Fan system

Heat flux from the torso surface is influenced by the wind conditions at the surface. The fan system shall be suitable to produce wind of (1 ± 0,1) m/s (up to 25% of turbulence level) at the surface of the torso (see 8.1.2). The distance of the fan system to the torso shall be at least 1,9 m.

NOTE Air circulation in climatic chambers affects stability of the climate and rates of changing climatic conditions. This air circulation will lead to different wind conditions on the surface of the torso as well. Additional air flow due to air circulation of the chamber has to be assessed.

5.5 Sweat water supply

Distilled water (ISO 3696, grade 2) or purified water (ISO 3696, grade 1) shall be used as sweat water.

Sweat water can be supplied by a gravimetric system as defined in 5.5.1 or any other system capable of providing reproducible sweat rates for each nozzle capable to achieve sweat rates between 0 and 1,5 l/m^2·h (according to Annex A).

The temperature of the supplied sweat water shall be within 0,5 °C of the temperature of the measurement cylinder.

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5.5.1 Gravimetric sweat water control system

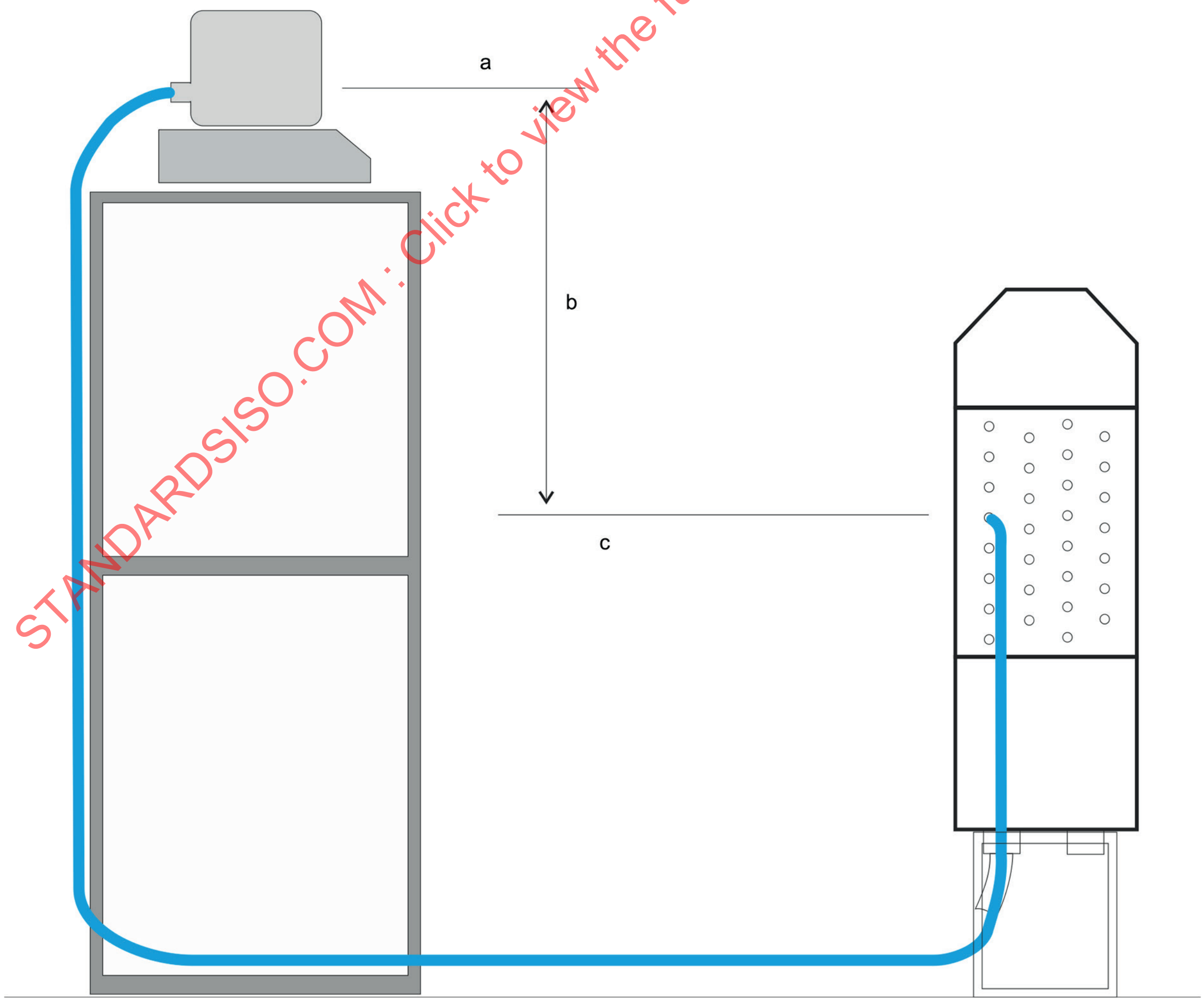
A tank positioned on a scale with computer interface and a range of at least 5 kg with a minimum precision of 0,1 g is used to monitor sweat water release. The tank is positioned at a constant, defined height with respect to the sweat nozzles (see Figure 2), which are connected to valves that can be electronically opened and closed. The average height difference between nozzles and sweat water tank shall be at least 70 cm.

Digital output signals from the data acquisition device are used to control valves for each nozzle. The nozzles are fed with sweat water by opening and closing the attached valves. The amount of sweat water is set by adjusting the opening frequency and duration of the valves. The opening time shall be kept constant since a minimal opening time has to be respected in order to get reproducible droplets of defined size at the nozzles. The opening interval for a set sweat water rate shall be calibrated for each valve separately.

NOTE 1 Height differences of ~85 cm between the nozzles and the storage tank have proved to be sufficient to produce reproducible droplets at an opening time of 200 ms when using tubes of 0,5 mm diameter and 1m length from valve to nozzle. For different opening times pressure difference or tube resistance will have to be adjusted.

NOTE 2 If it is intended to do experiments at low ambient temperature and even freezing conditions the tube for the water supply to the torso has to be insulated or, preferably, heated (e.g. Heating tube Isopad IHH 105, NW4, WISAG, Zurich, Switzerland).

Figure 2 shows the schematic drawing of the configuration of sweat water calibration. The amount of sweat water delivered with the above described system is reproducible but not linear with respect to interval between openings (see Annex B for details regarding calibration procedure).



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a Water level in sweat water tank (on balance).

b Height difference between sweating nozzle and sweat water tank level.

c Level of sweating nozzle.

Figure 2 — Schematics of water supply

5.6 Simulation of air layers

Air layers between the garments and the body influence the total thermal insulation and also moisture transfer. As the main purpose of this is to evaluate the influence of the garment or fabric layer system and to get results with a high reproducibility air layers are minimized in standard torso testing.

NOTE 1 Air layer distribution of a garment on the human body is dependent on parameters such as body shape, size and cut of the garment, body posture and layers worn below the garment. Prediction of air layer distribution for each particular case is not possible. Statistical assessment considering an average body shape and assuming a specific posture is possible.

