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TEXTIL+FASERFORSCHUNG

Self-cooling Textiles – Energy-free Method using Radiative Cooling Technology

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German Institutes of Textile and Fiber Research (DITF Denkendorf), Germany

Europe‘s Largest Textile Research Center

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Key Figures 2023

Employees

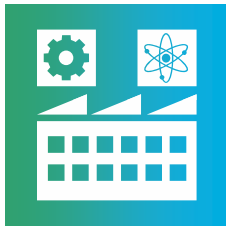
approx. **220**

ITVP approx. **40**

Sales Revenue

18,9 m € public
9,3 m € industry

ITVP approx. **6,9** Mio. €



Area

25,000 m²

Research

132 public
583 industry

Partners

1496 enterprises
81 % SME

Services

approx. **100** test customers
5 small batch series

Textile Vertical Integration

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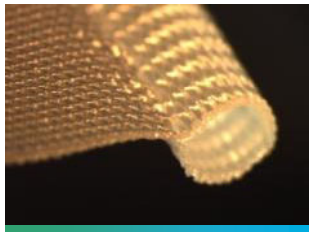
FROM MOLECULES TO PRODUCTS

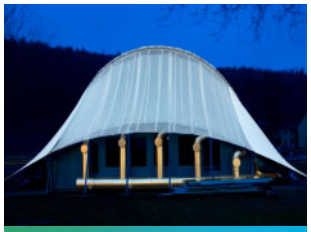
Polymer

Fibers and Yarns



Fabrics

Functionality



Product

Textile Future

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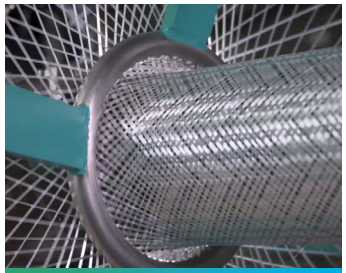
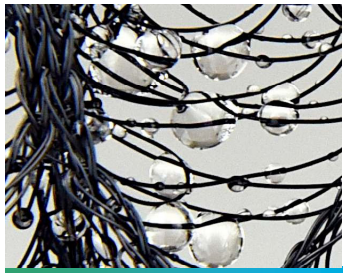
RESEARCH FIELDS

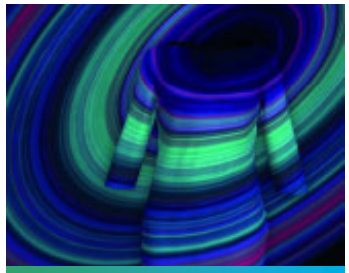
New Materials



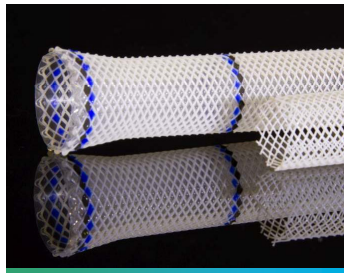
Lightweight Construction



Sustainability



Digitalization



Health

Motivation

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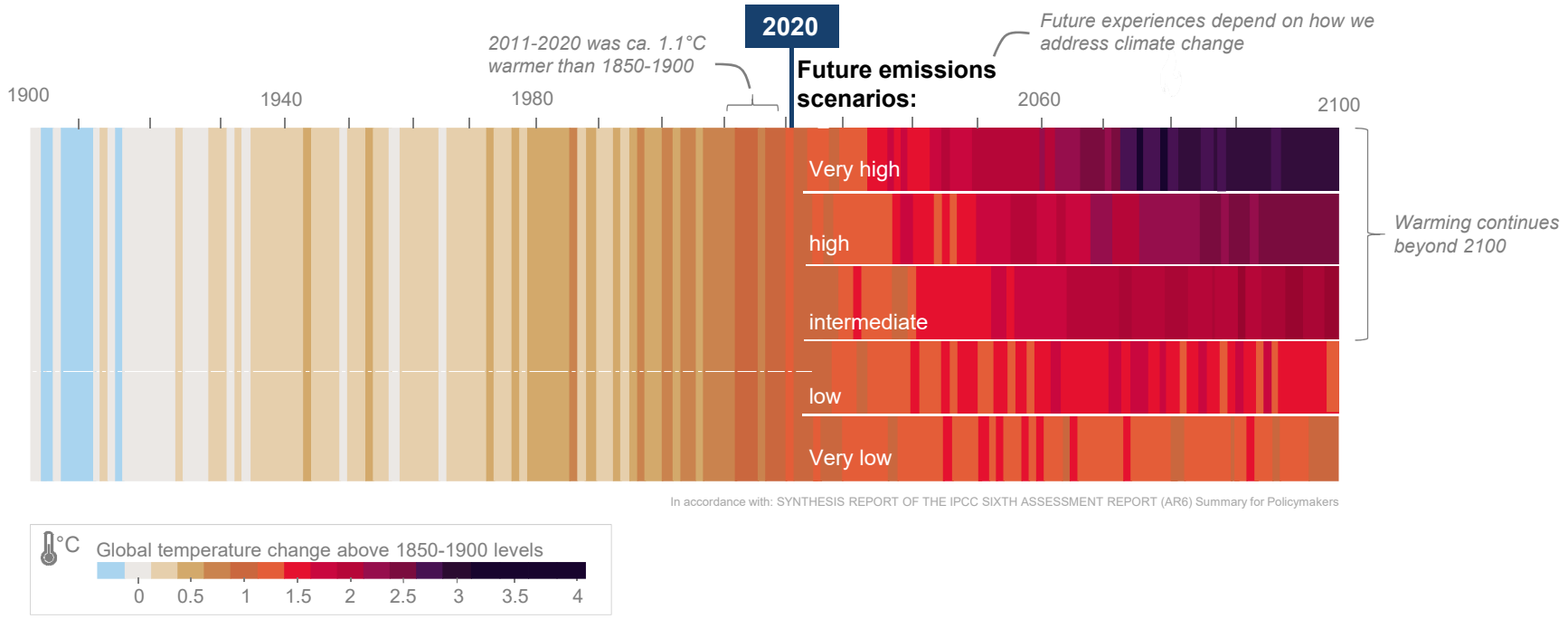
Climate Change | Increasing demand for sustainable cooling solutions



