Testing of Protective Outdoor Garments

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Content

1. **General testing approach: from fabrics to garments in the field**
2. **Lab tests**
   - **protection against rain**
   - **protection against wind**
3. **Methods to predict the protection from**
   - **cold strain**
   - **heat strain**
4. **Tests that differentiate good and bad base-layers**

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General testing approach
From fabrics in the lab to garments in the field for comfort

According to:

HOHENSTEIN INSTITUTES

Level Four: Controlled and limited Field test

Level Three: Controlled wearer tests with subjects in a Climatic Chamber

Predictive Calculations Physiological / empirical models

Level Two: Biophysical analysis of clothing systems using moving thermal manikin Ventilation measurements

Predictive Calculations clothing models

Level One: Physical analysis of fabrics using the Sweating hot plate, Base layers - sensorial tests

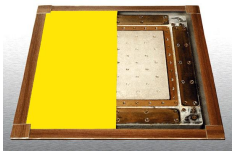
Fabrics are tested on the Skin Model
Rct and Ret Measurements (ISO 11 092) **" Physiological effects"**

Rct
Thermal Resistance to conductive heat transfer (textile)
The larger the value,
the more insulating the fabric

Ret
Thermal Resistance to evaporative heat transfer (textile)
The smaller the value,
the more water vapour permeable the fabric

Rating	Ret [m² · Pa / W]
Extremely Breathable	<6
Highly Breathable	6 to 13
Satisfactory	13 to 20
Unsatisfactory	>20

Regarding shell fabric



Level 2
Manikin evaluation of clothing for evaporative and thermal resistance

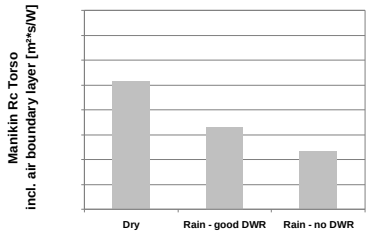
Manikin with sweating skin

Dressed manikin

- heated
- articulated
- measurement of thermal insulation
- calculation or measurement of evaporative resistance

Influence of Water Repellency on Heat Loss in the Rain
Effect Decreases with Increasing Insulation

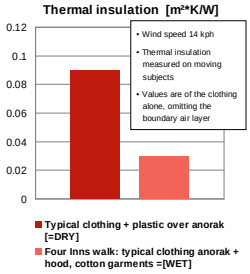
Gore internal study on manikin at Cord
2-Layer unlined jacket + long sleeved t-shirt



Rain
Wet Clothing loses its Thermal Insulation

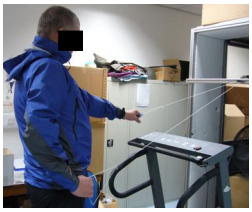
Insulation value of wet clothing is **reduced by** about **70%** over a wide range of water content

- Heat loss in wet clothing is about 3 times higher than in dry clothing



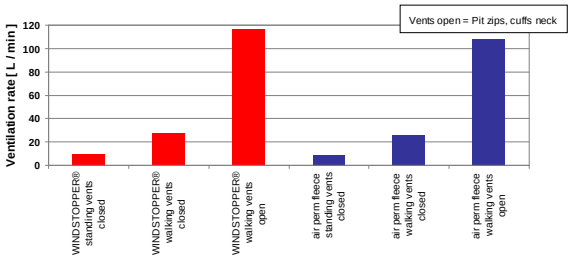
Source
Four Inns walk - G Pugh study on Clothing insulation and accidental hypothermia 1966

Level 2
Ventilation can be measured on manikins or more naturally on humans

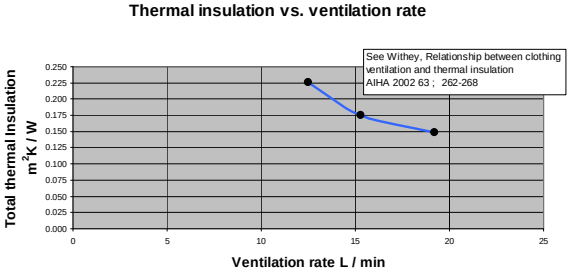


Ventilation rate of standard fleece and air impermeable fleece
No change if worn under rain suit