For specific applications air layers can be introduced in addition to the standard protocol by adding a spacer between the torso and the protective clothing system (see Figure 3). Two rings of an inner diameter to match the torso outer diameter which are separated by 24 rods are used to separate the clothing layers from the torso surface and to set a desired air gap thickness[15]. Default air gap is 10 mm with no contact area.

NOTE 2 Investigations to compare different experimental settings (single layer test, addition of underwear, air gaps and/or design features by testing readymade garments)showed correlation of the results. Added undergarment layers or air layers have lead in general to reduced differences between the materials/clothing systems. When testing readymade garments repeatability of results was generally reduced compared to reference measurements on fabrics.

Figure 3 — Example for optional supplement to simulate air layers

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Unless otherwise required by the product standard tests shall be undertaken without air layers or additional clothing layers and shall not be performed on readymade garments.

6 Sampling and test specimens

Specimen shall be cut to the size specified in 6.1.1. If not required differently by the applicable product standard all samples shall be pre-treated according to 7.1.

6.1 General

6.1.1 Size of samples

Size of specimen:

— 99 ± 1 cm × 66 ± 1 cm for outer layers or woven fabrics (including allowance for clamps);

— 87 ± 1 cm × 66 ± 1 cm for knitted fabrics (accounting for strain of approx. 10 %).

The specimen shall have a symmetrical overlap with the guards of at least 10,0 cm.

The specimens shall be wrapped around the torso with no air layers and wrinkles in the fabrics. If optionally air layers are simulated according to 5.6 sample sizes will have to be adjusted accordingly.

Knitted or stretchable underwear material shall be sewn to the shape of a tube based on the dimensions given above with a strain of ~10 %. Fabrics and additional knitted layers shall be wrapped around the torso and fixed with clamps (on leeward side).

6.1.2 Type of test specimen

Specimens shall be taken from a garment which fulfil the requirements of 6.1.1. If the sample size does not allow taking specimens from a garment, a specimen shall be taken from a fabric construction equivalent to that of the garment intended to be tested. It is recommended to apply specimens without additional clothing layers (i.e. underwear), air gaps and design features for a standard characterisation of the thermo-physiological impact.

NOTE A study conducted by Empa (Swiss Federal Laboratories for Materials Science and Technology, Switzerland) showed good correlation between results of standard torso tests (with neither underwear nor air layers on fabrics) to tests on fabrics with underwear, tests on fabrics with underwear and air layers and test on readymade garments (with underwear and with or without air layers) of the same material composition. Due to the added thermal insulation of the additional layers direct comparison of results between different measurement configurations is not possible.

6.1.3 Garment/ensemble specification

When used to evaluate garments or ensembles for a particular application or to a specification, the test specimens shall be of a material and garment/ensemble layering and composition representing the anticipated application.

6.2 Number of test specimens

Measurements shall be performed on three specimens of each sample.

7 Specimen preparation

Specimens shall be cut to fit to the torso according to Clause 6 above and pre-treated according to 7.1 and 7.2.

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7.1 Pre-treatment

One cleaning cycle (one wash and one dry cycle) shall be applied to remove manufacturing finishes, if not otherwise defined in applicable product standards. If cleaning takes place, it shall be in line with the manufacturer's instructions on the basis of standardized processes. If the specimen can be washed and dry-cleaned it shall only be washed. If only dry-cleaning is allowed the specimen shall be dry-cleaned in accordance with the manufacturers' instructions.

NOTE Manufacturer's instructions typically indicate one or several of the various methods and processes of ISO 6330, ISO 15797 ISO 3175-2 or equivalent as standardized processes for cleaning.

7.2 Conditioning

Each test specimen shall be conditioned for 24 h at (20 ± 2) °C and at a relative humidity of (50 ± 5) %. The time between removal from the conditioned area and testing shall be less than 10 min.

If the specimen cannot be tested within 10 min it shall be sealed in a polyethylene bag (or other material with low water vapour permeability) until testing. Test specimens stored in bags shall be tested within 10 min after removal from the bag. Test specimens shall not remain in the bags for more than 4 h.

8 Measurement procedure

Perform the following steps to conduct a sweating torso test and prepare the test report. Prior to dressing the torso, confirm that the surface temperature of the device is (35 ± 0,1) °C and the climatic chamber is stabilized at the ambient conditions [(20 ± 0,5) °C and (50± 5) % RH)].

8.1 Test preparation

8.1.1 Preparation of climatic chamber

The climatic chamber shall be turned on at least 6 h before start of testing or 30 h if chamber is also used for conditioning. Set the ambient conditions for testing (20 ± 0,5) °C and (50 ± 5) % RH and ensure the torso is turned on and the surface temperature set to the specified values (35 ± 0,1)°C.

8.1.2 Wind speed

Set the wind speed at the position of the torso with an appropriate measurement device (see Figure 4).

NOTE A hot-wire anemometer has proven to be suitable since not only directional air flow is measured and the potential influence of the climatic chamber air exchange will be considered.

Adjust fan speed such that wind speed at the normal distance, l, between torso and fan system will be (1,0 ± 0,25) m/s without torso in place [see M1, step A)]. Measure wind speed at half the distance, $l/2$, and use this measure as a reference to adjust wind speed with torso in place [see M2, step B)]. Position wind speed measurement device at the height corresponding to the centre of the measurement cylinder for wind speed measurements.

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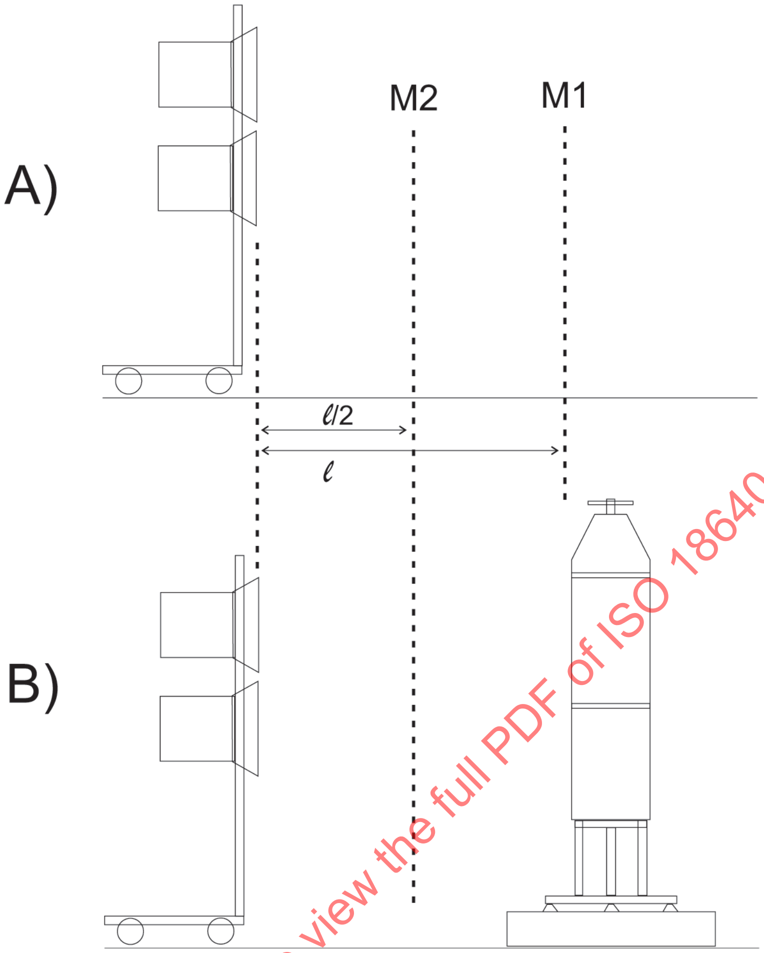