History

Development in radiative cooling| From nighttime to daytime cooling

persian ice houses „Yakchals“

“The Persian ice house, or how to make ice in the desert,” FieldStudyOfTheWorld, 2016

SkyCool Systems

https://www.skycoolsystems.com/technology/

Goal

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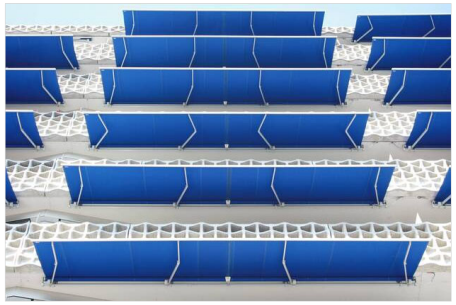
Energy-free cooling | How can we achieve sustainable cooling via textile applications?

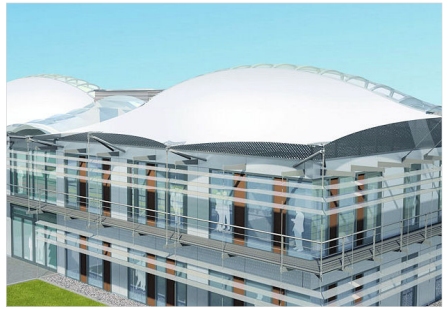
- ✗ High energy consumption
- ✗ Production of additional waste heat and CO_2 emissions

https://www.geo.de/natur/nachhaltigkeit/19353-rtkl-teufelskreis-wie-klimaanlagen-das-klima-aufheizen

- ✓ Development of an adaptive and resource-saving cooling coating for technical textiles using **radiative cooling.**



https://www.imago-images.de/fotos-bilder/basel-hochhaus



HTC - Würzburg

Stay cool in the hot desert:
Silver ant *Cataglyphis bombycina*

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https://www.zdf.de/dokumentation/terra-x/faszination-erde-sahara-schaetze-im-sandmeer-100.html

one of the land creatures best adapted to high temperatures

- Habitat: Sahara, Sinai and deserts of the Arabian Peninsula
- > 50°C daytime temperatures
- Silver ants come out of their nest at lunchtime to look for heat-stricken animals
- In order to survive under these conditions, silver ants need effective heat protection

Stay cool in the hot desert:
Silver ants – *cooling by specific hair geometry*

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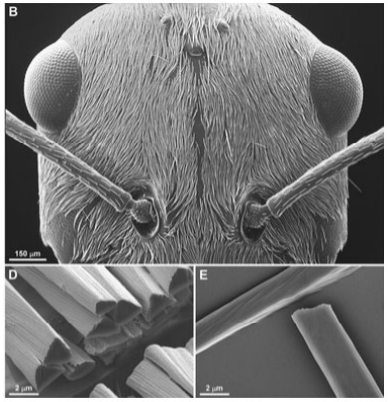
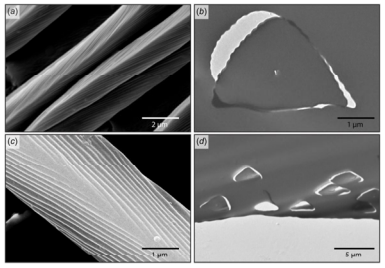


11 June 2015 10.1126/science.aaa8623

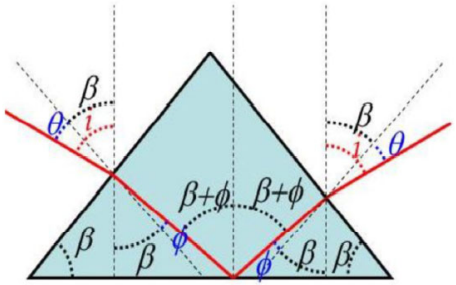


Willot et al. „Total Internal reflection Accounts for the Bright Color of the Saharan Silver Ant“ (2016)

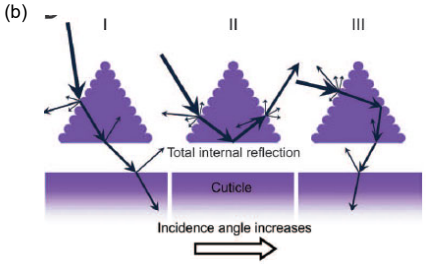
Geometry of hair structure, longitudinal and transverse views.

LZ1

- Internal total reflection – Depending on the angle of incidence, the light is completely reflected back
- At longer wavelengths in the mid-infrared, the reflection through the hair structure decreases - emission power increases, so that more heat can be given off



Willot et al. „ Total Internal reflection Accounts for the Bright Color of the Saharan Silver Ant“ (2016)



Shi et al. „ Keeping cool: Enhanced optical reflection and radiative heat dissipation in sharan silver ants“ (2016)

Total internal Reflecion.
a) Ray-tracing model of a triangular hair - light enters through an upper surface; is totally reflected at the basal plane and emerges through the opposite top.
b) Schematic representation of the interaction between visible/NIR light and a hair at small (I), medium (II) and large (III) angles of incidence. The wavy top two facets can enhance diffuse reflection in the ultraviolet and visible ranges..

