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Introduction

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Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

DRAFT INTERNATIONAL STANDARD

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Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles —

Part 4:

Determination of the equivalent temperature by means of a numerical manikin

ICS: 13.180; 43.020

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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.

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ISO 14505-4 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

ISO 14505 consists of the following parts, under the general title “Ergonomics of the thermal environment —Evaluation of thermal environments in vehicles”:

- Part 1: Principles and methods for assessment of thermal stress
- Part 2: Determination of equivalent temperature
- Part 3: Evaluation of thermal comfort using human subjects
- Part 4: Determination of the equivalent temperature by means of a numerical manikin

Introduction

The interaction of convective, radiant and conductive heat exchange in a vehicle compartment or similar confined space is highly complex. External thermal loads in combination with the air conditioning system in a vehicle compartment will create non-uniform thermal environments, which are often the main cause of complaints of thermal discomfort. In vehicles with poor or non-existent air conditioning systems, non-uniform thermal environments can also be created by the interaction between the ambient climatic conditions and vehicle structures. While a subjective evaluation reflects the total sensations of a human body, these often incur great costs while the study phase is being conducted. Physical measurements provide detailed and accurate local information; however, these results must be integrated in some way to predict the thermal effects on humans. Furthermore, since specific climatic factors sometimes play a dominant role in the overall heat exchange of a human body, an evaluation method that accounts for the relative importance of these factors is required.

The present standard is part 4 of the ISO 14505 standards series. To meet the above stated requirements, the following section provides calculation methods that utilize numerical simulations to assess the total thermal environment of vehicles. The equivalent temperature, obtained from measurements taken using a thermal manikin, was defined in part 2. Part 4 extends the definition of this standard to include numerical evaluation when this section is used in conjunction with the equivalent temperature previously defined in part 2.

As described in part 2, an equivalent temperature can be utilized in the assessment of vehicle cabins and other various enclosed spaces with non-uniform environments. As was the case for part 2, part 4 can also be applied to vehicle cabins and other enclosed spaces.

Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles —

Part 4:

Determination of the equivalent temperature by means of a numerical manikin

1 Scope

A human-shaped thermal manikin was designed to conduct assessments of the thermal environment from an ergonomic viewpoint. ISO 14505 part 2 defines the index of the environment, also referred to as the equivalent temperature, measured by such a manikin. Part 4 provides guidelines for extending this definition to predictive purposes and specifies a standard prediction method for the assessment of thermal comfort in vehicles using numerical calculations. Specifically, the following section sets forth a simulated numerical manikin as a viable alternative to the thermal manikin for the purpose of calculating the equivalent temperature.

This portion of ISO 14505 was written with the supposition this standard will be applied to various situations such as the following:

- in the case of experimental facilities that are not prepared,
- in the case of prototypes that are incomplete,
- in the case of conditions that are difficult to simulate in controlled experimental settings,
- in the case that occupants are extrapolated to unknown or virtual environments.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document (including any amendments) is applicable.

ISO 7243, *Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index*

ISO 7730, *Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*

ISO 7933, *Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using calculation of the predicted heat strain*

ISO 11079, *Ergonomics of the thermal environment — Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects*

ISO/TS 14505-1, *Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles — Part 1: Principles and methods for assessment of thermal stress*

ISO 14505-2, *Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles — Part 2: Determination of equivalent temperature*

ISO 14505-3, *Ergonomics of the thermal environment — Evaluation of thermal environments in vehicles — Part 3: Evaluation of thermal comfort using human subjects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13731, ISO 14505-2 and the following apply.

3.1

numerical manikin

a virtual thermal manikin recreating a thermal manikin, or a digital model of a thermal manikin used to calculate performance

3.2

physical manikin

a physical thermal manikin, defined to clearly distinguish such manikins from numerical manikins

3.3

CFD

simulation of a series of calculations based on specific boundary conditions and specific parameters associated with fluid and thermal fields using discrete equations based on the Navier-Stokes/Lattice-Boltzmann equations as well as heat transfer equations that consider convection, radiation, and conduction, and generally account for the effects of turbulent flow

4 Symbols

A complete list of symbols used in this standard is presented in [Table 1](#).

