I progetti R&D a supporto delle aziende del settore tessile-tecnico in Piemonte

R&D projects supporting the technical textiles industry in Piedmony

Ada Ferri

Department of Applied Science and Technology, Politecnico di Torino, Italy

Agenda

Politecnico di Torino

1859

- Research methodology for developing and testing advanced sportswear through in-vivo wear trials

- Case studies from the Comfort Lab @ POLITO

1.

Thermal balance equation

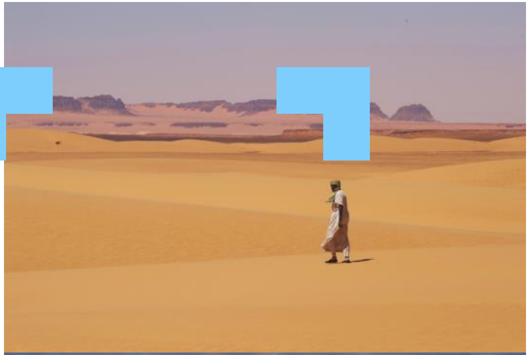
Garments as the interphase between the body and the environment

Heat gain & heat loss

Thanks to the ability to adapt to the external conditions, humans can live in very different thermal environments.

$$\boxed{M-W=Q_{res}+Q_{sk}+S}$$

$S>0$	heat gain greater than heat loss, body temperature rises
$S<0$	heat gain smaller than heat loss, body temperature decreases



Heat gain M-W: quantification

M metabolic rate (ISO 8996:2021)

- estimated from heart rate and physical features or measured via direct or indirect calorimetry
- unit Met (1 Met=60 W/m^2 or 3.5 ml O_2/min/kg)

W power output (ISO 8996:2021)

- easy to measure for some activities (cycling, running) but difficult for dynamic conditions

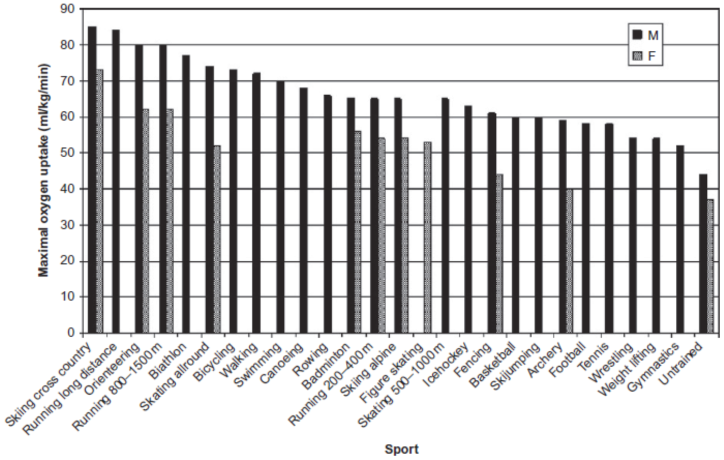


Figure 7.2 Average maximal oxygen uptake in milliliters per kg body mass per minute for male (black bars) and female (grey bars) Swedish national teams in different sports. Revised from Astrand et al. (2003).

Textiles for sport, Woodhead publishing, 2016

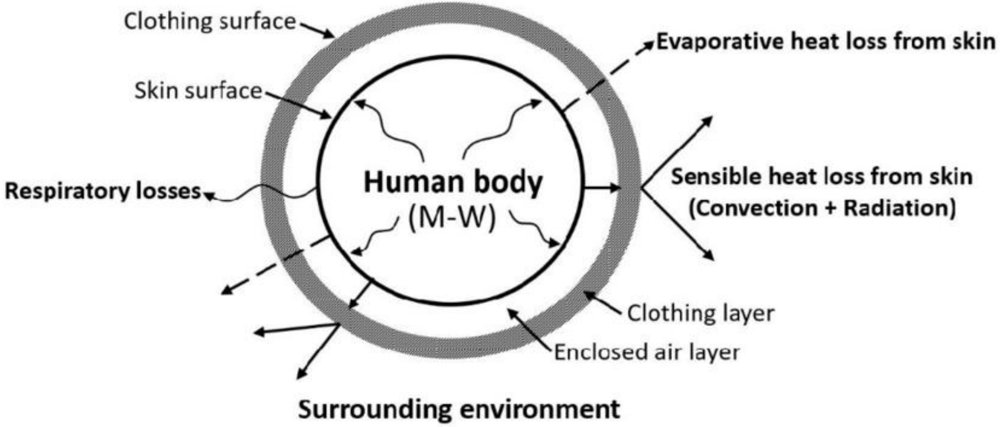
Heat loss: respiration and skin

- $Q_{res}=C_{res}+E_{res}$

  Heat loss through respiration is normally negligible, unless in very cold conditions