- Ventilation rate of GORE-TEX® suit worn with either windproof or air permeable fleece underneath
- no difference in ventilation rates under these conditions



Correlation of ventilation rate and thermal insulation
Measured simultaneously on a thermal manikin

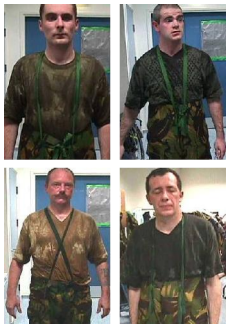


Level 3
Human subject testing in climatic chambers

- Measurement of physiological effect of clothing
  - thermal strain
    - core body temperature
  - skin temp
  - microclimate temperature and relative humidity
  - work rate
  - perceived exertion
  - tolerance time etc.

Disadvantages of chamber testing
Chamber tests should be done only if strictly needed

- Can involve considerable discomfort (see pictures)
- Human subject tests
  - time consuming (at least 4 to 8 weeks)
  - costly (£ 40 to 80,000)
  - minimum of 8 subjects needed
- To avoid them, enormous amounts of time and effort were invested to relate manikin data with wear trials
- Human subject tests will always be needed, but with predictive models they can be minimised



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Tests
Waterproofness and durability of waterproofness

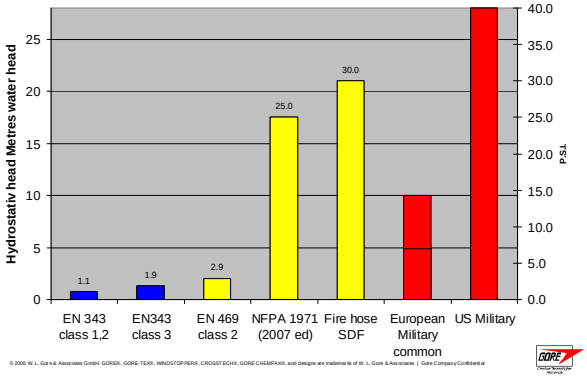
- Hydrostatic head test

- Dry flex followed by suter testing
- Wet flex followed by suter testing

- Shower tests
- Field testing

Fabric
Hydrostatic head test ISO 811 – destructive

Waterproofness
Different requirements of hydrostatic head pressure



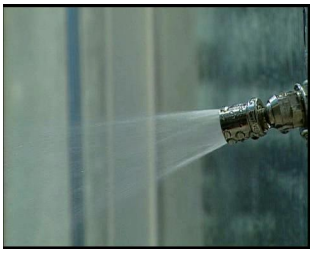
Durability of waterproofness of laminates
Flex testing followed by constant pressure suter testing

- Dry Flexing – followed by Suter testing

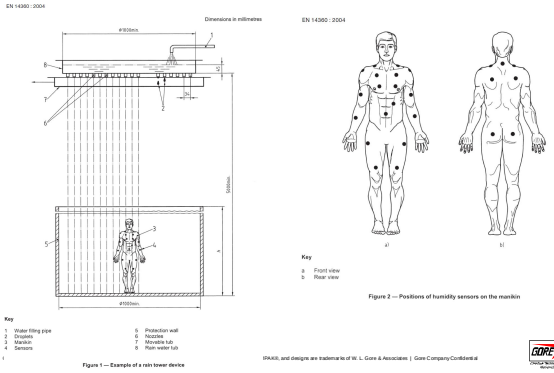
- Wet Flexing – followed by Suter testing

Test for waterprofness of garments
Rain tower testing depending on end use

- Vertical “rain” is equivalent to a violent shower
  - 76 mm / hr
- Side nozzle flow is 4 L/min through each



European standard for shower tests (EN 14360 – 2004)
Overhead rain only – for some applications not severe enough