Key

l normal distance between torso and fan system

l/2 half the distance between torso and fan system

M1 wind speed measurement at distance l to the outlet of fan system

M1 reference wind speed measurement at distance *l*/2 to the outlet of fan system

Figure 4 — Schematic drawing of wind speed setting

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8.2 Specimen testing

A standard test consists of experiments performed on each of three specimens, prepared according to Clause 7.

8.2.1 General

8.2.1.1 Standard phase profile

Experiments are done in three consecutive phases which allow simulating different situations covering the requirements for the assessed specimen (see Figure 5). Climatic chamber settings, and the number and sequence are set as follows for standard measurements:

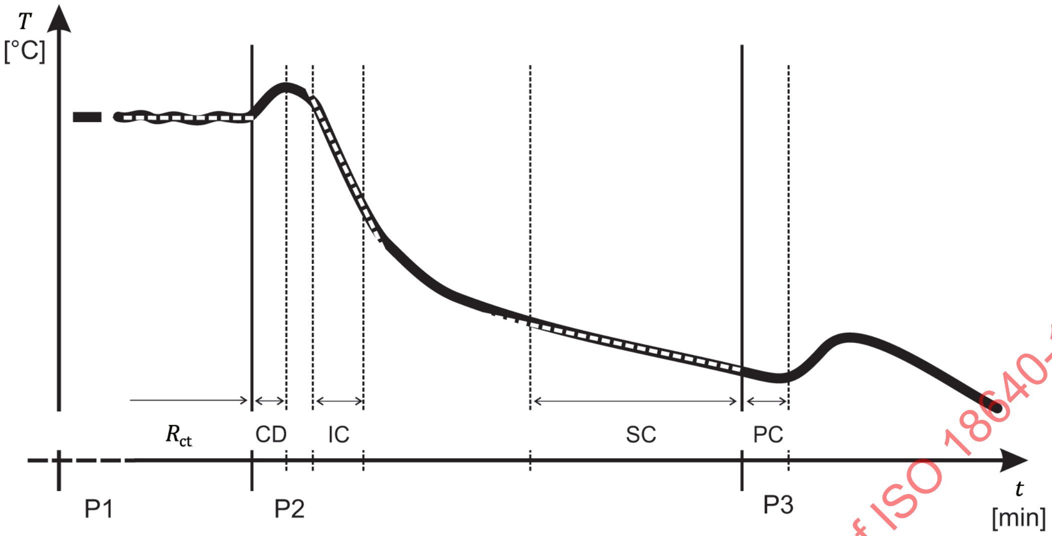
— Climatic chamber settings: (20 ± 0,5) °C and (50 ± 5) % RH.

— Standard phase profile:

— Phase 1: constant temperature of 35°C, without sweating, 60 min;

— Phase 2: constant heating power of 125 W, sweat rate of 100 g/h, 60 min;

— Phase 3: constant heating of 25 W, without sweating, 60 min.



Key

t time, in minutes

T temperature, in degrees °C

R_{ct} thermal resistance

CD cooling delay

IC initial cooling

SC Sustained cooling

PC post cooling

P*x* phase 1 to phase 3

Figure 5 — Schematic temperature course during a standard 3 phases experiment

8.2.2 Dressing the torso

The specimens shall be prepared as specified in Clause 6. The individual layers will be put on the torso in the same sequence as they would be for normal use. The specimens shall be put on the torso such that they are centred with respect to the middle of the measurement section.

8.2.3 Recording specimen identification and test observations

The software used to control experiments shall prompt for the following data (which shall be part of the report and measurement protocols):

— specimen identification (e.g. description including material composition);

— test observations.

8.2.4 Starting the test

The software is used to start data recording. After putting on the test specimen temperatures may increase due the enhanced thermal insulation compared to 'nude' state. For a valid experiment ensure

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transient effects due to adding the specimen have subsided before starting the measurement (stable surface temperature and heating power).

NOTE The software might provide possibilities to delay the start for a selectable period of time allowing the system to stabilize again before the start of the experiment.

8.2.4.1 Data acquisition

Data acquisition is started automatically by the controlling software. All relevant data will have to be recorded at least twice per minute:

— temperature of each segment;

— heating power of each segment;

— weight of torso;

— weight of sweat water tank (gravimetric system) or amount of released sweat water.

All parameters defining the experiment will have to be stored as well:

— settings of climatic chamber;

— phase profile;

— date and time.

Measurement data and data related to the experiment definition can be stored in the same file (header and data) or in separate files.

8.2.5 Calculated values

Depending on the applied software data acquisition and evaluation might be done by different programs.

NOTE A sample Matlab code to calculate the values is given in Annex F as an additional information to the definitions of this clause. In Addition Annex C shows examples of measured data and calculated results.

8.2.5.1 Thermal insulation: $R_{ct\,(torso)}$ (phase 1 of standard experiment)

Thermal insulation will be calculated from the steady state data of phase 1 (phase with constant surface temperature without sweating) (see Formula 2). $R_{ct\,(torso)}$ value needs to be adjusted with a device dependent correction value R_{ct0} (torso) [determined by measurement without specimen but with wicking layer at the set experiment ambient conditions (temperature and rel. humidity of the climatic chamber and set wind speed)].

$$R_{ct\,(torso)} = \frac{A_{torso} \cdot \left(T_{surface} - T_{ambient}\right)}{P_{heating}} - R_{ct0\,(torso)} \quad (2)$$

where:

$R_{ct\,(torso)}$: is the thermal insulation in $m^2 \cdot K/W$;

$R_{ct0\,(torso)}$ is the correction factor for $R_{ct\,(torso)}$ in $m^2 \cdot K/W$;

A_{torso} is the surface area of torso in m^2;

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$T_{surface}$ is the mean surface temperature of measurement cylinder in °C;

$T_{ambient}$ is the mean temperature in climatic chamber in °C;

$P_{heating}$ is the mean heating power of measurement cylinder in W.

8.2.5.2 Cooling properties (phase 2 of standard experiment)

In phase 2 with constant heating power and sweating the cooling performance can be assessed by looking at the surface temperature course. Water absorption and moisture transport in the specimen will influence evaporation and therefore cooling properties of the specimen. Moisture which evaporates close to the surface of the torso will cool it down more efficiently.