- $Q_{sk}= C_{sk}+R_{sk}+E_{sk}$

  The total heat loss from the skin surface (Q_{sk}) includes the heat loss by conduction (C_{sk}), the heat loss by radiation (R_{sk}) and the evaporative heat due to sweating and perspiratio insensibilis (E_{sk})



Lee et al., Assessment of a Real-Time Prediction Method for High Clothing Thermal Insulation Using a Thermoregulation Model and an Infrared Camera Atmosphere 2020, 11, 106

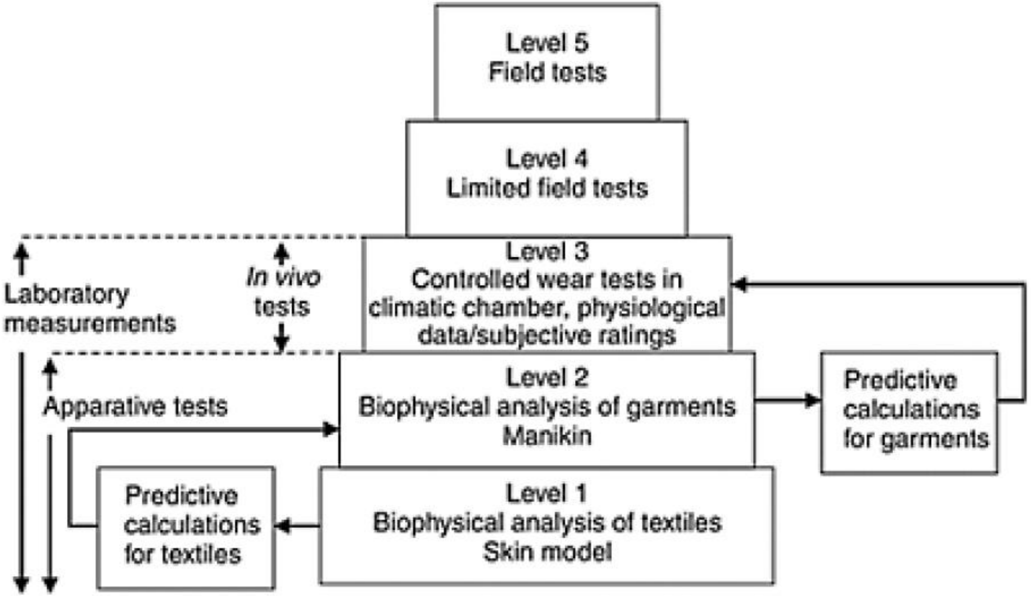
2.

Research methodology for in-vivo wear trials

Measuring body response to different thermal environments in different types of clothing

Comfort pyramid

Developed by Umbach (1988), the comfort pyramid sets five different levels to quantify clothing comfort.