Folie 9

LZ1 Bild unterschriften links bearbeiten

Lea Zimmermann; 17.04.2023

Stay cool in the hot desert: Silver ants – *cooling hairs*

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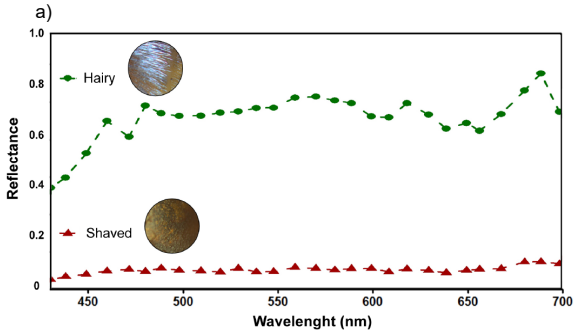
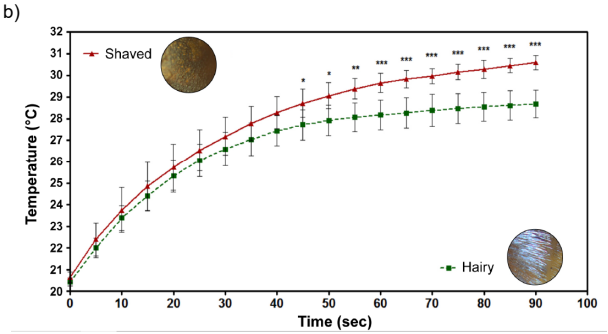
Silver ants *Cataglyphis bombycina*.
a) Ants have a metallic sheen in sunlight. (b,c) the hair is located on the back of the head (b) the thorax and the abdomen of the workers (c).

Reflection and temperature profile of hairy and shaved ants *C. bombycina*.



a) Reflectance – light incidence 50° and azimuth 0 from 425-700nm



b) Temperature history - exposed to light from a solar simulator for 90 seconds, whose visible spectral intensity is identical to the Saharan summer sun.

Willot et al. „Total Internal reflection Accounts for the Bright Color of the Saharan Silver Ant" (2016)

Radiation cooling – broadband wave length

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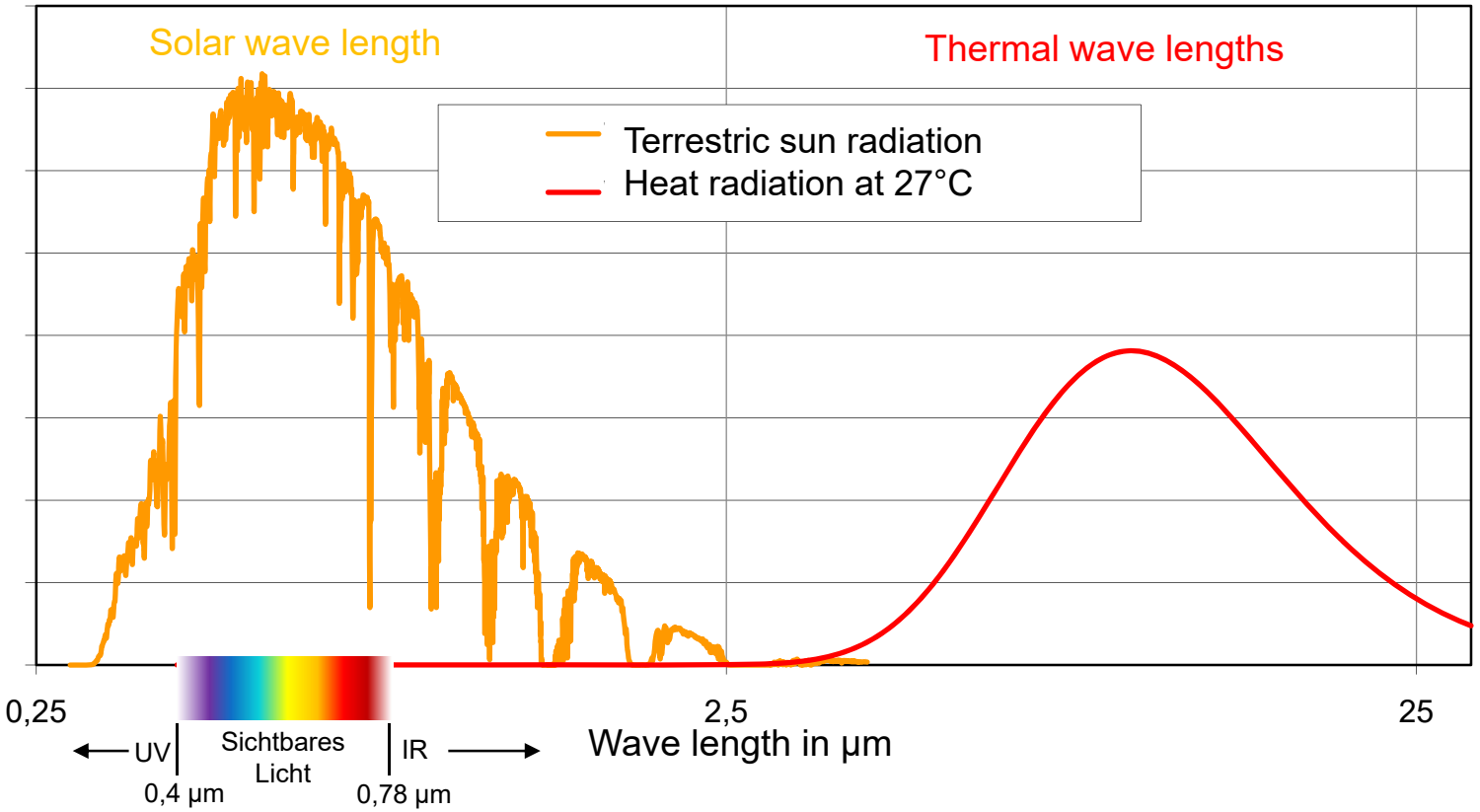