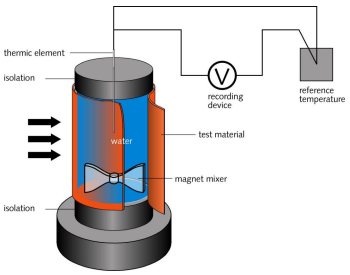


Field Tests for durability of waterproofness

- Need
  - Sufficient number of garments (>40) for statistics
  - Reference fabric of known durability
    - Half and half garments ensure equal use and reduce number of samples

Effect of wind on thermal insulation
Measured with a heated cylinder or preferably a thermal manikin

Heated cylinder test



Tore manikin, Sweden

Wind reduces the total insulation value of clothing
Insulation of air permeable clothing drops drastically in the wind

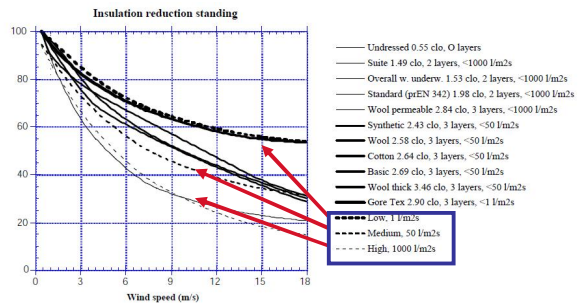


Figure 2. The combined effect of air permeability, wind on TORE standing still.

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Protection from the Cold
Required insulation levels can be estimated

- ISO 11079 (pub. 2005): **Determination of Required Clothing Insulation (IREQ)**
- Calculation applet at: *wwwold.eat.lth.se/Research/Thermal/IREQ2002alfa.htm*
- Input
  - clothing thermal insulation
  - activity
  - environmental conditions
- Output
  - prediction of the exposure time
  - Required basic insulation value

Clothing insulation data
Values for typical clothing ensembles from ISO 11079

Table C.2 — Basic insulation values (I_{cl}) of selected garment ensembles measured with a thermal manikin (based on from ISO 9920)

Clothing ensemble	I_{cl} m^2K/W	clo
1. Briefs, short-sleeve shirt, fitted trousers, calf length socks, shoes	0,08	0,5
2. Underpants, shirt, fitted trousers, socks, shoes	0,10	0,6
3. Underpants, coverall, socks, shoes	0,11	0,7
4. Underpants, shirt, coverall, socks, shoes	0,13	0,8
5. Underpants, shirt, trousers, smock, socks, shoes	0,14	0,9
6. Briefs, undershirt, underpants, shirt, overalls, calf length socks, shoes	0,16	1,0
7. Underpants, undershirt, shirt, trousers, jacket, vest, socks, shoes	0,17	1,1
8. Underpants, shirt, trousers, jacket, coverall, socks, shoes	0,19	1,3
9. Undershirt, underpants, insulated trousers, insulated jacket, socks, shoes	0,22	1,4
10. Briefs, T–shirt, shirt, fitted trousers, insulated coveralls, calf length socks, shoes	0,23	1,5
11. Underpants, undershirt, shirt, trousers, jacket, overjacket, hat, gloves, socks, shoes	0,25	1,6
12. Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes	0,29	1,9
13. Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes, hat, gloves	0,31	2,0
14. Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes	0,34	2,2
15. Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes, hat, gloves	0,40	2,6
16. Arctic clothing systems	0,46–0,70	3–4,5
17. Sleeping bags	0,46–1,4	3–9

Metabolic rate estimation
Examples for general activities from ISO 11079 – use with care

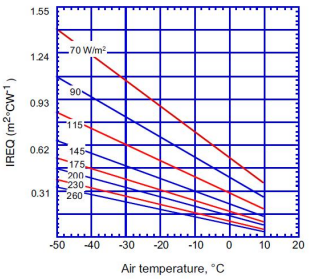
Table C.1 — Classification of metabolic rate for kinds of activities (modified from ISO 8996). Indicated metabolic rate refers the average of 60 minutes of over a shift's continuous work