ISO 9920:2009

Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble

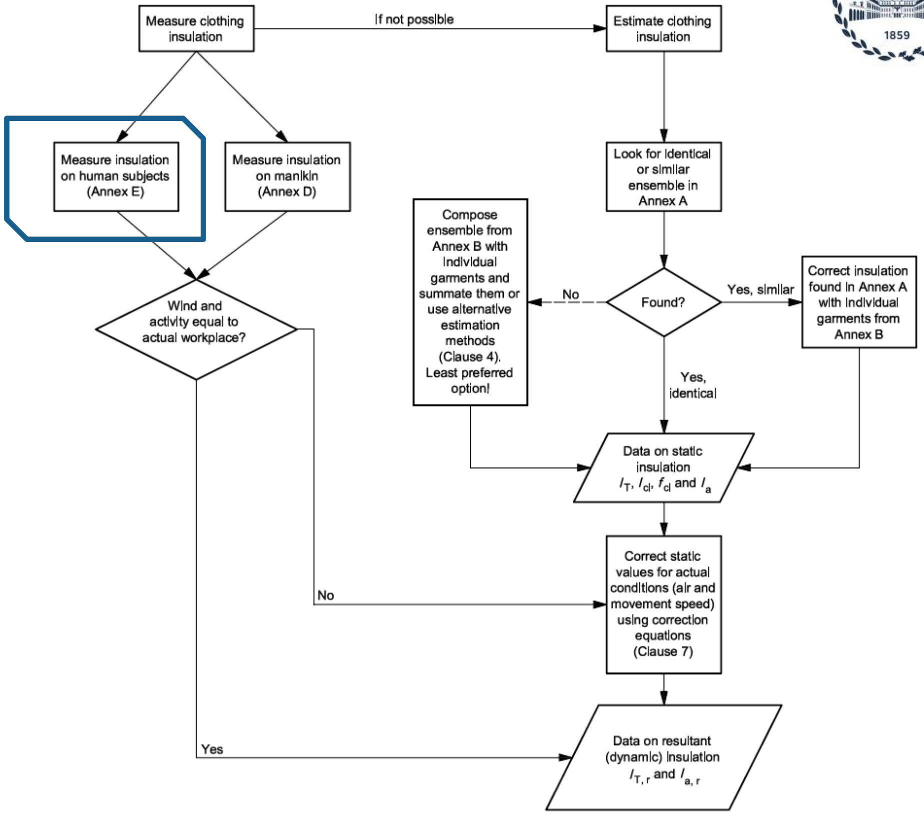


Figure 2 — Determining clothing insulation

Template Credit: SlidesCarnival

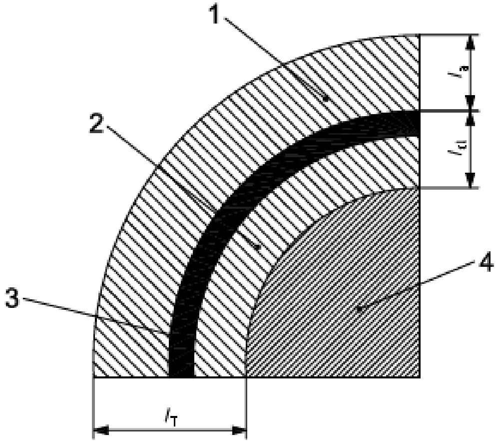
Total thermal insulation, I_T

- Thermal insulation from the body surface to the environment (including **all clothing**, **enclosed air layers** and **boundary air layer**)
- Expressed in ($m^2 \cdot K \cdot W^{-1}$)

Overall temperature gradient (K)

$$I_{T,r} = \frac{(\overline{t}_{sk} - t_o)}{M - W - E - E_{res} - C_{res} - S}$$

Total heat flux from the body per unit surface (W/m^2)



Key
1 surface (or boundary) air layer
2 enclosed air layer
3 clothing
4 body

Figure 1 — Schematic representation of total, basic and air insulations

Total evaporative resistance, Ret

$$R_{\mathrm{e,T,r}} = \frac{P_{\mathrm{sk}} - P_{\mathrm{a}}}{E}$$

Skin humidity

Environment humidity

Measured from weight loss of the tester

- P_{sk}, vapour partial pressure at skin (Pa)
- P_a, vapour partial pressure of the air (Pa)
- E, evaporative heat loss from the body (W/m^2)

ISO 10551:2019 Ergonomics of the physical environment
Subjective judgement scales for assessing physical environments

Point of origin	Degrees of intensity	
0	1 2 3 (4)	Unique pole

	Degrees of intensity	Point of indifference	Degrees of intensity	
Pole A	(–4) –3 –2 –1	0	+1 +2 +3 (+4)	Pole B

Perceptual scale

- Results comparable with the Predicted Mean Vote (PMV) **ISO 7730: 2005** (thermal comfort model for neutral environment)

Table A.1 — Scale of perceptual judgements on personal thermal state

(after the question "How are you feeling now?")

Poles	Degrees	English
HOT	(+5)	Extremely hot
	(+4)	Very hot
	+3	Hot
	+2	Warm
	+1	Slightly warm
INDIFFERENCE	0	Neutral
COLD	−1	Slightly cool
	−2	Cool
	−3	Cold
	(−4)	Very cold
	(−5)	Extremely cold
Common introductory term(s)		I am feeling/I am

NOTE The central tendency of the perceptual judgements obtained by applying one of the above-mentioned scales (in continuous form) yields an observed mean vote which can be compared with the Predicted Mean Vote (PMV index) determined according to ISO 7730[2].