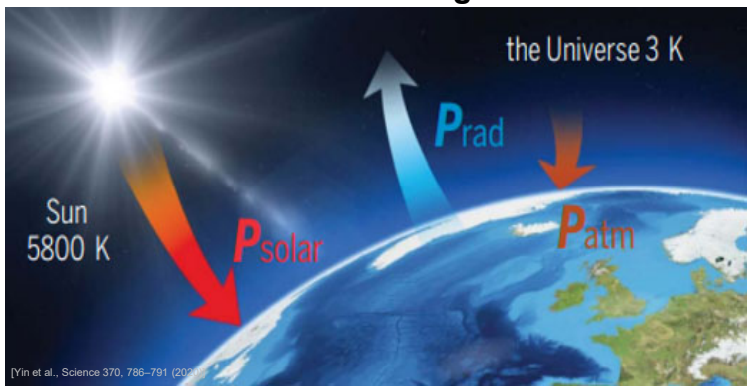
Solution

Working principle| Radiative Cooling Technology

T_{high} – Heat Source

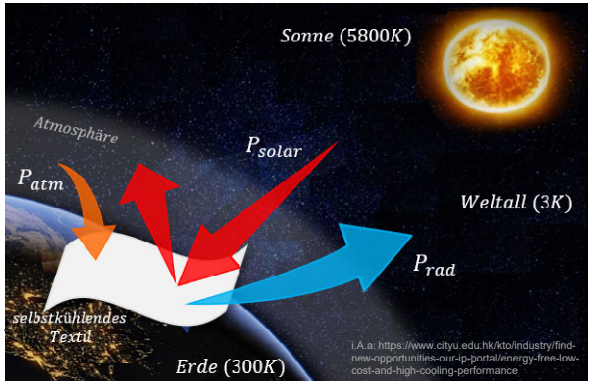
T_{low} (cold reservoir/heat sink) = ambient temperature

Using the cold Universe as a heat sink



Heat radiation fluxes on the terrestrial surface

P(solar): absorption of solar radiation; P(rad): outgoing terrestrial thermal radiation; P(atm): Absorption of downward atmospheric thermal radiation.



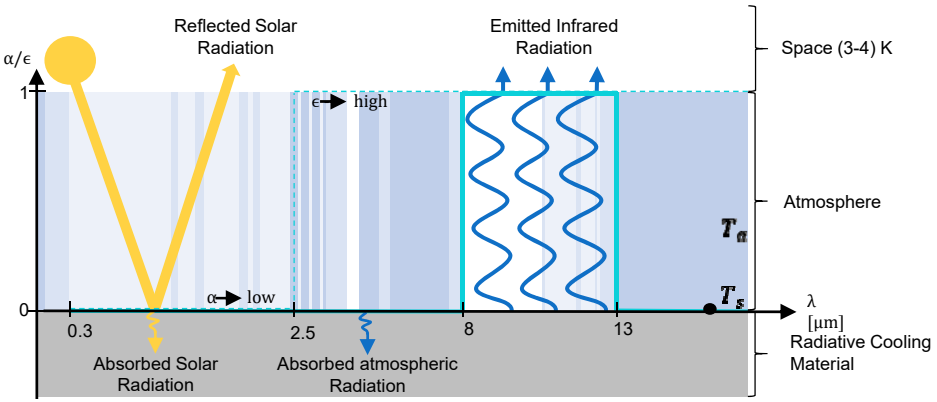
Functional principle of a self-cooling material

P(solar): absorption of solar radiation; P(rad): outgoing heat radiation from the self-cooling textile; P(atm): Absorption of downward atmospheric thermal radiation.

Physical Background

Spectral curve| Influencing factors and material design opportunities

wavelength-dependent adaptation of the material design for high energy-free cooling performance



T_a Ambient Temperature
T_s Surface Temperature of the cooling material
Transmissivity of the atmosphere for long-wave radiation: Light-blue = high; dark-blue = low

Arvind Srinivasan; Thermal Performance of Passive Radiative Cooling Strategies on Building Envelopes; Dissertation (2020)

Net radiation balance

$$q_{cooling} = q_{rad} - q_{solar} - q_{atm} - q_{nonrad}$$

$$q_{rad} = 2\pi \int_0^{\infty} \int_0^{\pi/2} \varepsilon_r(\lambda,\theta) I_b(\lambda,T_r) \sin\theta \cos$$

$$q_{solar} = \int_0^{m} I_{AM\,1.5} \varepsilon_r(\lambda$$

$$q_{atm} = 2\pi \int_0^{\infty} \int_0^{\frac{\pi}{2}} \alpha_r(\lambda,\theta) I_{atm}(\lambda,\theta,T_a,\varphi) \sin\theta \cos$$

$$q_{nonrad} = h_{nonrad}(T_a -$$

Zhao *et al.* (2019)

q(cooling): Cooling power [W/m²]
q(solar): Absorption of solar radiation
q(rad): thermal radiation of the radiative cooler
q(atm): Absorption of downward atmospheric thermal radiation
q(nonrad): Absorption of non-radiative heat sources due to convection/conduction