Class	W m^{-2}	Examples
Resting	65	Resting, sitting
Very low metabolic rate	80	light manual work (writing, typing, drawing); inspection, assembly or sorting of very light materials;
Low metabolic rate	100	hand work (small bench tools); arm work (driving vehicle in normal conditions, operating foot switch or pedal); machining with low power tools; light strolling.
Low to moderate metabolic rate	140	Hand and arm work at moderate pace. Mounting and assembling light pieces of material.
Moderate metabolic rate	165	Sustained hand and arm work (hammering in nails, filing); work with light equipment and tools; arm and leg work (off-road operation of lorries, tractors or construction equipment
Moderate to high metabolic rate	175	arm and trunk work; work with pneumatic hammer; intermittent handling of moderately heavy material, pushing or pulling light-weight carts or wheelbarrows, walking at a speed of 4 km/h to 5 km/h; snowmobile driving.
High metabolic rate	230	Intense arm and trunk work, carrying heavy material; shovelling; sledgehammer work; cutting trees by chainsaw; hand mowing; digging; walking at a speed of 5 km/h to 6 km/h. Pushing or pulling heavily loaded handcarts or wheelbarrows; chipping castings; concrete block laying; snowmobile in heavy terrain.
Very high metabolic rate	290	Very intense activity at fast to maximum pace; working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps; running; walking at a speed greater than 6 km/h, walking in deep loose snow.
Very, very high metabolic rate (up to 1-2 hours)	400	Very intense activity sustained without breaks. Emergency and rescue work at high intensity

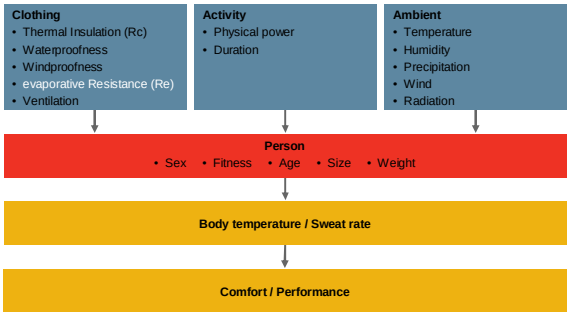
How much protection from the cold is needed?
Example calculation with the IREQ-software

- IREQver4 ISO 11079 Oct 2008

Required minimal insulation (ISO 11079)
Influence of work rate and temperature



Protection against heat strain Influencing Factors on Body Core Temperature and Performance
Reducing heat strain requires lowest possible evaporative resistance



General testing approach
From fabrics in the lab to garments in the field for comfort

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Predictive Calculations Physiological / empirical models

Predictive Calculations clothing models

Lab Testing and Prediction Methods
Effect of shell fabric Ret moistute vapour permeability) on ensemble performance

Fabrics
- Vapour permeability (Ret)
- Insulation (Rct)

skin model

	Fabric 1	Fabric 2
Ret [m2*Pa/W]	5	10

- Design, Construction
- Pockets, Doublings, Linings, Tape...

Garment pieces
- Vapour permeability (Re)
- Insulation (Rc)

calculations

Typical jacket	Fabric 1	Fabric 2
Re [m2*Pa/W]	9.7	16.7

- Underwear, Mid layers, Socks, Shoes...
- Air layers, ventilation

Clothing ensemble
- Vapour permeability (Re)
- Insulation (Rc)

manikin

Ensemble (long underwear + rain suit)

	Fabric 1	Fabric 2
Re [m2*Pa/W]	24.3	33

- Wearer, Activity, Weather

Wearing scenario
- Ambient Conditions
- Activity Levels

physiology model

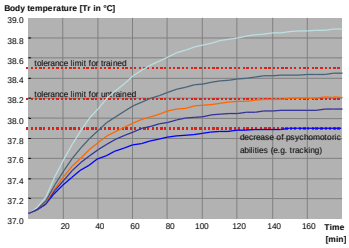
Prediction of body temperature, heart rate, skin wettedness ⇨ comfort and performance

According to NATO AC PP1

Influence of shell Ret only on heat strain
Garments with lower shell Ret (higher MVP) reduce heat strain