Evaluative scale

- Results comparable with the Predicted Percentage of Dissatisfied PPD (**ISO 7730:2005**)

Table A.2 — Scale of evaluative judgements on personal thermal state

(after the question "Do you find this....?")

Pole	Degree	Wording of degrees
	0	Comfortable
	1	Slightly uncomfortable
DISCOMFORT	2	Uncomfortable
	3	Very uncomfortable
	4	Extremely uncomfortable
Common introductory terms		I find the thermal environment....
NOTE By summing up the judgements which express discomfort, one obtains an observed percentage of dissatisfied people, which can be compared with the Predicted Percentage of Dissatisfied (PPD index) determined according to ISO 7730.		

3.
Case studies from Comfort Lab

Garments as the interphase between the body and the environment

Design & Test lab facilities

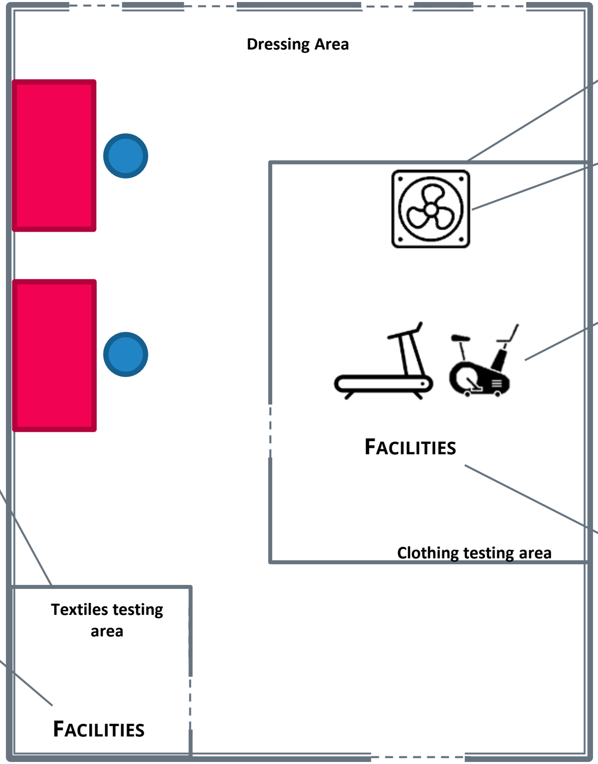
Condizioned lab
21°C; 65% RH

Air permeability
37/S, Branca Idealair

Moisture management tester
MMT, Atlas

Tensiometer
K100, Kruss

Cutometer
MPA580, Courage+Khazaka electronic



Climatic chamber
56 m^3 working from -40/+50°C; 20-90% RH

Movable ventilation unit
up to 50 km/h

Treadmill
Fit – bike
Cycle ergometer

Thermo-camera

Wireless temp sensor

Wireless humidity sensor

Heart rate monitor

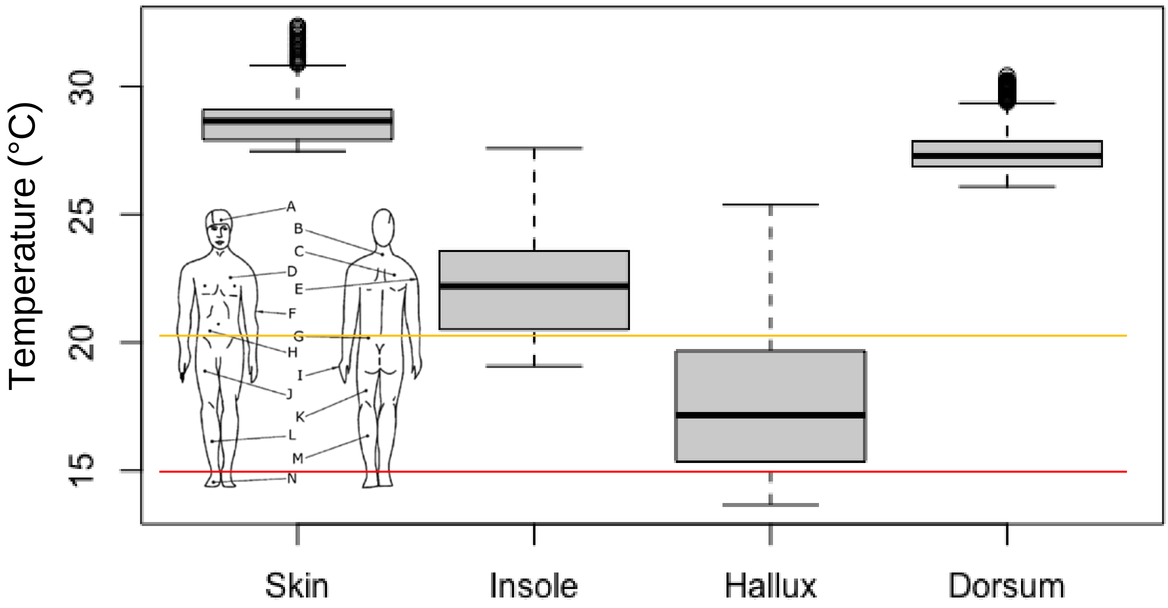
Metabolic measurement system

Core temperature probes CorCap

Evaluation of the performance of mountaineering boots

- Simulating the type and intensity of the physical activity (M estimated according to ISO 8996:2021)