The following characteristic values in Table 2 will be calculated (see also Annex F: example Matlab code).

Table 2 — Definition of results phase 2

Value	Description	Definition	Remark	Unit(s)
CD	Cooing delay (time)	Time until surface temperature reduction can be observed at the beginning of phase 2. Possible reasons for a delay in the effective cooling are elevated heating power, release of sorption heat and not yet effective evaporation cooling (delayed distribution/evaporation of sweat water). In case no cooling delay is observed, CD is set to 0. In case no cooling is observed during phase 2, CD is set to n/a)	Depending on material not detectable	min
IC	Initial cooling (temperature difference per time)	Rate of temperature change in the initial part of cooling after potential CD. In case no effective cooling is observed during phase 2, IC is set to n/a.	Measure for short term cooling performance	°C/h
SC	Sustained cooling (temperature difference per time)	Rate of temperature change for steady state part of cooling after potential IC towards end of phase 2. In case no effective cooling is observed during phase 2 but an increase in surface temperature, a negative value for SC is provided.	Measure for long term cooling performance	°C/h
	Moisture uptake	Amount of moisture in the specimen at the end of phase 2. Difference in torso weight at the end of phase 2 compared to the start of phase 2.		g
	Dripped off moisture	The amount of sweat water that has run off the torso and has been collected from the balance with a cloth[a]		g
	Evaporated moisture	Difference between given off moisture and moisture uptake and dripped off water.		g

[a] Mass difference of a hydrophilic cloth with which dripped off water on the balance has been collected.

8.2.5.3 Drying properties and post-cooling (phase 3 of standard experiment)

In phase 3 with constant heating power without sweating (following phase 2 with sweating) will be applied to assess the time needed to dry out the test sample, see Table 3. This will be undertaken by monitoring the weight (see Figure 6) and by assessing the surface temperature.

NOTE The end of evaporative cooling can be seen normally as a difference in the surface temperature: period of temperature increase or difference in declination of temperature.

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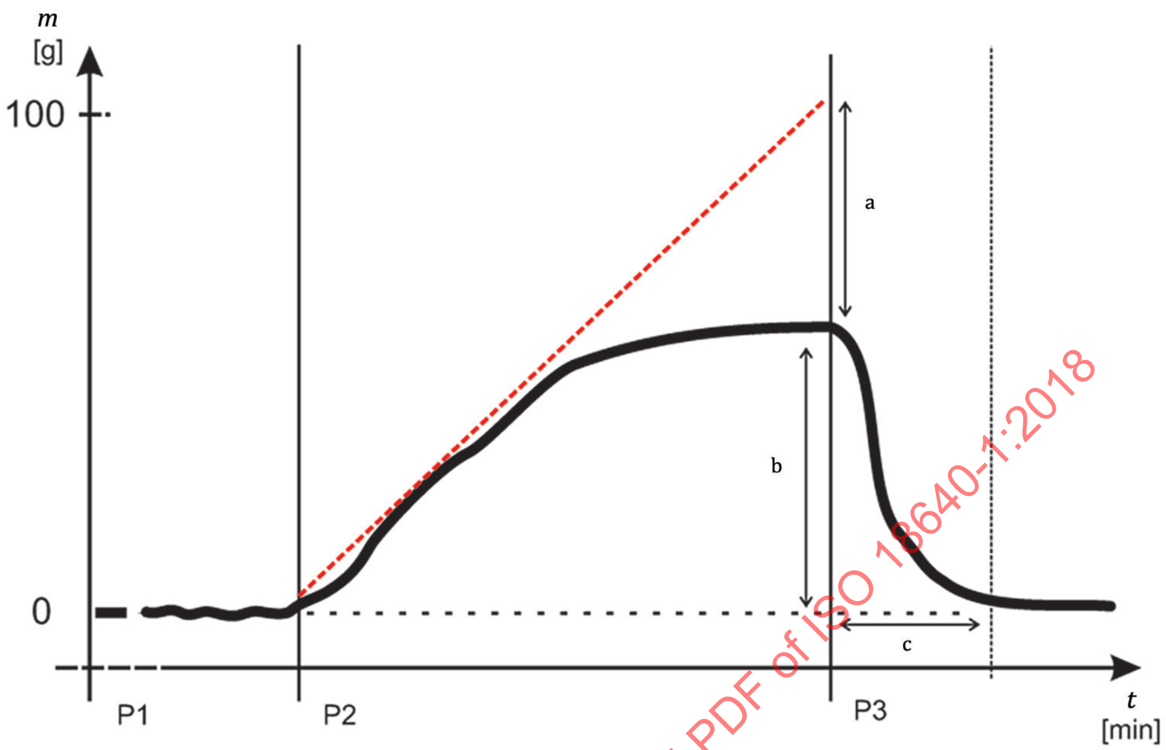

Key

t time, in minutes

m mass, in grams

P*x* phase 1 to phase 3

a Evaporated moisture or dripped off water.

b Moisture uptake..

c Drying time.

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Figure 6 — weight course during measurement

Table 3 — Definition of results phase 3

Value	Description	Definition	Remark	Unit(s)
PC	Post cooling	Time until remaining moisture has evaporated. Detectable from temperature course or weight course.	Change in temperature decrease might not be detectable	min
t_{dry}	Drying time	Time to reach steady state of weight in phase 3.	Weight of the sample might be slightly different at the end of the test	min

8.2.5.4 End of experiment, data storage

After the 3 experiment phases have been completed the recorded data will be assessed and stored. The following information shall be saved:

— experiment conditions:

  — environmental conditions;

  - phase profile;
- experiment data:
  - temperatures;
  - weight course;
  - heating power;
  - sweat rate;
  - dripped off moisture;
- experiment results:
  - $R_{ct\ (torso)}$ (steady state);
  - cooling properties (e.g. CD, IC, SC);
  - post-cooling and/or drying behaviour (PC, t_{dry});
  - sample weight before and after experiment.

9 Test report

9.1 General

Test report shall reference this document and include the data described in the following clauses and include all the elements of the Annex D.

9.2 Specimen identification

Describe the specimen(s) in terms of the following information: garment/fabric type, size, fabric basis weight, fibre type, colour, and non-standard garment features and design characteristics. Include a description of any conditioning and pre-treatment of the garment/ensemble fabric components, such as laundering.

9.3 Experiment conditions

Describe the environmental conditions set for the experiment and the applied phase profile. Environmental data is defined by ambient temperature, relative humidity and wind speed. Phase profile shall be described in a list of entries containing information about control mode and set value, duration, sampling interval, sweat rate, wind and other parameters necessary to reproduce an experiment (including $R_{ct0\ torso}$ and $R_{ct\ wicking\ layer}$).

Standard conditions are described in 8.2.1.1.

9.4 Calculated results

Report the calculated results as described in 8.2.5.