Table 1 — Symbols and Units

Symbol	Term	Unit
α	Solar absorptivity on clothing (skin on unclothed area) surface	-
A	Skin surface area	m ²
C	Convective heat loss from clothing (skin on unclothed area) surface	W/m ² °C
f_{cl}	Area factor (ratio of clothed to nude area)	-
h_c	Convective heat transfer coefficient	W/m ² °C
h_{cal}	Total heat transfer coefficient in a standard environment	W/m ² °C
h_{cs}	Convective heat transfer coefficient in a standard environment	W/m ² °C
h_r	Radiant heat transfer coefficient	W/m ² °C
h_{rs}	Radiant heat transfer coefficient in a standard environment	W/m ² °C
I_{cl}	Thermal insulation of clothing	m ² °C/W
Q	Total heat loss from skin surface	W/m ²
Q_{set}	Set value of Q at constant heat flux mode	W/m ²
R	Radiant heat loss from clothing (skin on unclothed area) surface, including effect of solar radiation	W/m ²
R_{cr}	Imaginary thermal resistance between the imaginary core temperature (t_{cr}) and skin surface	m ² °C/W
S	Mean solar radiation reached on clothing (skin on unclothed area) surface	W/m ²
t_a	Air temperature	°C
t_{aset}	Air temperature at h_{cal} calculation	°C
t_{cl}	Clothing (skin on unclothed area) surface temperature	°C
t_{cr}	Imaginary core temperature	°C
t_{eq}	Equivalent temperature	°C

Table 1 (continued)

Symbol	Term	Unit
t_r	Mean radiant temperature	°C
t_{sk}	Skin temperature	°C
t_{skset}	Set value of t_{sk} at constant temperature mode	°C
v_a	Air velocity	m/s
n	Suffix: Segment number of each body part	-
$whole$	Suffix: whole body	-

5 Assessment of thermal environments in vehicles

The method of assessment by equivalent temperature is defined in ISO 14505 part 2. The assessment procedures in part 2 are applicable to numerical evaluations, for which "numerical manikin" is defined above in this section. Figure 1 shows the role of this part and its relations with parts 1 through 3 of the ISO 14505 standard as well as different international standards.