- Simulating the real environment (Ta from -15 to -30°C)
- Measuring physiological temperatures during different activities (average skin temperature Tsk and core temperature Tc according to ISO 9886:2004, feet temperature)

Results



- When toe temperature is above 25°C, feet are in **comfort.**
- When toes temperature reaches 20°C, **discomfort** starts to be felt.
- Below 15°C, **pain** receptors override the cold receptors.
- Below 10°C, pain sensation becomes **unbearable**. For prolonged exposition, **tissue death** occurs.

Kuklane, K., a. 16 - Footwear for cold weather conditions, in: Williams, J.T. (Ed.), Textiles for Cold Weather Apparel. Woodhead Publishing. Woodhead Publishing Series in Textiles, pp. 342–373.

Combining manikin and in-vivo testing (ISO 15831:2004 and ISO 11079:2007)

T (°C)	ACTIVITY	IREQmin < IREQ < IREQneutral (Km^2/W)	Icl (Km^2/W)	
-15	Rest (R) (81 ± 1.28 bpm)	0,682 < IREQ < 0,7285	0,202	Dlim = 0.3 (hours)
	Walking (W) (104 ± 2.8 bpm)	0,1085 < IREQ < 0,1395		
	Climbing (C) (108 ± 18.95 bpm)	0,062 < IREQ < 0,0755		
-20	Rest (R) (79 ± 0,6 bpm)	0,744 < IREQ < 0,806	0,208	Dlim = 0.3 (hours)
	Walking (W) (108 ± 1.22 bpm)	0,124 < IREQ < 0,155		
	Climbing up a ladder (CL) (107 ± 6067 bpm)	0,1705 < IREQ < 0,217		
	Climbing (C) (115 ± 18,6 bpm)	0,0775 < IREQ < 0,124		
-30	Rest (R) (84 ± 2.3 bpm)	0,9145 < IREQ < 0,961	0,446	Dlim = 0.6 (hours)
	Walking (W) (107 ± 2.5 bpm)	0,1395 < IREQ < 0,1705		
	Climbing up a ladder (CL) (106 ± 3 bpm)	0,2325 < IREQ < 0,2635		

