INTERNATIONAL STANDARD

ISO 18640-2

First edition
2018-05

Protective clothing for firefighters — Physiological impact —

Part 2: Determination of physiological heat load caused by protective clothing worn by firefighters

Vêtements de protection pour sapeurs-pompiers — Impact physiologique —

Partie 2: Détermination de la déperdition de chaleur provoquée par les vêtements de protection portés par les sapeurs-pompiers

Reference number
ISO 18640-2:2018(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 — Protective clothing and equipment*, Subcommittee SC 14, *Firefighters' personal equipment*.

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

Introduction

Protective clothing for (structural) firefighting may have a serious physiological impact[1),2)]on the wearer and a serious effect on the acute physical condition of the wearer during activities with increased metabolic heat production[3][4]. Protective clothing impedes heat exchange by sweat evaporation and therefore maintenance of a constant core body temperature and thermal homeostasis is disturbed. This could increase the risk of heat strain and subsequently impact on the length and time that the firefighter is able to work safely. If this is identified in a risk assessment, it is important that (thermal) physiological parameters are obtained to ensure the suitability of the protective clothing chosen under the expected conditions of use. The assessment of the physiological impact of the protective clothing provides important information about the effect on individuals undertaking different tasks in various environmental conditions. In ISO 18640-1, relevant physical parameters of protective clothing are measured with a Sweating torso. Standard Sweating torso measurements provide physical parameters about combined and complex heat and moisture transfer (ISO 18640-1). By coupling the sweating torso to a mathematical model for thermo-physiological responses, the thermo-physiological impact of protective clothing is estimated and the maximum exposure time for defined environmental conditions and a defined activity protocol are predicted by Thermal Human Simulator (THS) measurements.

The purpose of this document is to consider aspects of protective clothing performance that cannot be determined by tests described in other standards. The aim of this document is to quantify the thermo-physiological impact of protective garments for (structural) firefighting under relevant exposures. This document provides the background for the specification of a minimum level of performance requirements during defined firefighting scenarios for the assessed firefighters' protective clothing by calculation of the maximum allowable work duration in order to avoid heat stroke.

NOTE The method allows to characterizing the thermo-physiological impact for different levels of complexity. This includes the characterisation of the single PPE ensembles (standard procedure) as well as the characterisation of protective clothing ensembles including under wear and protective clothing, including air layers or including design features of protective clothing ensembles (e.g. pockets, reflective strips) as optional procedures[3)].

1) Nunneley (1989) reported a significant physiological burden due to the protective clothing upon the wearer, both in the form of increased metabolic rate and reduced heat dissipation.

2) Taylor (2012) showed that the relative influence of the clothing on oxygen cost was at least three times that of the breathing apparatus.

3) This listing of standard and optional procedures is a first proposal for prioritization. The expressiveness of the different levels of complexity for the characterisation of the thermo-physiological impact needs to be further investigated. Results will be presented at the next ballot.

Protective clothing for firefighters — Physiological impact —

Part 2: Determination of physiological heat load caused by protective clothing worn by firefighters

1 Scope

This document specifies a method for evaluating the thermo-physiological impact of protective fabric ensembles and potentially protective clothing ensembles in a simulated activity under defined relevant conditions for firefighters.

This document is intended to be used to assess the thermo-physiological impact of protective fabric ensembles and potentially protective clothing ensembles but not the risk for heat stress due to actual fire conditions. The results of this test method can be used as elements of characterisation and comparison of thermo-physiological impact of various types of protective fabric ensembles and potentially protective clothing ensembles.

Default measurements are undertaken 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 protective clothing ensembles including underwear, air layers and certain design features[4]. In addition measurements on readymade garments are optionally possible.

NOTE The presently used evaluation methods are only validated for structural firefighting garments.

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

ISO 18640-1, *Protective clothing for firefighters-physiological impact — Part 1: Measurement of coupled heat and mass transfer with the sweating torso*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18640-1 and the following 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 http://www.electropedia.org/

4) A study conducted at Empa (Swiss Federal Laboratories for Materials Science and Technology, Switzerland) showed good correlation between results of standard torso tests (without both 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 different thermal insulation of the systems direct comparison of the results is not possible.

3.1
core body temperature
T_{co}
temperature of deep body tissues of the human body

3.2
firefighting scenario
set of environmental conditions, a defined workload and a defined exposure time relevant for a firefighters' task

3.3
heart rate
number of heartbeats per unit of time

Note 1 to entry: The heart rate is usually expressed in per minute.

3.4
heat storage
heat accumulation in the body affected by metabolic heat produced, external heat load and heat dissipated from the body

3.5
maximum allowable work duration
MAWD
value calculated from thermo-physiological simulation (THS measurement) predicting the time to reach heat stress based on the definitions of this document

Note 1 to entry: See also Annex A.