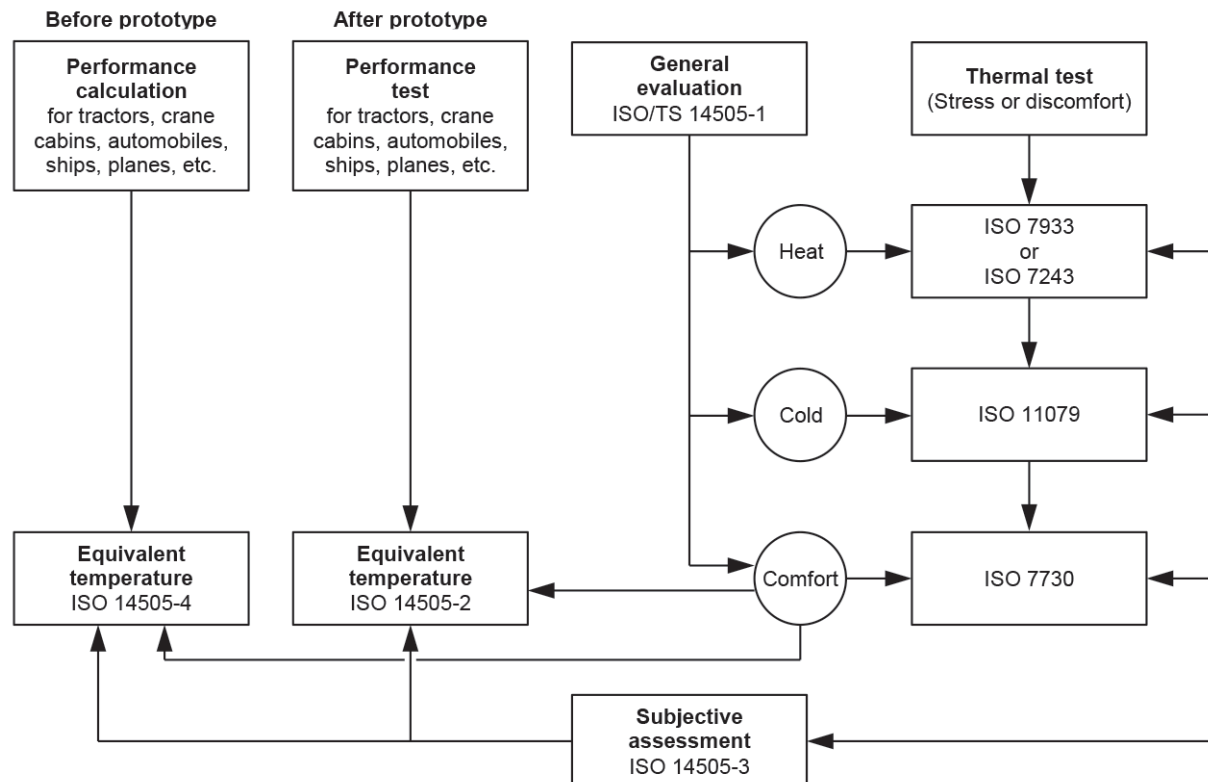


Figure 1 — Role of numerical evaluation among different international standards

6 Principles of assessment utilizing a numerical manikin

ISO 14505 part 4 presents two methods for calculating the equivalent temperature. One is a calculation method coupled with a numerical manikin, as described in chapter 7. The other is a calculation method using thermal factors, as described in chapter 8. Either method can be used to evaluate the thermal environment in vehicles.

The former calculation method coupled with a numerical manikin is intended to use with a simulation tool, such as CFD. A numerical manikin imitates a physical manikin to calculate the equivalent

temperature. The method of calculation using thermal factors estimates the equivalent temperature by assuming the existence of the imaginary numerical manikin. In this method, the equivalent temperature is calculated using the thermal factors, air temperature, radiant temperature, air velocity, and solar radiation. [Figure 2](#) shows a schematic of the two methods.