Effect of metabolic rate on foot temperature

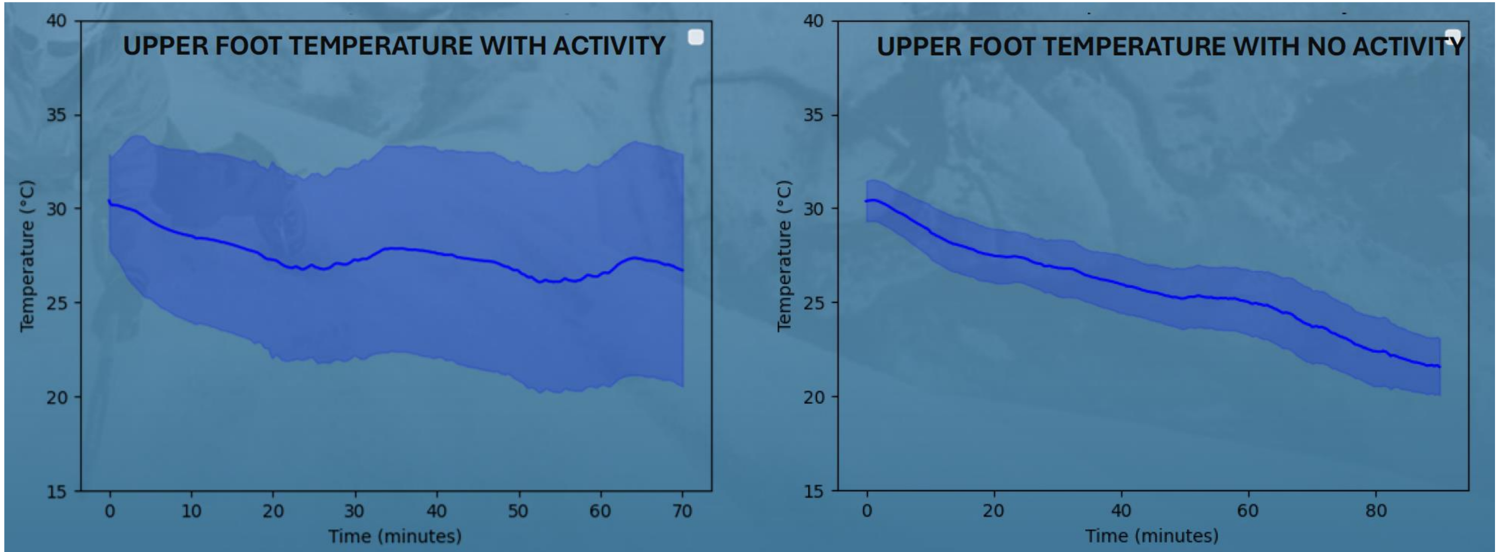


Fig. 1: Same environmental conditions, same Icl, but different MR. In the case of the test in which constant physical activity was performed, the dorsum temperature appears to be more constant and **HIGHER**. In the test where no physical activity was performed, dorsum temperature appears to be **LOWER** and with a **STEEPER** drop.

Effect of overall insulation on big toe temperature

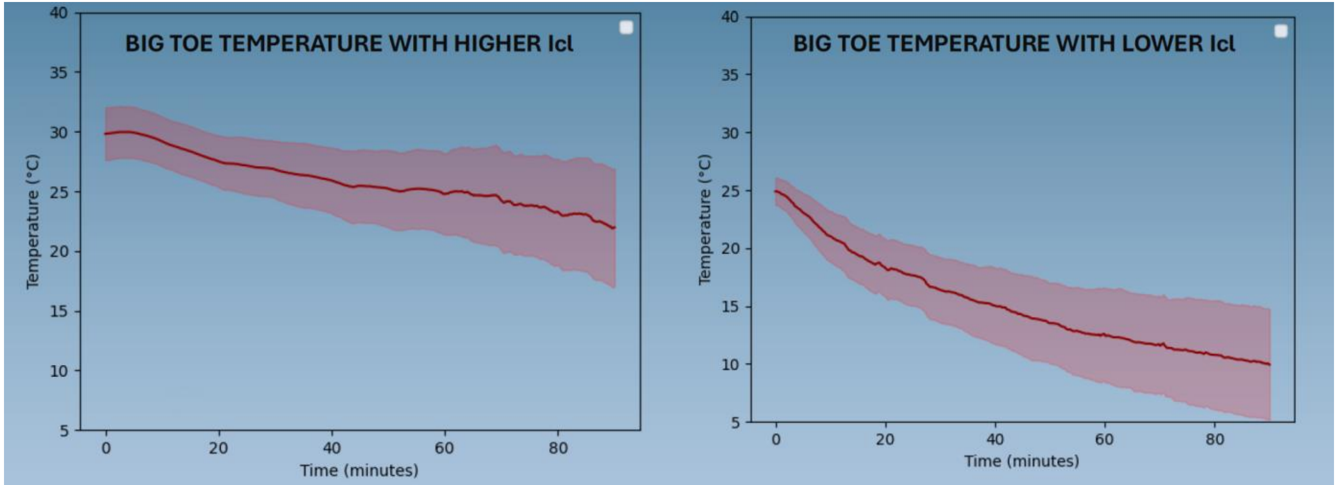


Fig. 2: Same test duration, same metabolic activity, but different level of insulation. Even though the ambient temperature was **LOWER** in the test whose results are shown on the left, the **HALLUX** temperature was much **HIGHER** than in the test shown in the graph on the right.