Note 2 to entry: This value is given in minutes.

3.6
mean skin temperature
$T_{m,sk}$
mean temperature of the outer surface of the (human) body measured at several locations of the skin

3.7
skin diffusion
E_{sk}
evaporative heat loss due to insensible skin perspiration and has to be provided for THS measurements

3.8
sweating torso
upright standing cylindrical test apparatus, simulating the human trunk with thermal guards on the upper and lower end as defined in ISO 18640-1

3.9
sweat rate
amount of moisture perspired per time on the surface of the torso

Note 1 to entry: The term sweat rate is also used as the physiological response of the human body to elevated metabolic rate and/or activity wearing protective clothing with high thermal insulation.

3.10
thermal human simulator measurement
THS
measurement with the sweating torso according to ISO 18640-1 where the device is coupled with a validated physiological model

Note 1 to entry: Test cases and requirements for the validation of the physiological model are provided in A.3.

3.11
torso surface temperature
average temperature on the surface of the measurement area (0,43 m^2) of the torso device

4 Symbols and abbreviations

For the purposes of this document the following symbols and abbreviated terms apply, in addition to the terms and definitions in ISO 18640-1.

C_{sk}	Wicking layer correction
E_{sk}	Skin diffusion
MAWD	Maximum allowable work duration (in minutes)
$T_{m,sk}$	Mean skin temperature in °C
T_{co}	Core body temperature in °C

5 Evaluation method

5.1 General

Physical parameters based on thermal properties of protective clothing resulting from standard torso measurements do not contain direct information about the thermo-physiological impact on the wearer for various firefighters' scenarios. Physiological data are deducted by doing measurements coupling sweating torso system to a physiological model as described in this document.

The results of these measurements are used to predict the maximum allowable work duration (MAWD) according to thermal characteristics and moisture management properties of the tested protective clothing system. This procedure was validated based on human subject trials (see Annex A).

5.2 Firefighting scenarios

Firefighters deal with a variety of tasks and challenges. Therefore, many scenarios have to be considered. In order to ensure a maximum level of comparability a moderate scenario has been defined which is applicable to a wide range of protective clothing inclusive of firefighting. The background and reasoning and the relevance for this standard are described in Annex C.

5.2.1 Standard scenario for THS measurements

For the purpose of this standard a scenario was selected which reflects a moderate firefighter activity without fighting fire (see also Annex C).

The applied scenario is defined as follows:

— Ambient condition is set to 40 °C air temperature and 30 % RH;

— No radiation is present;

— Unidirectional wind speed of 1 m/s is applied;

— Physical activity is set to 6 Met[5)] (350 W/m^2 metabolic rate, which equals 285 W/m^2 metabolic heat production);

— Initial condition of the human body is assumed to be thermo-neutral (T_{co} = 36,8 °C; $T_{m,sk}$ = 34,2 °C);

5) MET: Metabolic Equivalent of Task (1 MET = 1 kcal/(kg·h) = 4,184 kJ/(kg·h) alternatively 1 MET = 58,2 W/m^2).

— Exposure time is set to 90 min;

— The onset of heat stress is defined at the core body temperature of 38,5 °C.

NOTE This scenario was selected in order to be compatible with an ethically acceptable work load for human subject trials used to validate the physiological impact of firefighter clothing (See Annex C).

5.3 THS measurement

5.3.1 General

Thermal Human Simulator (THS) measurements are based on coupling the sweating torso system, in accordance with ISO 18640-1, with validated physiological model in accordance with Annex A, in a climatic chamber simulating a defined activity according to the firefighters' scenario. In order to have a common starting point for the measurements initial conditions for THS measurements are set such that the torso mimics thermal neutral state.

5.3.2 Apparatus and software

THS is controlled with the same hardware and software as for standard torso experiments in accordance with ISO 18640-1, with the addition and cooperation of a physiological model (coupling with continuous data exchange).

5.3.3 Heat flux

For THS measurements heat flux data off the surface shall be measured, as they are is needed as input for the physiological model. Accuracy for heat flux measurement shall be better than 5 W/m^2 in the range of 0 W/m^2 up to 500 W/m^2. Measurement can be done by the procedure described in 5.3.3.1 or equivalent methods matching the requirements of this clause.