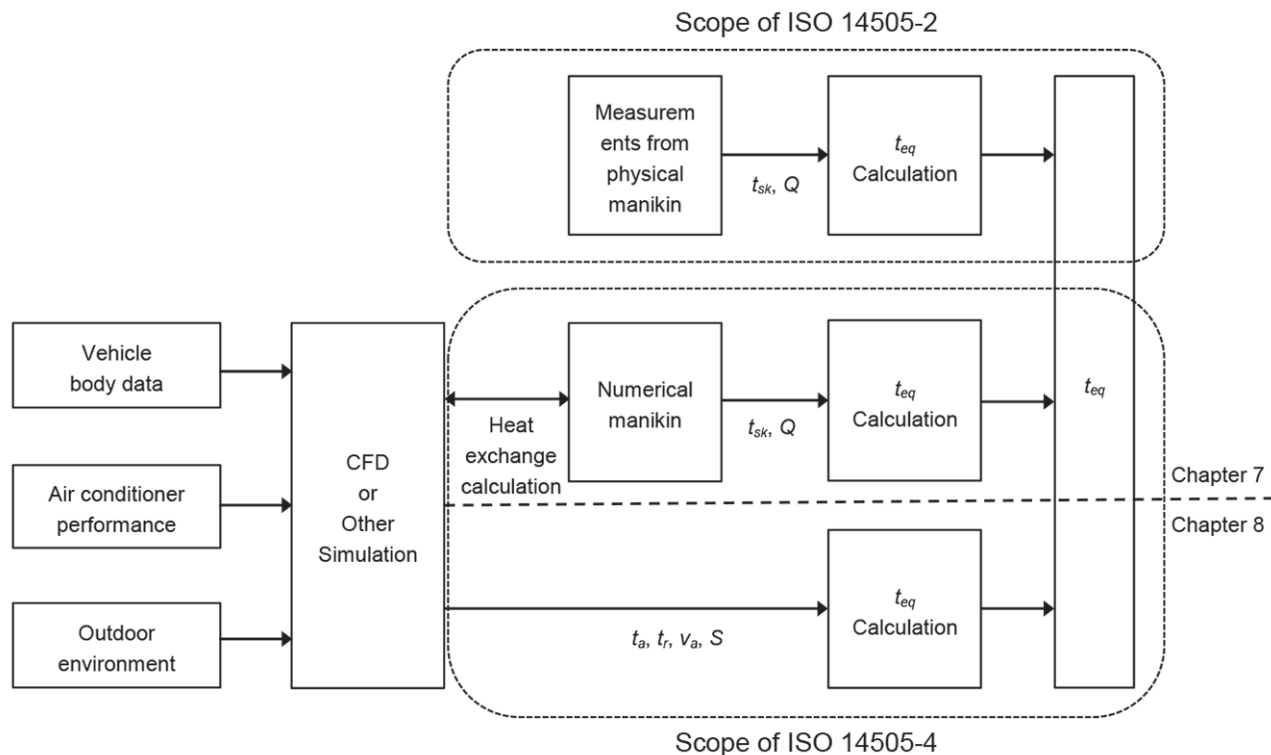


Figure 2 — Two methods for calculating equivalent temperature

7 Calculation method coupled with numerical manikin

This section describes the framework of the calculation. To evaluate the indoor environment of a vehicle numerically, the following issues should be considered and taken account ([Figure 3](#)),

- i) Heat flow through the shell structure of the vehicle,
- ii) Flow and thermal field in the cabin,
- iii) Radiant field (including solar radiation) in the cabin,
- iv) Conductive heat exchange,
- v) Heat balance of the thermal manikin model (numerical manikin).

Part 4 is intended to be applied to the region around the manikin, relating to items ii) and v). The heat flow through the structure of the vehicle body is defined as suitable. This section defines indispensable ideas concerning the above items, which will enable successful and useful calculations in these situations. However, this part does not define any specific methods for utilization because all methods present both advantages and disadvantages for particular problems.

Once the environmental state concerning thermal comfort in the cabin is calculated, evaluation becomes possible. The above stated items i) through iv) give the principal local parameters of air velocity, temperature, and radiation, though some simultaneous calculation coupling with the heat balance calculation is required. This calculation will produce a heat transfer values close to that measured using the physical manikin. Therefore, the evaluation method described in ISO 14505 part 2 is applicable.