Thermal strain in motor sports: effect of protective garments

- Motorsport places high demands on thermal comfort (cockpit **temperature up to 50-60°C**).
- Fatigue caused by driving a racing car for hours has a significant impact on the driver's **alertness, performance and safety**.
- Racing suits must comply with international standards such as ISO 9151:2016 regarding the thermal conductivity of the suit in the event of a high radiant heat flux, such as occurs in a fire.

Method details

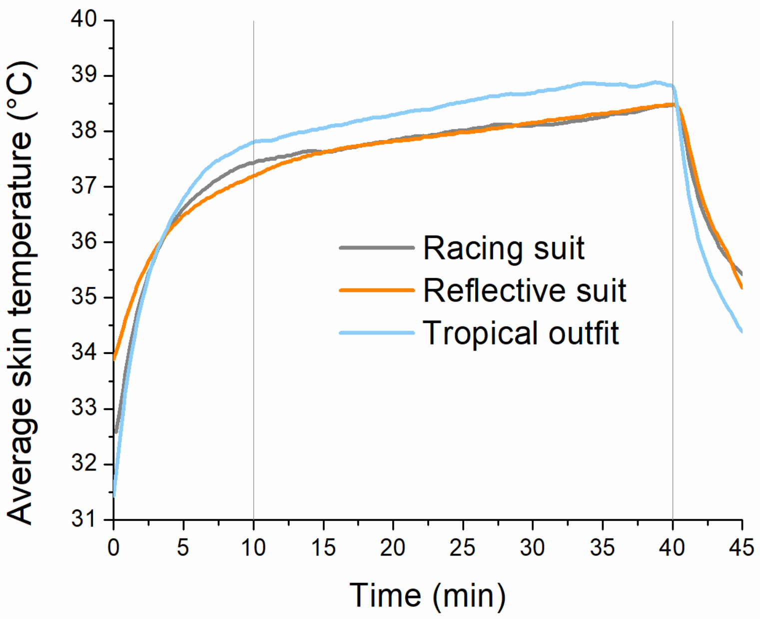
- Three testers (age 19-22 – BMI: 18.6-21.8)
- Air temperature 50°C and relative air humidity 50%
- Three outfit configurations

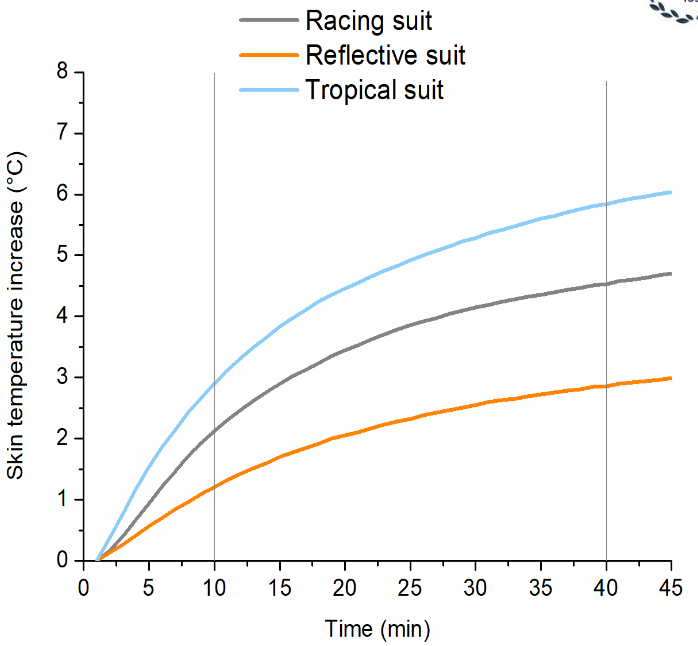
(1) Motorsuit certified by FIA (Federation International de Automobile)

(2) Motorsuit certified by FIA + reflective blanket

(3) “Tropical outfit” - shorts and T-shirt

Results





+ 6°C
+ 4°C
+ 2°C

When the environment is hotter than the body, clothing must act as heat barrier.