5.3.3.1 Heat flux measurement with additional temperature sensors

In this configuration the torso needs to be equipped with additional temperature sensors in the aluminium interior part of the device (see Figure 1) to allow more accurate assessment of heat flux from the surface. These temperature sensors are used to calculate the average surface heat flux based on the thermal resistance of the outer layers of the torso according to Formula (1) below:

$$q_{\text{torso}} = \left(T_{\text{NF}} - T_{\text{Ni}}\right) \cdot \frac{1}{R_{\text{torso}}} \qquad (1)$$

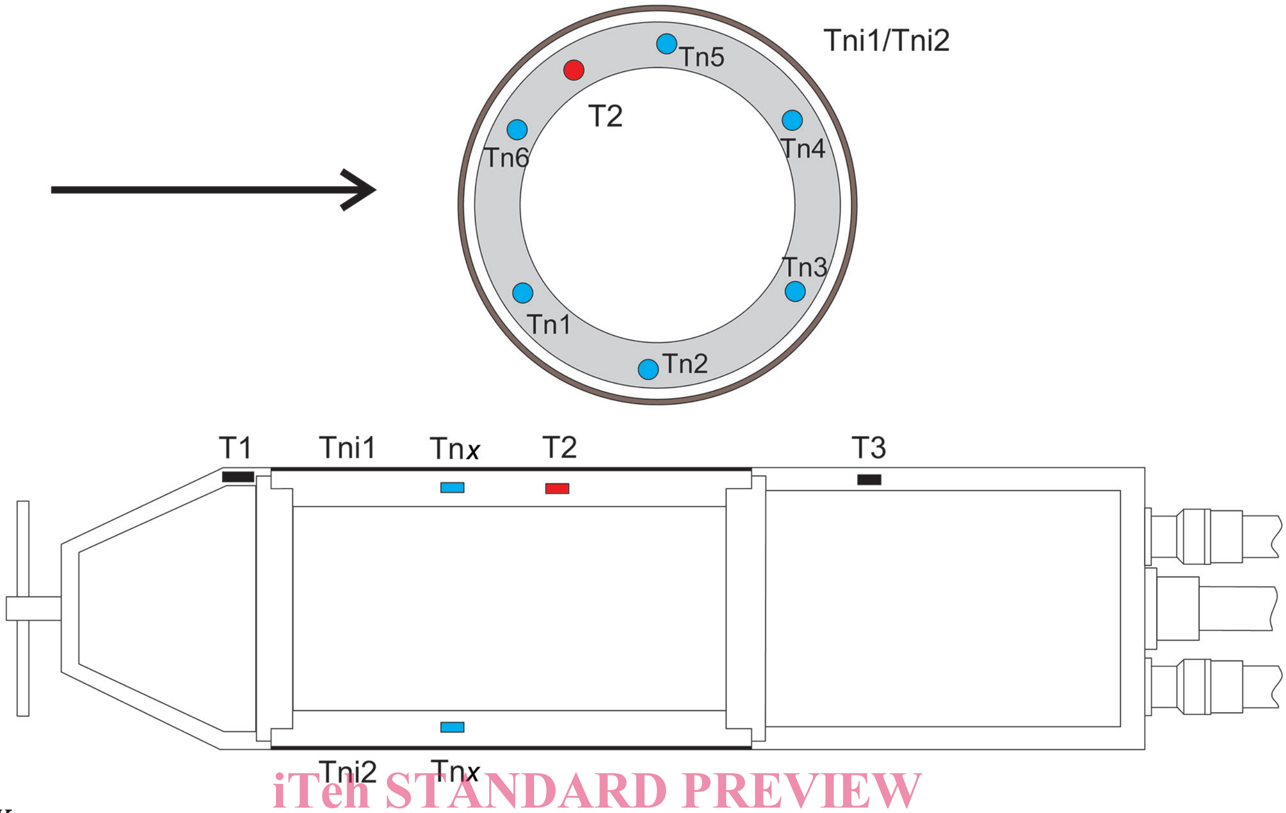
where

T_{NF} is the average temperature of additional sensors in °C;

T_{Ni} is the average temperature of nickel wire sensors (surface temperature) in °C;

R_{torso} thermal resistance of the aluminium/HDPE layers between additional sensors and nickel wires in m^2·K/W;

q_{torso} average surface heat flux of the cylinder in W/m^2.



Key

Tni1 nickel wire sensor 1

Tni2 nickel wire sensor 2

T1 temperature sensor in upper guard

T2 temperature sensor in measurement section

T3 temperature in lower guard

Tn*x* optional additional sensors for THS measurements

Figure 1 — Configuration of temperature sensors for heat flux assessment

5.3.4 Wicking layer correction

A wicking layer according to ISO 18640-1:2018, 5.1.6, is used for all THS measurements.

A correction value (wicking layer correction) is used to compensate for the increase in thermal resistance by using the wicking layer on the torso main cylinder. The correction is calculated as a ratio between thermal resistances of the torso with the wicking layer to the thermal resistance of the nude torso (see Formula 2). Thermal resistances are calculated for torso surface temperature at 35 °C, air velocity <0,25 m/s at 20 °C ambient temperature with no radiation and exposure time of at least 60 min.

$$C_{\text{sk}} = \frac{R_{\text{ct,sk layer}}}{R_{\text{ct,nude}}} \qquad (2)$$

The wicking layer correction has to be provided to the physiological model.