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10 Maintenance and calibration

10.1 Maintenance

10.1.1 Sweat water tank

Distilled water (ISO 3696, grade 2) or purified water (ISO 3696, grade 1) shall be used as sweat water. Before each experiment the operator will have to ensure that there is enough water in the tank for the experiment. The sweat water tank and the tubes will have to be rinsed at least twice a year (potential growing of algae)[3] or more frequently if the flow rate at the sweating nozzles cannot be attained (see Annex B).

10.1.2 Valve checks

There might be air bubbles trapped in the tubes feeding the sweating nozzles. The proper functioning of each valve has to be checked at least once per year. A software option shall be provided to allow checking each valve individually.

10.2 Calibration

10.2.1 General

The following measurements shall be confirmed on a monthly basis as described in 10.2.2 and 10.2.3:

— the correction value for thermal resistance, $R_{ct0\ (torso)}$;

— verification of wicking layer properties by monitoring changes to calculated values according to 8.2.5 for a standard measurement.

The following measurements shall be confirmed on a yearly basis and the sensors calibrated as described in 10.2.4, 10.2.5, 10.2.6, and 10.2.7:

— torso temperature sensors (Pt-100 or equivalent and nickel wire);

— torso heating power (output of power supplies);

— torso sweat rate (valve interval and opening time);

— Environmental conditions (temperature, rel. humidity and wind speed);

See Annex B for more details on calibration.

Additionally, experiments with a standard fabric shall be done every three months. Register experiments and results in log book.

10.2.2 Correction value for thermal resistance, $R_{ct0\ (torso)}$

To assess $R_{ct0\ (torso)}$ perform an experiment without a test specimen at standard conditions (see 8.2.1.1) with only phase 1 according to the standard phase profile. Calculate the $R_{ct\ (torso)}$ for this experiment. Register this value as $R_{ct0\ (torso)}$ in the log book.

10.2.3 Wicking layer

To ensure continuous valid performance of the wicking layer perform an experiment with only the wicking layer in place and compare the evaluated results according to 8.2.5 to values in new state of the

3) Grows of algae depends on a large list of parameters (e.g. light exposure, number of tests, purity of water, ambient temperature etc.).

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wicking layer. Exchange wicking layer if evaluated values for $R_{ct\ (torso)}$, CD, IC, SC, PC deviate by more than 5 % from original value.

Thermal and moisture transport properties according to the requirements of Table 1 have to be verified prior to using it and whenever a new batch of material is bought.

10.2.4 torso temperature sensors

Temperature calibration shall be done at least at 4 temperature points. Temperature range shall cover 15 °C to 45 °C with emphasis on normal skin temperature (~35 °C). Sensors with an accuracy of at least 0,1 °C after calibration are adequate for the torso system.

In order to avoid any disturbance of the measurement all electrical parts within the torso will have to be turned off for temperature adaptation. Before the calibration measurement the torso has to be covered with an insulating layer to minimize the influence of variations in chamber temperature. Calibration measurement of each step is then done after 6 h of adaptation.

10.2.5 torso heating power

Heating power measurement will have to be calibrated between 1 W and 250 W. Accuracy of measurement shall be better than 0,1 W. Calibration measurements shall be repeated three times. The resulting linearized relationship between the measured values and the known values will be used for heating power correction.

10.2.6 torso sweat rate

The correlation between opening interval of a valve at a given opening time and the resulting given off water is non-linear and depends on the height difference between balance and nozzle. The exponential curve shall be approximated with at least 6 points covering a water release rate per valve from 0,25 g/h to 7,5 g/h (corresponding to a sweat rate of 50 g/h·m^2 to 1 500 g/h·m^2 of a human being). The measurement period for each point shall be determined such that the cumulated amount of water is at least 1 g or 10 times the accuracy of the balance.

10.2.7 Environmental conditions

The sensors used to register environmental conditions during an experiment (temperature, rel. humidity and wind speed) shall be calibrated on a yearly basis:

— Temperature in the range of 15 °C to 45-50 °C with an accuracy of 0,1° C;

— Rel. humidity in the range of 25 % RH to 75 % RH with an accuracy of 2 % RH;

— Wind speed in the range of 0,5 m/s to 2,5 m/s with an accuracy of 0,1 m/s.

10.3 Experiments with a standard fabric (optional)

Experiments with a standard fabric may be used for quality assurance purposes, to verify proper functioning of the system and to identify potential long-term changes in any part of the measurement system. Parameters which should be checked, and differences over time noted, are $R_{ct\ (torso)}$, CD, IC, SC and PC. Basic requirements for standard fabric:

— woven fabric;

— intrinsic hydrophilicity;

— single layer;

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Annex A
(informative)

torso size and materials definition

A.1 torso system

As described in Clause 5 the sweating torso basically consists of 3 sections (see Figure A.1):

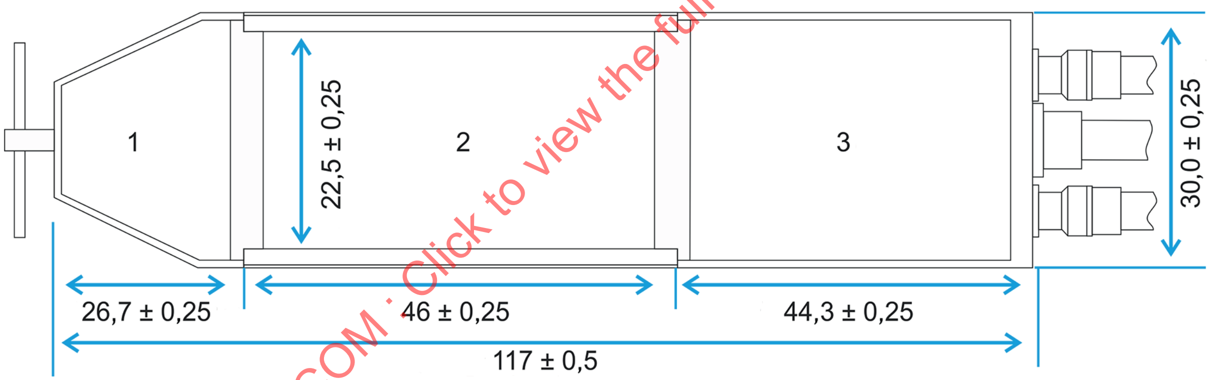
— upper guard;

— measurement cylinder;

— lower guard.

Each of these sections is equipped with a separate heating and temperature control. In addition, there are sweating nozzles in the measurement cylinder. The whole device exclusive of connection tubes and the optional handle shall have a length of. (117,0 ± 0,5) cm and a mass of (82,5 ± 2,5) kg.

Dimensions in centimetres



Key

1 upper guard

2 measurement cylinder

3 lower guard

Figure A.1 — Principal drawing sweating torso (including connection tubes and optional, removable handle to move the device)

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A.2 Measurement cylinder

The measurement cylinder is made of aluminium and has an outer diameter of (28,6 ± 0,25) cm which is covered by a layer of HDPE (thickness approx. 0,6 cm) and an adhesive foil of PTFE (thickness approx. 0,1 cm). The inner diameter of this aluminium cylinder is approx. 22,5 cm. Together with HDPE layer and the PTFE foil this will result in an overall diameter of (30,0 ± 0,25) cm.