Technical Implementation

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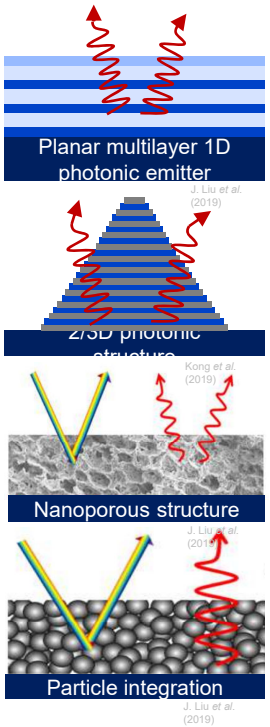
Material Design | Solution for technical textile applications

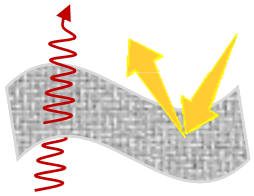
State of Research



Deficits:
- highly precise manufacturing process required (e.g. laser lithography)
- no cost-effective upscaling possible on textile surfaces

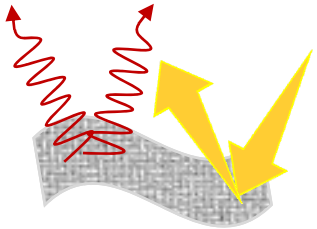
Deficits:
- Focus on clothing applications
- High thicknesses for substrate-independent application needed

Advantage:
- Large scale, low costs
- Simple application process possible



High NIR-reflectivity
High IR-transparency

- Reduce body heat
- Breathability – nano porous structures
- IR permeability
- Moisture Transport / Evaporation



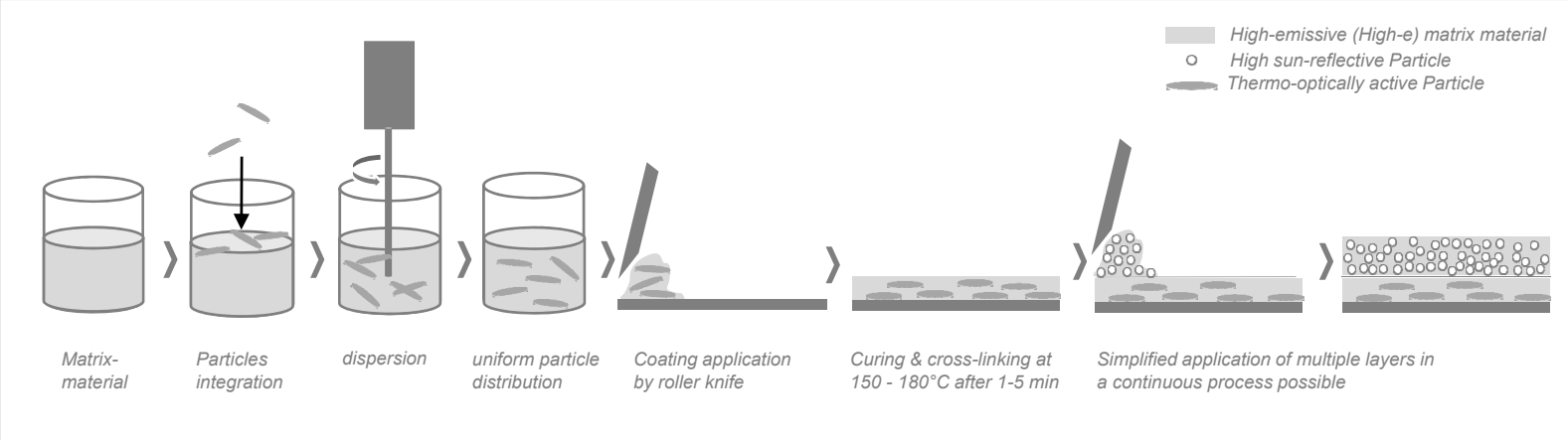
High ViS & NIR-reflectivity
High MIR-emissivity
Low transparency over all wavelengths

- Reduce temperature below the textile
- Cooling below ambient temperature (ΔT>0)
- Radiation exchange with space

- substrate-independent coating
- simple application
- high scalability

Development Steps

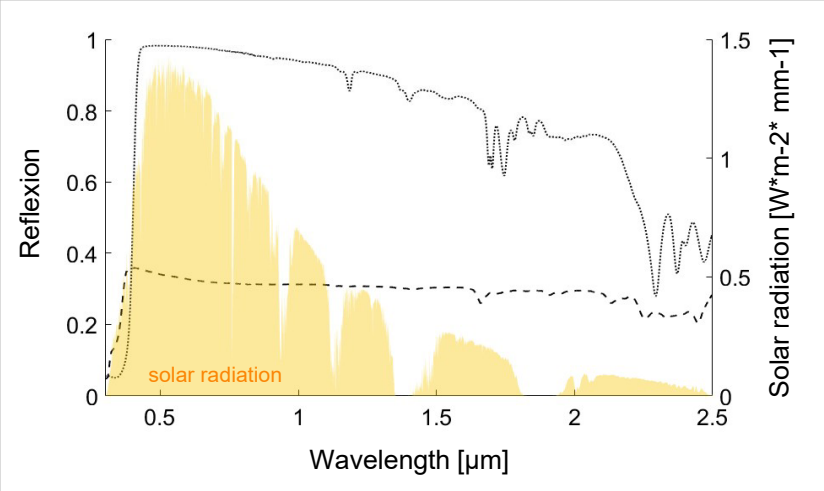
Coating application | Doctor-blade Coating