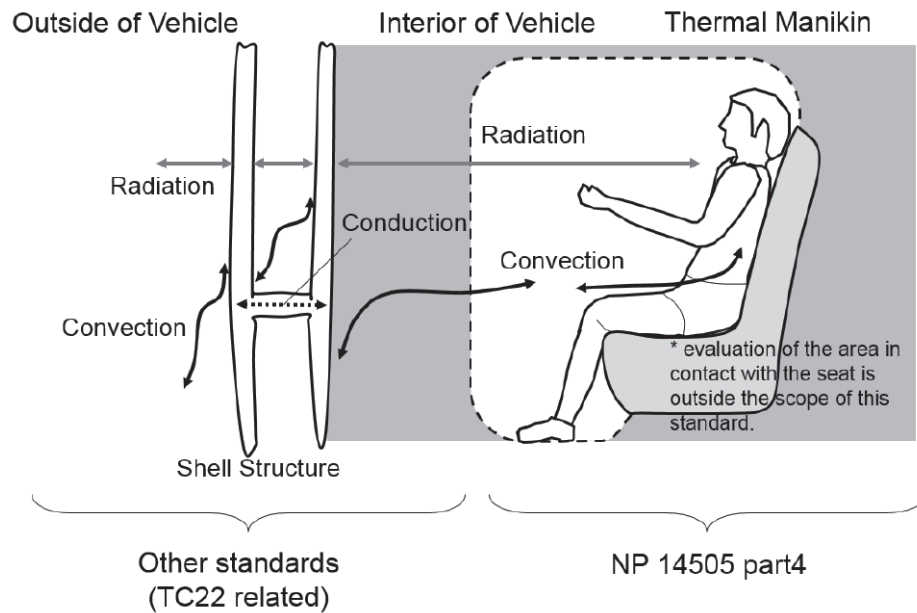


Figure 3 — Framework of heat transfer system

7.1 Flow and thermal field around manikin

7.1.1 Convective heat

The flow and thermal field in the cabin are estimated via calculations. One practical option for this is CFD. The informative concrete contents of this method are represented in [Annex A](#). The outputs are the air velocity vector and air temperature in a cabin. The heat flux on the wall and surface are also obtained through this calculation.

The primary problem in CFD calculations is the treatment of boundary conditions. This can be overcome in practice by selecting any of the following :

- 1) Calculate the heat transfer on the surface of the manikin using CFD directly,
- 2) As a preliminary, calculate the heat transfer coefficient on the surface of the manikin using CFD. Then calculate the flow and thermal field coupling using the heat balance calculation of the manikin,
- 3) Utilize the heat transfer coefficient obtained by measurement. Then calculate the flow and thermal field coupling with the heat balance calculation of the manikin, as described above,
- 4) Estimate the heat transfer coefficient using a predictive equation based on the air velocity or temperature. Then, calculate the flow and thermal field coupling using the heat balance calculation for the manikin, as described above.

7.1.2 Radiant heat

The radiant field is calculated based on the geometric condition in a cabin separated from the flow field calculation. Regarding long wave radiation, as a preliminary, one should calculate the view factor relating to all potential combinations between different surface elements of the wall and the manikin or human body. Once those factors have been obtained, the radiant heat exchange is calculated when the temperature of a pair of surface element is given. As stated previously, the radiant heat is involved in the boundary conditions of the heat transfer equation, so that the temperature is calculated iteratively until convergence. For convenience, those factors are converted to the mean radiant heat transfer coefficient.

Short wave radiation (solar radiation) can be treated as energy flux striking the surface. Here, the transmission loss through the window glass should be taken into consideration. Solar radiation can be regarded as divided into the following components:

- 1) Direct solar radiation,
- 2) Sky solar radiation,
- 3) Reflection on the ground.

The solar radiant heat is also involved in the boundary conditions of the heat transfer equation. In the case of a climate wind tunnel test performed without use of a solar lamp, it is supposed that the effects of solar radiation are neglected. Concrete informative treatments are represented in [Annex C](#).

7.1.3 Conductive heat

Evaluation of the contacted segment is outside the scope of this standard. In addition, the conductive heat transfer between the manikin and seat is disregarded in the calculations and the contact surface area between the manikin and seat is assumed to be an adiabatic boundary.

7.2 Calculation of heat exchange on manikin

7.2.1 Structure and control of numerical manikin

[Figure 4](#) shows the theoretical structure of the numerical manikin with regard to a human shaped one. The center of each segment is assumed to consist of an adiabatic core. A heat generator is equipped on the surface of the manikin.

The shape of the manikin is defined by calculation grids for CFD, as shown in [Figure 5 a](#)). The partition is performed to imitate an actual manikin, as in [Figure 5 b](#)). Boundary conditions are given for each segment.