A heating system capable of at least 500 W is required. Also temperature sensors will have to be provided to monitor the temperature course and to control the temperature of the cylinder. The following temperature sensing elements are needed:

— Sensor to assess the temperature in the aluminium;

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— Means to register the average surface temperature in two segments.

NOTE 1 Flexible heating foils have proved to fulfil the purpose of heating devices and can be easily glued to the inner surface of the aluminium cylinder.

NOTE 2 Ni wires wound evenly distributed over the surface of the two half-cylinders are suitable to assess the surface temperature by measuring the electrical resistance and convert it to a temperature (see Figure A.2).

A.3 Lower guard

The shell of the lower guard shall have the same outer diameter than the measurement cylinder (30,0 ± 0,25) cm and a length of approx. (44,3 ± 0,25) cm. The hull of the lower guard shall be made of aluminium to allow a uniform temperature throughout the guard. This guard section shall be equipped with a heating device capable of at least 240 W and a sensor to control temperature.

A.4 Upper guard

The shell of the lower guard shall have the same outer diameter than the measurement cylinder (30.0 ± 0,25) cm and a length of approx. (26,7 ± 0,25) cm. The hull of the upper guard shall be made of aluminium to allow an even temperature distribution on the whole surface. This guard section shall be equipped with a heating device of at least 240 W and a sensor to control temperature.

A.5 Discs separating cylinder from guards

The air inside the torso might heat up unevenly which could lead to convection. In order to decrease heat exchange between the three sectors they will have to be separated. A disc made of a material with a low thermal conductivity (<0,35 W/m·K) shall be inserted between the guards and the measurement cylinder.

A.6 Water supply and nozzle distribution

Water is supplied to the torso by means of a gravimetric system (see Figure 2) or any equivalent system compatible with the requirements of 10.2.5. Distilled water (ISO 3696, grade 2) or purified water (ISO 3696, grade 1) shall be used. The electronics controlling the amount of water transported to the nozzles can be positioned in the cavity of the lower guard section[4].

Water supply shall be designed and calibrated such that sweat rates between 0 l/m²·h and 1.5 l/m²·h can be achieved.

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4) If electronics are placed inside the guard section the amount of dissipated heat has to be assessed and the heating power of the affected guard section will have to be corrected if the heating power is larger than 5 W.

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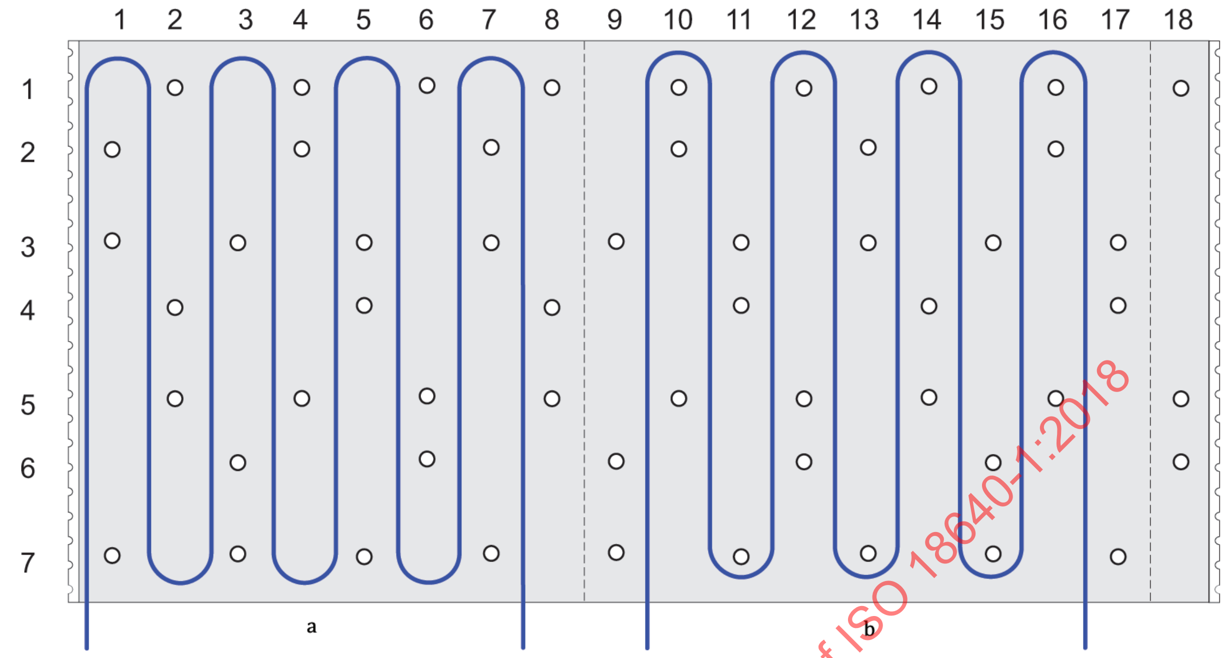

Key

a Front (facing wind).

b Back (opposite fan).

Figure A.2 — Two dimensional schematic drawing of nickel wires layout and nozzles positions on the surface of the torso

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A.6.1 Distribution of sweating nozzles

The nozzles are arranged in 7 rows and 18 columns. The distance between the columns is approximately 50 mm.

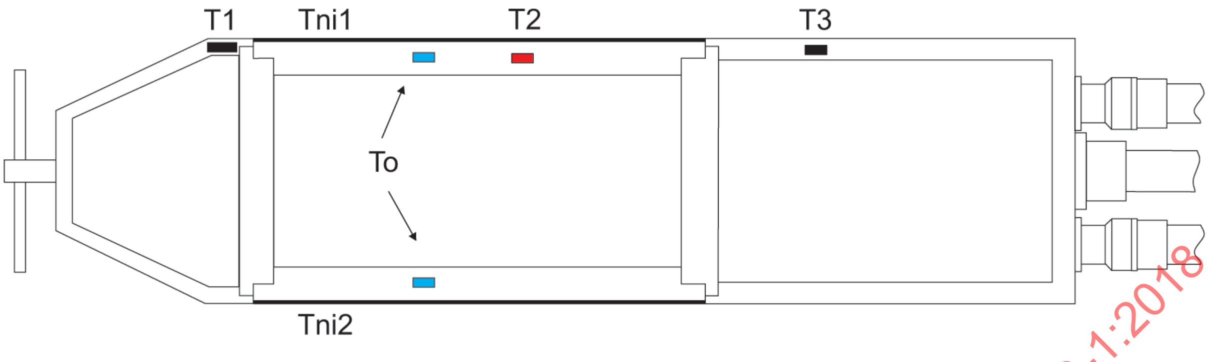
Table A.1 — Number and position of sweating nozzles

Row	No of nozzles	Distance from top	columns
1	9	38,0 mm	2, 4, 6, 8, 10, 12, 14, 16, 18
2	6	89,5 mm	1, 4, 7, 10, 13, 16
3	9	166,0 mm	1, 3, 5, 7, 9, 11, 13, 15, 17
4	6	217,5 mm	2, 5, 8, 11, 14, 17
5	9	294,0 mm	2, 4, 6, 8, 10, 12, 14, 16, 18
6	6	345,5 mm	3, 6, 9, 12, 15, 18
7	9	422,0 mm	1, 3, 5, 7, 9, 11, 13, 15, 17
Total	54		

A.7 Temperature sensors

A minimum of three temperature sensors to control the three sections of the torso are needed (see T1 to T3 of Figure A.3). Temperature sensors will have to capable to measure temperature between 15 °C and 50 °C with an min. accuracy of 0,1 °C. These sensors are positioned in the aluminium parts of the guards and the measurement cylinder.