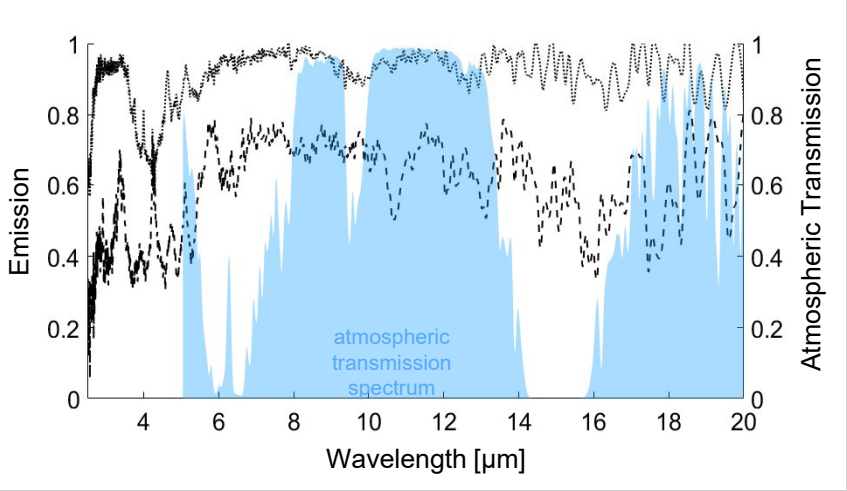
Development Steps

Spectral measurements | with and without self-cooling coating

Reflection ($\lambda = 0{,}3 - 2{,}5\ \mu m$)



Emission ($\lambda = 2{,}5 - 20\ \mu m$)

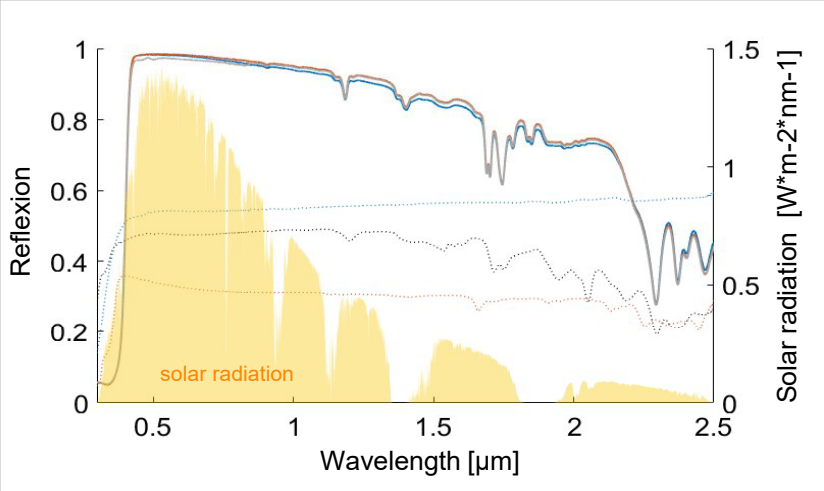


Textile with cooling coating
Reference textile without coating

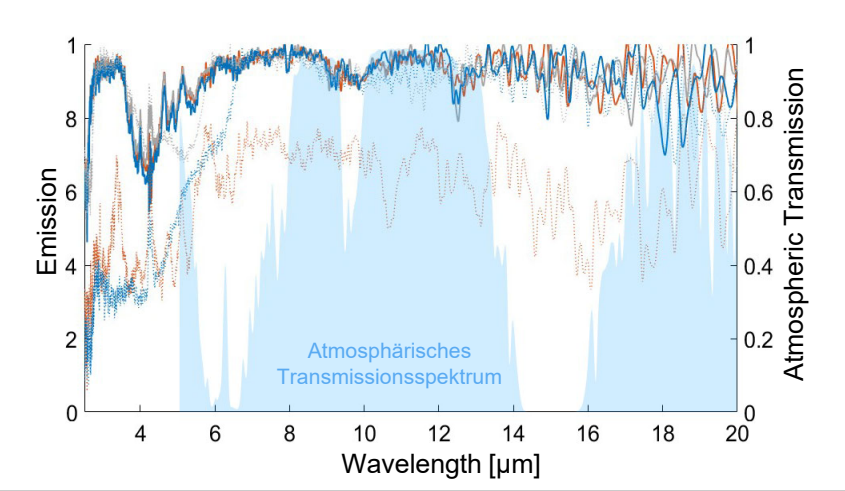
Development Steps

Spectral measurements | Substrate independence

Reflection ($\lambda = 0{,}3 - 2{,}5\ \mu m$)



Emission ($\lambda = 2{,}5 - 20\ \mu m$)



PA6.6 150 g/m²
Glas 163 g/m²
PES 65 g/m²

Textile with cooling coating
Reference textile without coating

Assessment and Validation

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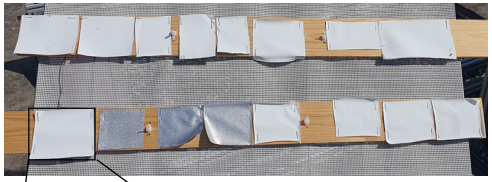
Weather stability | Long-term weathering on the institute roof



Weather extremes:
Hottest month: July (up to 43°C)
Most humid month (since 2017): November
Snow & freezing temperatures: November/December (up to -3°C)

Start of outoor exposure

Water-repellent surface no significant dirt build-up visible after one month

dirt particles are deposited on the surface

After wiping - no more dirt visible on the surface

Left side untouched since outdoor exposure
Right side last been wiped on 31.08.2023 – stays relatively un-dirty over a period of three month