Role of evaporative cooling

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Amount of produced sweat (g)

Tester	*Racing outfit*	*Reflective outfit*	*Tropical outfit*
# 1	675	640	655
# 2	395	400	415
# 3	1065	1005	1160

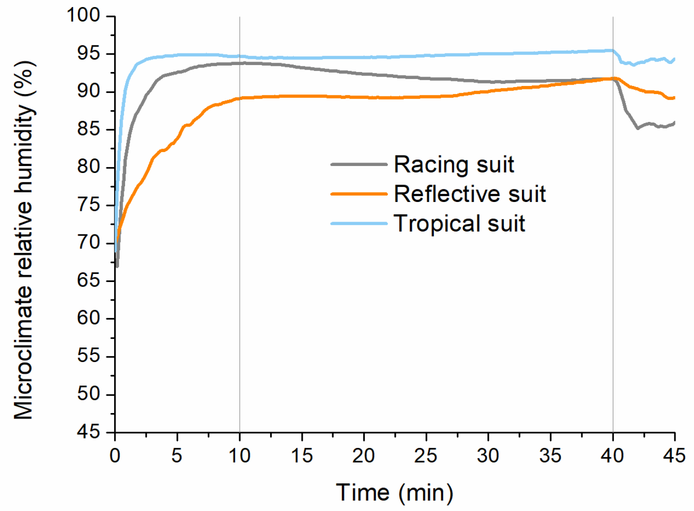
- Strong individual differences.

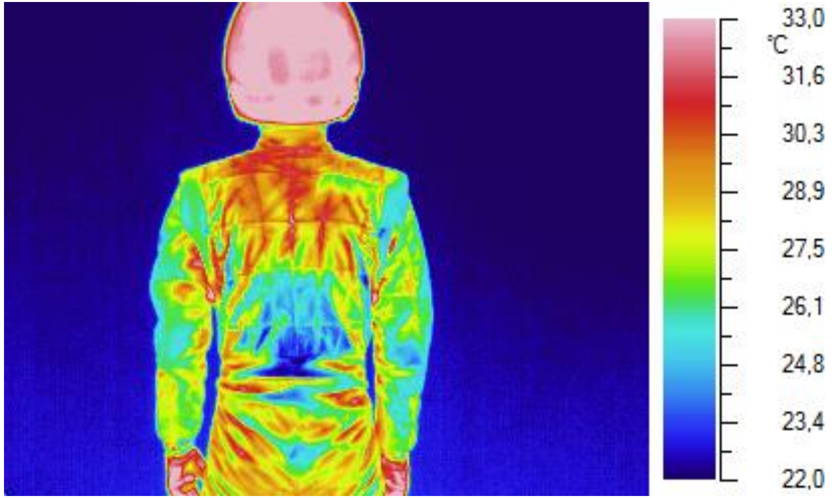
Amount of residual sweat in the garments (g)

Tester	*Racing outfit*	*Reflective outfit*	*Tropical outfit*
# 1	477.6 (71%)	466.8 (73%)	320.3 (49%)
# 2	259.0 (66%)	265.6 (86%)	99.6 (24%)
# 3	828.9 (78%)	870.0 (87%)	531.9 (46%)

- Poor evaporative cooling.

Moisture in the air gap





- Microclimate is quickly saturated with moisture.
- Thermo-mapping shows the most sweat-soaked areas.

Template Credit: SlidesCarnival

Conclusions

- International standards provide guidelines for in vivo testing of sportswear performance.
- Measuring the physiological response in a controlled environment provides valuable information about the garment's heat and moisture management.
- Its application is important in extreme environments where safety aspects are paramount.

Industrial collaborations

ARTSANA GROUP

Smartex

SLAM ADVANCED TECHNOLOGY SPORTSWEAR

NUREL

MONTURA

STAMPERIA ALICESE s.r.l.

COLMAR

DIRECTAPLUS PARTNERS IN NANOTECHNOLOGY

Pella advanced technology sportswear

ZEGNA BARUFFA LANE BORGOSESIA S.p.A.

REDA REWOOLUTION

GEOX

Loro Piana

LEVEL HANDWEAR TECHNOLOGY

eurojersey

SINTERAMA

TINTORIA FINISSAGGIO 2000

MICO TOOLS ON

NILIT

sparco

Industrial collaborations

SALEWA

Rapha®

RSE®

FERRINO

DECATHLON

alpinestars

SCARPA®

Scientific collaborations

Associazione Tessile e Salute

Centro Cardiologico Monzino

INSTM

National Interuniversity Consortium of Materials Science and Technology

Università degli Studi di Padova

Ospedale di Biella

Alma Mater Studiorum Università di Bologna