Two nickel wires (Tni1 and Tni2), or equivalent, are placed in meander lines (see Figure A2) on the surface of the measurement cylinder to assess the mean temperature of the front and back of the torso respectively.



Key

T1	temperature sensor upper guard
T2	temperature sensor measurement cylinder
T3	temperature sensors lower guard
Tni1/Tni2	nickel wire sensors measurement cylinder
To	6 optional additional sensors for THS (used to calculate heat flux)

Figure A.3 — Schematic of torso with temperature sensors

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Annex B
(informative)

Calibration

B.1 Temperature calibration

Temperature calibration has to be done on at least 4 points in the range of use of the torso (15 °C to 45 °C). The nude torso will have to be acclimatised to a calibration temperature point for at least 6 h before it will be enclosed in a highly insulating container or covered with several layers of insulating textile layer. A re-traceable reference temperature sensor has to be taped to surface of the torso (centre of measurement cylinder). During the acclimatisation all devices which could produce heat within the torso will have to be detached or turned off. This applies also for the reference temperature sensor. The assembly of torso, reference sensor and insulation will be left for at least another 6 h. After stabilisation of the temperature, data acquisition and reference sensor will be attached again and two series of readings will be performed.

Requirements:

— Accuracy of temperature sensors: 0.1 °C or better (Pt-100 or similar)

— Min. 4 points between 15 °C and 45 °C

Temperature calibration shall be repeated once per year.

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B.2 Sweat water

It has to be considered that light might induce growth of algae which might block water transport to the nozzles. The whole system will have to be rinsed with a disinfecting agent from time to time (see also support and maintenance section).

For an accurate calibration of the sweat rate at least 6 points between 0 l/h·m^2 to 1,5 l/h·m^2 have to be applied. Use calibrated reference devices traced to national standard to calibrate sweat water delivery of the system and ensure an accuracy of better than 5 %.

B.2.1 Calibration gravimetric system

The amount of sweat water delivered by the nozzles is defined by the opening time and the interval between opening and closing cycles. Additionally, it is influenced by the height difference between the, supply tank and the nozzle and the surface tension of the water or the water quality in general. It is therefore essential that sweat rate will be re-calibrated if one of the influencing parameters has changed. In addition to the material, diameter and length of the tubes will influence the calibration values.

Depending on the diameter of the tubes used to connect the valves to the nozzles and the diameter of the nozzle itself a minimal opening time is required in order to generate a droplet. An opening time of 200 ms has proved to be sufficient for the system described in 5.4.

The correlation between the interval between consecutive openings and the delivered amount of water has proved to be nonlinear. The resulting amount of water is approximately inverse to the interval between openings

For an accurate calibration of the sweat rate at least 6 points have to be used. It is recommended to distribute them logarithmically between 500 ms and 2 s interval. The duration of each step has to be selected such that the given off water equals to at least 10 times the accuracy of the used balance.

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This calibration shall be repeated once a year.

B.3 Heating power

Heating power may be assessed by an interface to the power supply (equipped with sense wires or another appropriate way to account for the wire resistance), using a shunt resistor or any other way to assess the heating power with an accuracy of at least 0,1 W.

At least 5 points between 1 W and 250 W for the guards and 500 W for the measurement section will have to be calibrated. The device used as a reference will have to be traced back to national standards.

Accuracy of heating power assessment shall be 0,1 W or better in the range between 1 W to 250 W or 500 W respectively.

This calibration shall be repeated once a year.

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Annex C
(informative)

Example of data evaluation

The following two clauses show examples of a single and a multi-layer specimen tested on the sweating torso. For the tests standard parameters have been applied:

— Environmental conditions: 20 °C and 50 % RH;

— Wind: 1m/s;

— Standard phase profile:

  — Phase 1: 60 min. constant temperature 35 °C, no sweating (acclimation);

  — Phase 2: 60 min. constant heating power of 125 W and a sweat rate of 100 g/h (simulated activity);

  — Phase 3: 60 min. constant heating power of 25 W and no sweating (rest phase);

— Standard evaluation:

  — $R_{\text{ct (torso)}}$, dry thermal insulation in phase 1;

  — Moisture management and cooling properties in phase 2;

  — Post cooling and drying behaviour in phase 3.

C.1 Single layer specimen(low thermal insulation)

Figure C.1 shows the typical temperature course (torso surface temperature) for a standard torso experiment of a single layer specimen with low thermal insulation. Due to the low thermal resistance good uptake and distribution of moisture and fast drying there is a distinct temperature drop in phase 2 and almost no post cooling in phase 3.

Due to the low thermal resistance and good moisture transport properties almost no cooling delay (CD) is detected in phase 2. There is also a clear difference between temperature drop at the beginning and the second part of phase 2. This results in distinct differences between initial cooling (IC) and sustained cooling (SC).

The variations of temperature courses compared to the average as shown in Figure C.1 show a good reproducibility of repeated measurements. Variations are highest during phase 2 where minor changes in moisture transfer and evaporation rate may occur.

Once moisture accumulated during phase 2 is completely evaporated torso surface temperature rises since there is no more cooling by evaporation (see phase 3 of Figure C.1). As the applied heating power in phase 3 is not enough to maintain temperature constant it decreases after the specimen is dry.