Assessment and Validation

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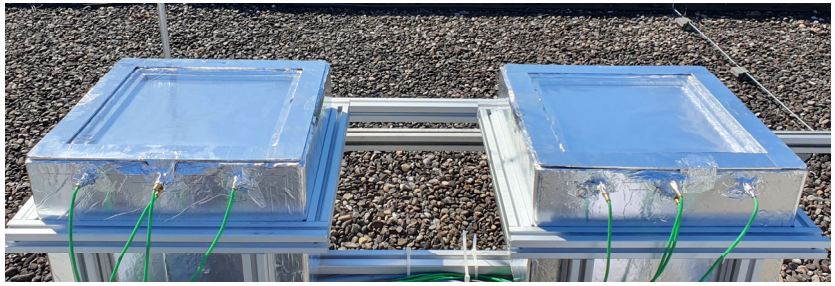
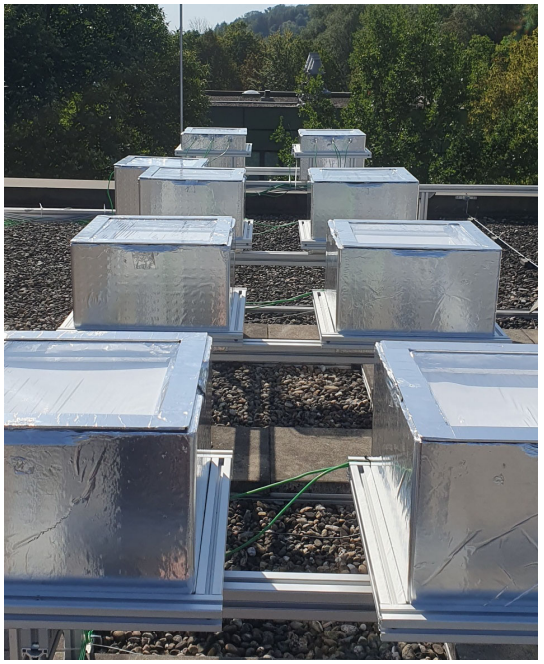
Measurement set-up | Measurement under real weather conditions

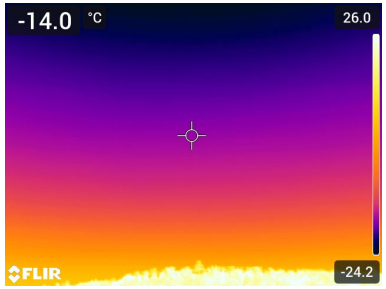
Measurement set-up on the rooftop of the Institute



Test module for measuring temperature and cooling performance



Test module for measuring temperature for direct comparison of different materials



The cold sky serves as a cold sink

Influencing values to be measured:

- Wind [m/s]
- Solar Radiation [W/m²]
- Humidity [%]
- Ambient Temperature [°C]
- Temperature of the sample [°C]
- Atmospheric Radiation

Assessment and Validation

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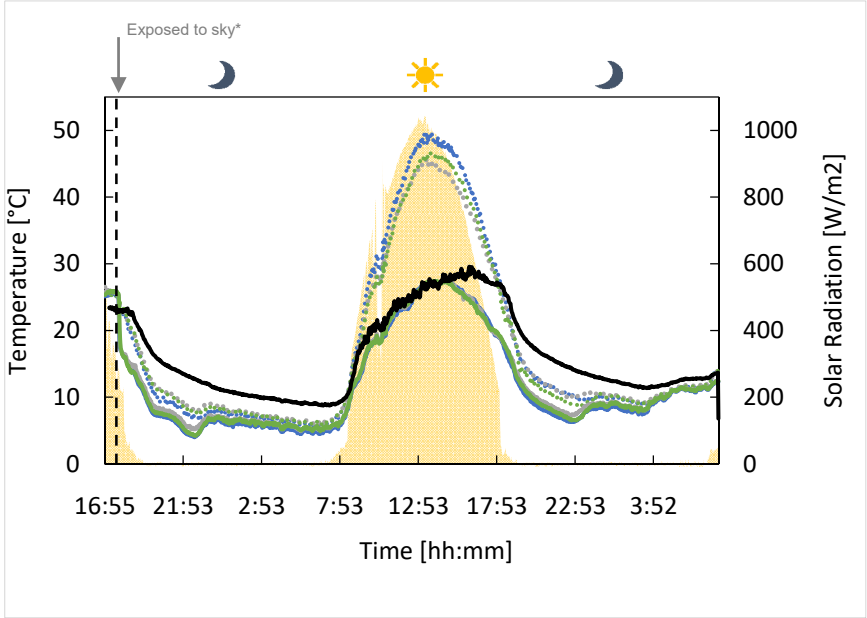
Temperature measurement | Cooling below ambient and Substrate Independent

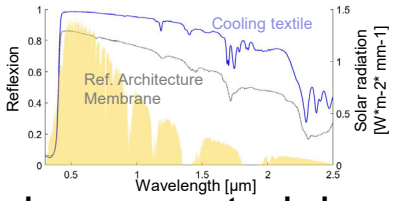


Textile-Sample	ØT [°C] (7 a.m. – 7 p.m.)		ΔT [°C]
	Without coating	With coating	
PES	33,3	19,8	**-13,7**
PA6.6	31,1	19,9	**-11,2**
Glas	30,7	20,0	**-10,7**
$T_{amb.}$	22,7°C		

Evaluation: ambient Daytime Temperature 20.09.2023

Ambient Conditions 20.09.2023 Denkendorf:
(7 a.m.-7 p.m.):
I sun= 587,4 W/m2
U wind = 0,7 m/s
RH = 59,3%