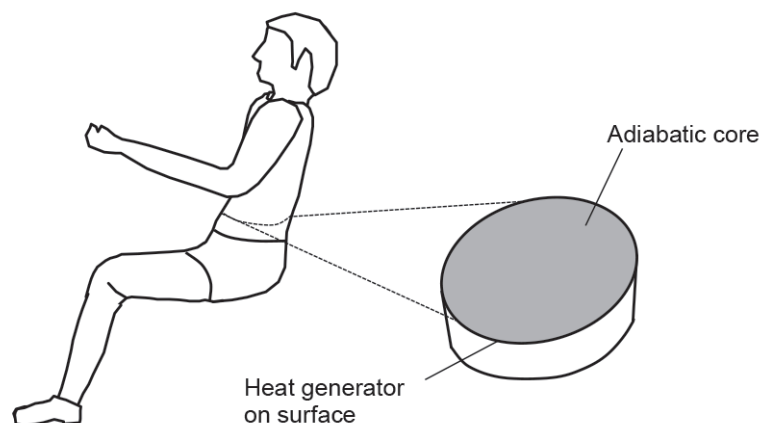
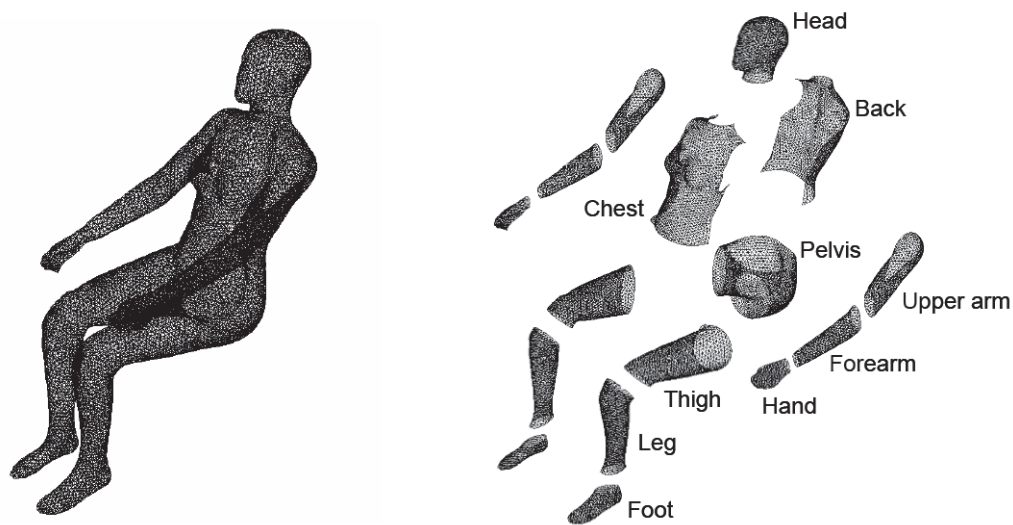


Figure 4 — Theoretical structure of numerical manikin



a) Full body model of manikin

b) Partition of surface grids (16 segment case shown)

Figure 5 — Surface grids for numerical calculation

The control model is intended to imitate a physical manikin and includes the following three operating modes:

- 1) Controlled surface temperature (constant temperature mode): Generally, the surface temperature of all segments is maintained at 34 °C^[1].
- 2) Controlled heat generation (constant heat flux mode): This method uses a metabolic rate to represent the heat flux for all segments. An example of the metabolic rate during vehicle driving is shown in ISO14505-1^[2] and ISO 8996^[3]. Note that this method is less commonly used than the other two.
- 3) Described by comfort equation (comfort equation mode): Generally, the parameter values for all segments in this mode are $t_{cr} = 36.4$ °C and $R_{cr} = 0.054$ m²°C/W^[4].