- varying fabric Ret
- Long Underwear + Rain suit
- Ambient 10°C / 80%
- Activity level 450 W

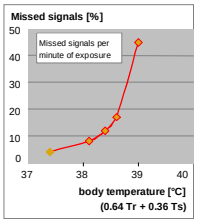
Predicted Core Temperatures for different Shell Fabric Ret for same activity



Source: GORE simulation based on Hohenstein physiology model

Heat Stress affects performance e.g. diminishes vigilance

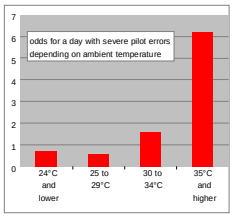
Study
- Analysis of literature on vigilance and thermal stress
  - Goal
    understand the influence of thermal stress on vigilance
  - Conduction
    auditory signal detection while walking on a treadmill in different temperature conditions
  - Finding
    Increasing body temperature impairs attention and vigilance



Source: Hancock, Sustained Attention under Thermal Stress, Psych. Bul. 1986, Vol. 99, No 2, p 263ff, data from Benor and Shvartz, 1971

Heat stressed helicopter pilots more likely to crash

Study
- Severe helicopter pilot errors in Israel
  - Goal
    Find out why there are many more crashes in summer
  - Conduction
    Investigation of temperature distribution of days with and without accidents and near miss occurrences
  - Finding
    Higher heat stress on hot days increases significantly the chance of severe pilot errors



Source: Froom et al, J. o. Occ. Med., Vol. 35, No 7, 1993, p 271 ff

Content

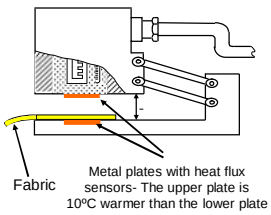
Differentiation between good and bad base-layers

Opinion of professional field testers (KLETS)

- Comments from a report of a test field comparing base-layers including Capilene® and Cotton
- "The Capilene® vest is previously nominated here as among the best base-layers available
- In low activity all testers had no complaint until the Cotton vest became damp and adhered against the skin.
- In high activity the Cotton vests became saturated and a **chill** effect was experienced during short stops. It retained this accumulated wetness and **clung** to the skin and was very uncomfortable"

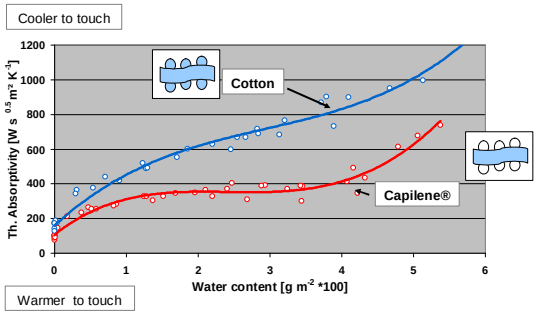
Measurement of thermal absorptivity with Alambeta Tester

Correlates well with "coldness to touch" feeling



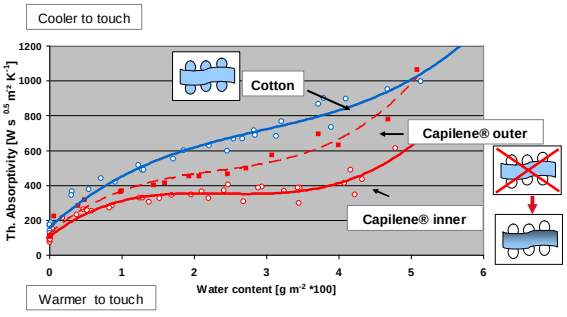
Coolness to touch of wet fabrics

Thermal absorbtivity vs. water content of Cotton and Capilene®



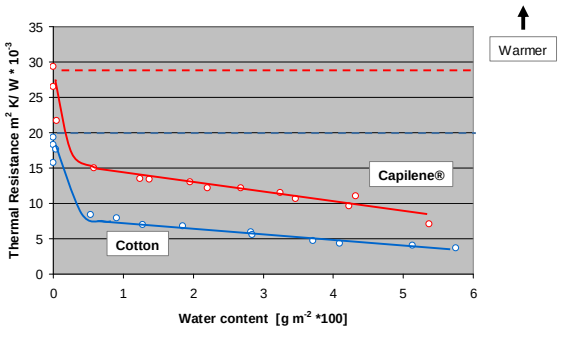
Coolness to touch of wet fabrics

Cotton much colder than Capilene ® inner



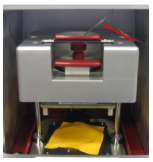
Thermal resistance (insulation) of wet base-layers