Assessment and Validation



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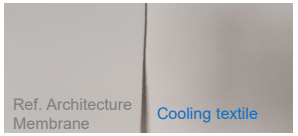
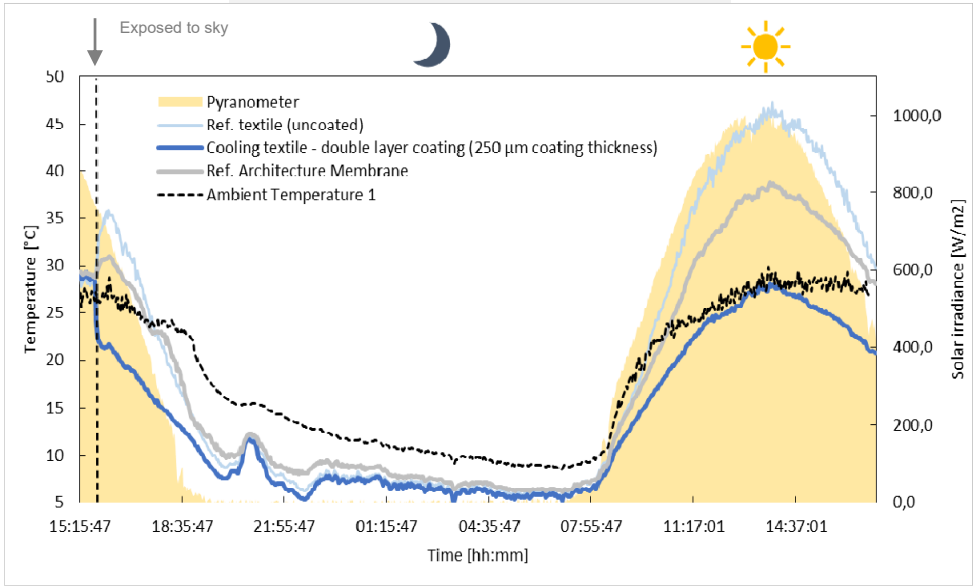
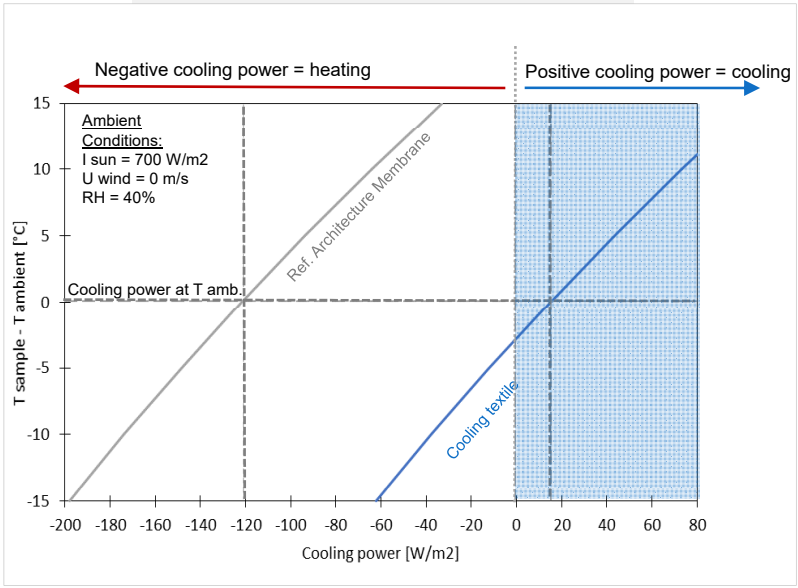
Comparison | commercially available architectural membrane material



Temperature Measurement > 24h



Cooling Power Calculation



Transfer of structural principles proven in nature for energy-free cooling

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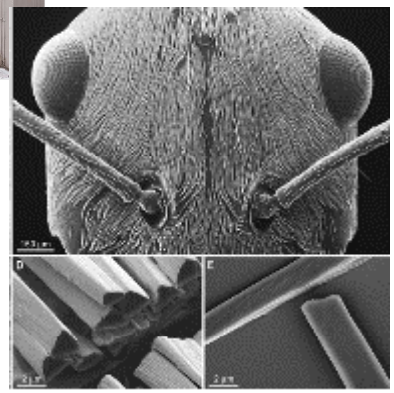
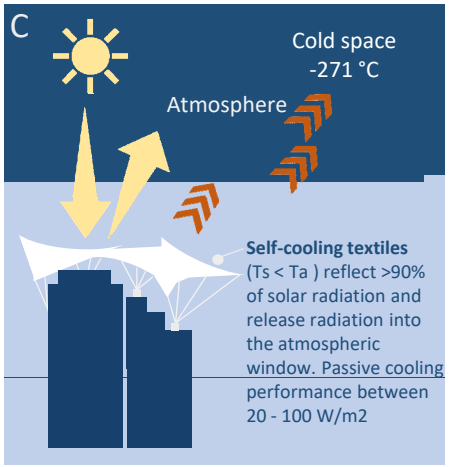
https://www.geo.de/natur/nachhaltigkeit/19353-rtkl-teufelskreis-wie-klimaanlagen-das-klima-aufheizen



Willot et al. „Total Internal reflection Accounts for the Bright Color of the Saharan Silver Ant“ (2016)

Self-cooling textile surfaces (Ts) remain colder than the surroundings (Ta) even at maximum solar radiation.



Reflection of solar radiation (ViS/NIR)
Heat emission (MIR)

Status of technology transfer

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Patent pending

Aimed for:
Demonstration building

“The extent to which current and future generations will experience a hotter and different world depends on choices now and in near-term” (IPPC-Report 2023)

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