7.2.2 Calculation of heat exchange

The primary problem for the heat transfer calculation is determining the appropriate treatment of the boundary condition on the surface of the manikin. Once this has been designated, the following treatments may be considered:

- 1) Flow field, radiant field, and heat transfer on the surface of the manikin are solved simultaneously. The temperature distribution is calculated directly by solving for entrainment of heat in the boundary layer; however, the convective heat transfer coefficient is not explicitly calculated. In this case, the grid size near the surface should be small enough to resolve the heat transfer (the boundary layer). Otherwise, a well-tuned wall function developed to calculate the heat transfer near the solid boundary should be adopted.
- 2) The convective and mean radiant heat transfer coefficients are treated as known values. In this case, the grid structure near the surface can be determined only to calculate the flow field, resulting in coarser grids as compared to the prior treatment (1).

Regardless of the calculation method used, flow field calculations should account for buoyancy effects when the air velocity is small (i.e. less than 0.1 m/s). As such, the air motion should be calculated via coupling with the heat transfer equation.

7.3 Calculation of h_{cal}

Three methods of calculating and defining the value of h_{cal} are considered, as listed below:

- 1) Apply the CFD calculation to standard conditions to obtain the "calibrated" characteristics of h_{cal} . Informative concrete treatments for this are presented in [Annex E](#),
- 2) Adopt measured data gleaned using a physical manikin corresponding to the "numerical manikin". Practical measurement methods for this item are detailed in part 2 of ISO 14505,
- 3) Estimate it using [equation \(10\)](#) stated below in [section 8.3](#).

7.4 Calculation outputs

The input and output data to/from numerical manikin is shown in Table 2. The informative concrete treatments used to calculate the equivalent temperature are presented in [Annex B](#).

Table 2 — Input and output to/from numerical manikin

Control principle	Inputs	Outputs
Constant temperature mode ($T_{sk,n}=T_{skset}$)	$T_{skset}, I_{cl,n}$	$Q_{,n}$
Constant heat flux mode ($Q_{,n}=Q_{set}$)	$Q_{set}, I_{cl,n}$	$T_{sk,n}$
Comfort control mode ($Q_{,n}=(T_{cr}-T_{sk,n})/R_{cr}$)	$T_{cr}, R_{cr}, I_{cl,n}$	$T_{sk,n}, Q_{,n}$

The equivalent temperature in each body segment is calculated using the following equation, as defined in part 2 of ISO 14505.

$$t_{eq,n} = t_{sk,n} - \frac{Q_{,n}}{h_{cal,n}} \quad (1)$$

The whole body equivalent temperature is calculated using the following equations, as defined in part 2 of ISO 14505.

$$t_{eq,whole} = t_{sk,whole} - \frac{Q_{,whole}}{h_{cal,whole}} \quad (2)$$

$$t_{sk,whole} = \frac{\sum_{n \in n(whole)} (t_{sk,n} \cdot A_{,n})}{\sum_{n \in n(whole)} A_{,n}} \quad (3)$$

$$Q_{,whole} = \frac{\sum_{n \in n(whole)} (Q_{,n} \cdot A_{,n})}{\sum_{n \in n(whole)} A_{,n}} \quad (4)$$

The calculated values differ depending on the control mode even if the environmental conditions are the same (see annex [D.2](#)). As described in ISO 14505-2[1], it is recommended that either constant temperature mode (at 34 °C) or comfort equation mode (with $t_{cr} = 36.4$ °C and $R_{cr} = 0.054$ m²°C/W) be used. The calculated t_{eq} should be presented together with the control mode and its parameter(s).

8 Calculation method using thermal factors

It is also possible to calculate the equivalent temperature without the coupling calculation by assuming the existence of an imaginary numerical manikin. In this method, the equivalent temperature is calculated from the thermal factors, air temperature, radiant temperature, air velocity, and solar radiation. It should be noted that the effect of environmental heating by manikin is neglected in this one-way calculation.