Comparison of R_{ct} of wet cotton and Capilene®



Moisture Management Tester

The movement of sweat on either side of a fabric

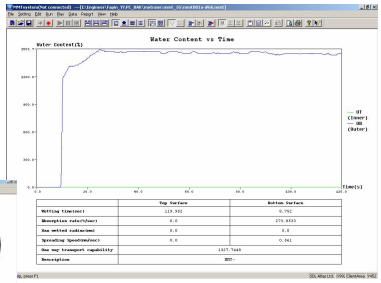


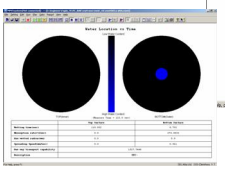
Measures electrical resistance between the upper and lower sets of pins and also concentric circles of pins.

Moisture Management Tester
Example: "Water penetration fabric"

Changed !

Properties
- Small spreading area
- Excellent one-way transport

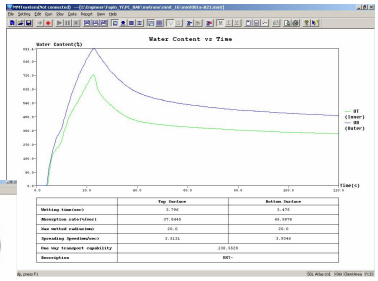


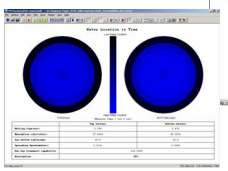


	Top Surface	Bottom Surface
Wetting time(sec)	119.992	0.792
Absorption rate(%/sec)	0.0	279.8333
One wetted radius(mm)	0.0	0.0
Spreading Speed(mm/sec)	0.0	0.041
One way transport capability	1327.7449	
Description	000-	

Moisture Management Tester
Example: "Moisture management fabric"

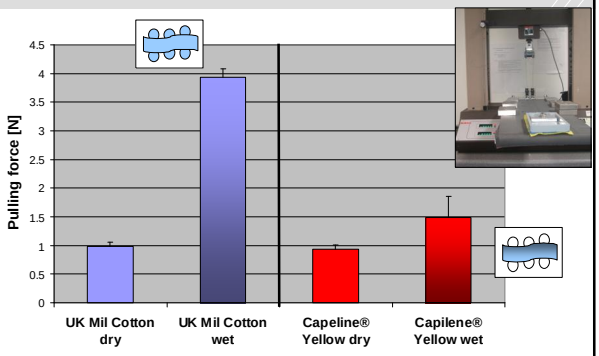
Properties
- Medium to fast wetting
- Medium to fast absorption
- Large spread area at bottom surface
- Fast spreading at bottom surface
- Good to Excellent one-way transport





	Top Surface	Bottom Surface
Wetting time(sec)	0.744	0.672
Absorption rate(%/sec)	37.5403	40.5979
One wetted radius(mm)	20.0	20.0
Spreading Speed(mm/sec)	3.6131	3.9244
One way transport capability	139.5919	
Description	000-	

Dry and wet cling
Force to pull a fabric over a smooth dry and wet surface



Conclusions

- Testing all aspects of protective clothing performance and comfort is relatively complex,and takes much effort.
- For comfort, the use of thermal manikins and physiological modelling cuts the evaluation cost considerably, whilst at the same time enabling more questions to be answered.
- Testing for product integrity, performance, and durability is a severe cost factor e.g.

  Garment Shower Testing

  Factory support for seam sealing etc.