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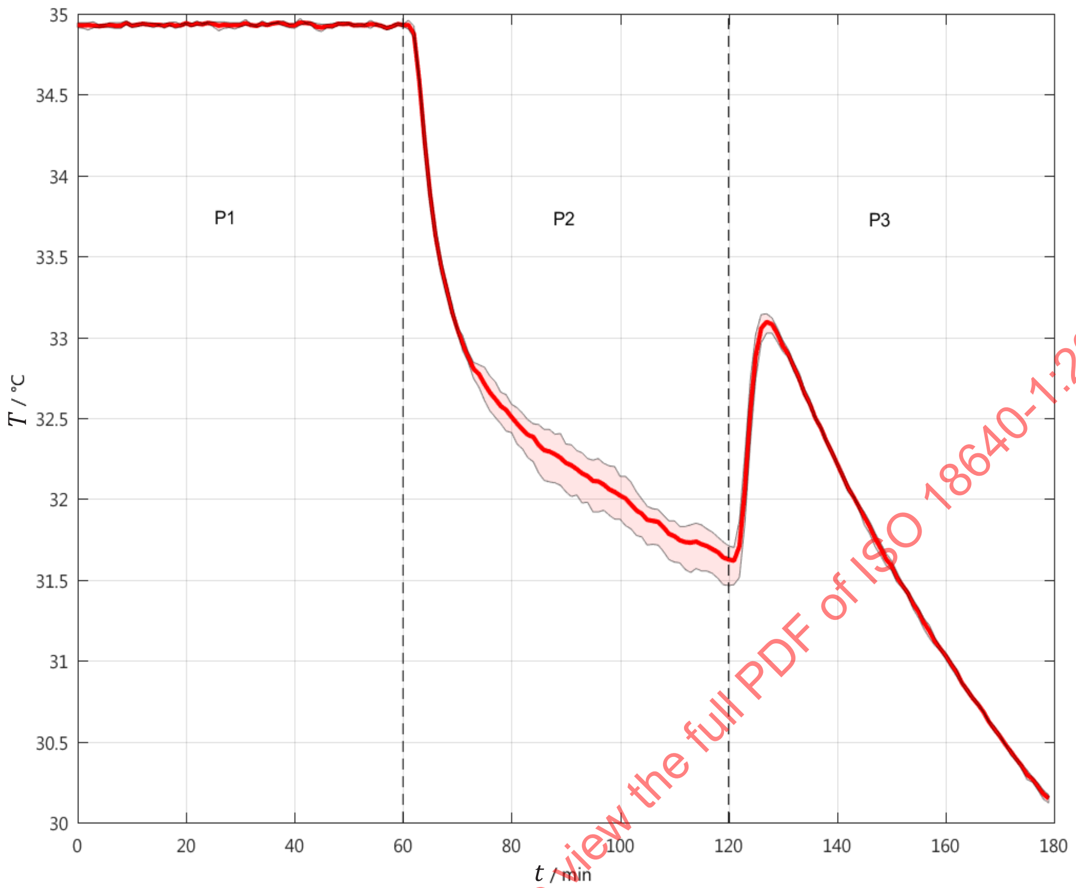

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Key

t time

T temperature

P*n* phase 1 to 3 of the measurement

Figure C.1 — Temperature course single layer (torso surface temperature): 3 experiments and mean value

The calculated results described in 8.2.5 are displayed in Table C1.

Table C.1 — Results single layer evaluation

Calculated value	unit	value	Phase
$R_{ct\ (torso)}$	[K·m²/kW]	18,6	1
CD cooling delay	[min]	1,0	
IC initial cooling	[°C/h]	12,9	2
SC sustained cooling	[°C/h]	1,3	
PC post cooling	[min]	2,0	3

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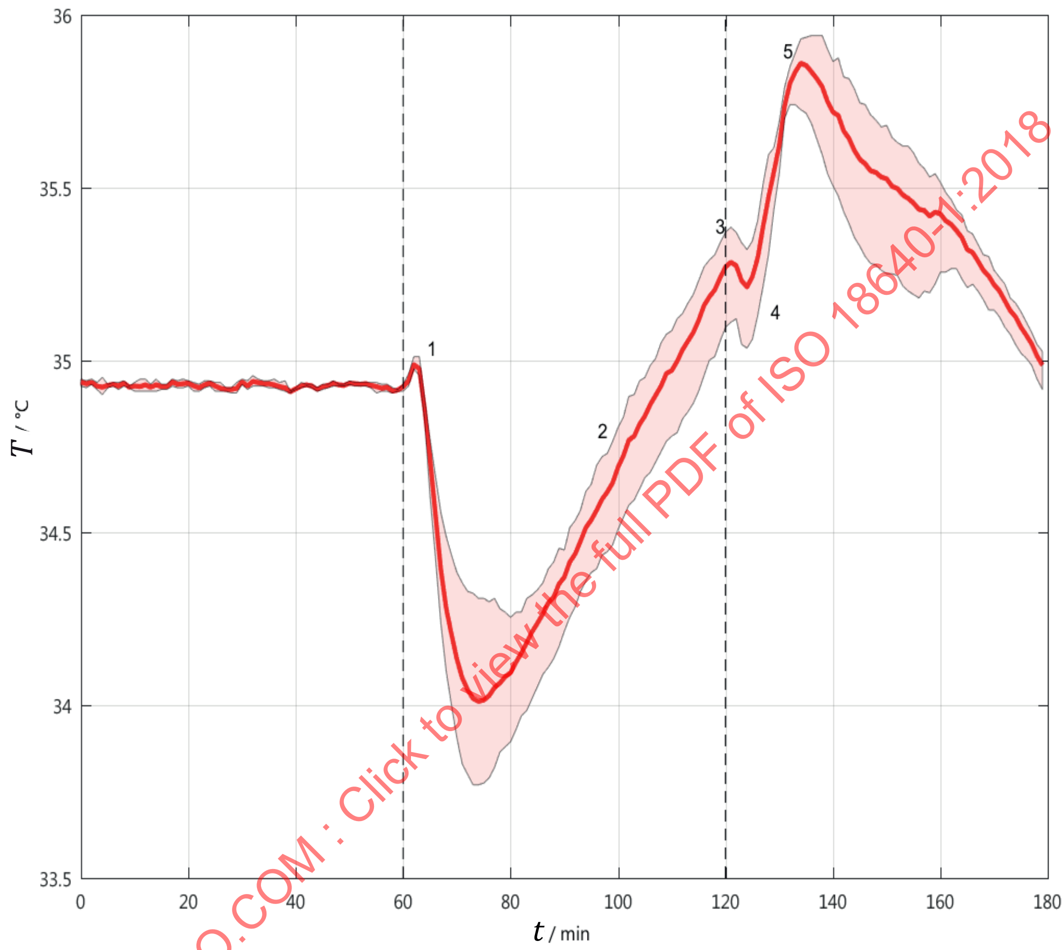
C.2 Multi-layer specimen (high thermal insulation)

Multi-layer combinations have a higher thermal insulation and usually also a higher water vapour resistance than single layer specimen. The typical temperature course for a multi-layer combination is shown in Figure C.2.



Key

t time

T temperature

P*n* phase 1 to 3 of the measurement

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Figure C.2 — Temperature course multi-layer (torso surface temperature): 3 experiments and mean value

In comparison to the single layer test displayed in Figure C.1 a more pronounced initial cooling delay can be observed which is due to the higher thermal insulation and also dependent on whether the material is hygroscopic and moisture transport properties (see 1 in Figure C.2). The biggest difference is the increase in temperature in the second part of phase 2. Initial cooling relates to evaporation close to the torso surface based on water vapour pressure difference. After an initial part of cooling the surface temperature of the sweating torso begins to rise again (see 2 in Figure C.2). This leads to a negative sustained cooling rate (heating or temperature increase) as can also be seen in Table C.2. In phase 3 heating power is reduced and sweating is stopped (simulation of resting after physical activity) which leads to a drop in temperature (see 3 in Figure C.2) due to reduced heating and continuing cooling

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