Transsolar
KlimaEngineering

Physik - Mikroklima gestalten
Thermischen Komfort planen

Dr. Wolfgang Kessling

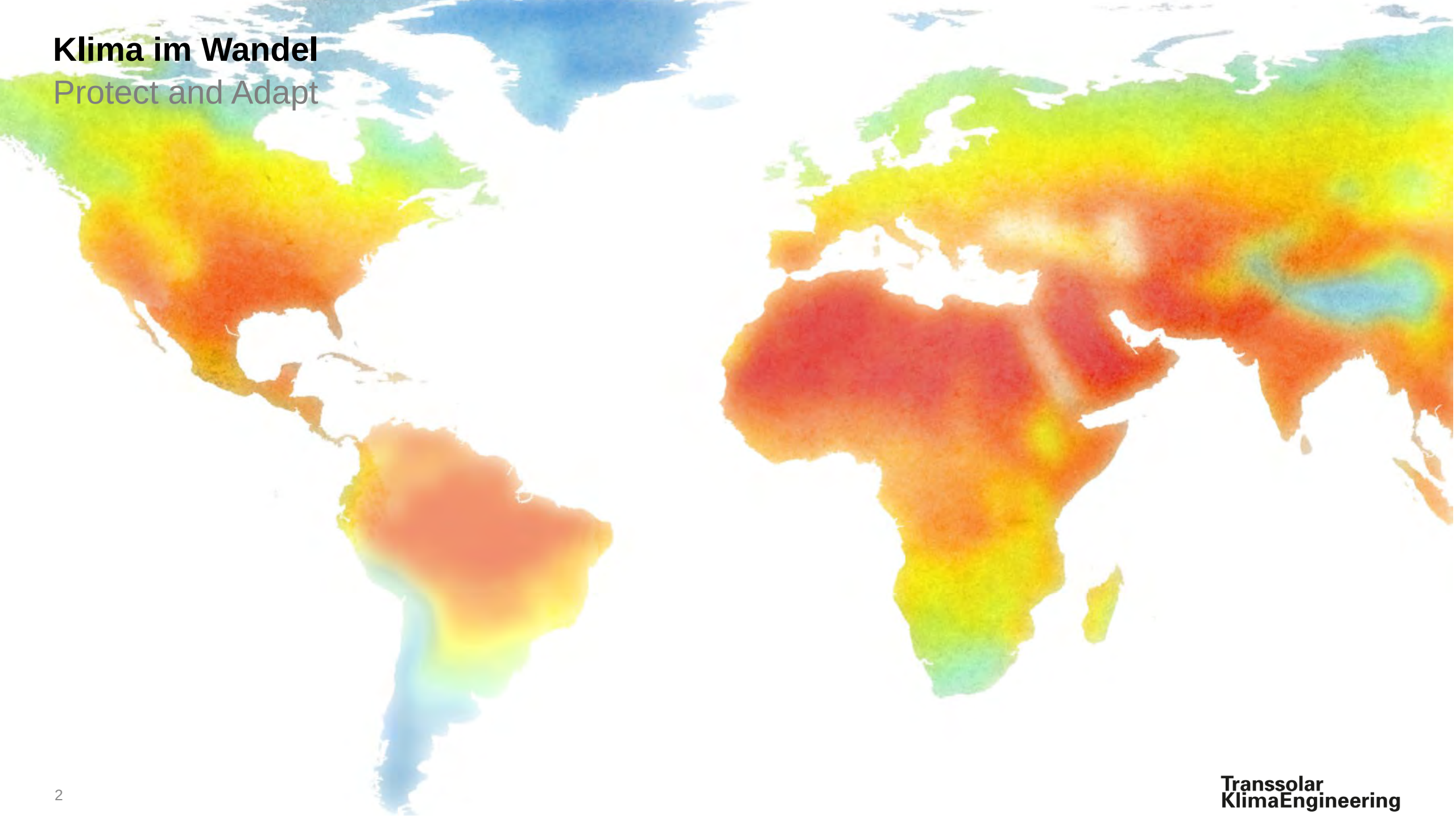
Transsolar

Sommerorte die Wirkung zeigen,
Runge, BDLA, DAM, Frankfurt

26. August 2026

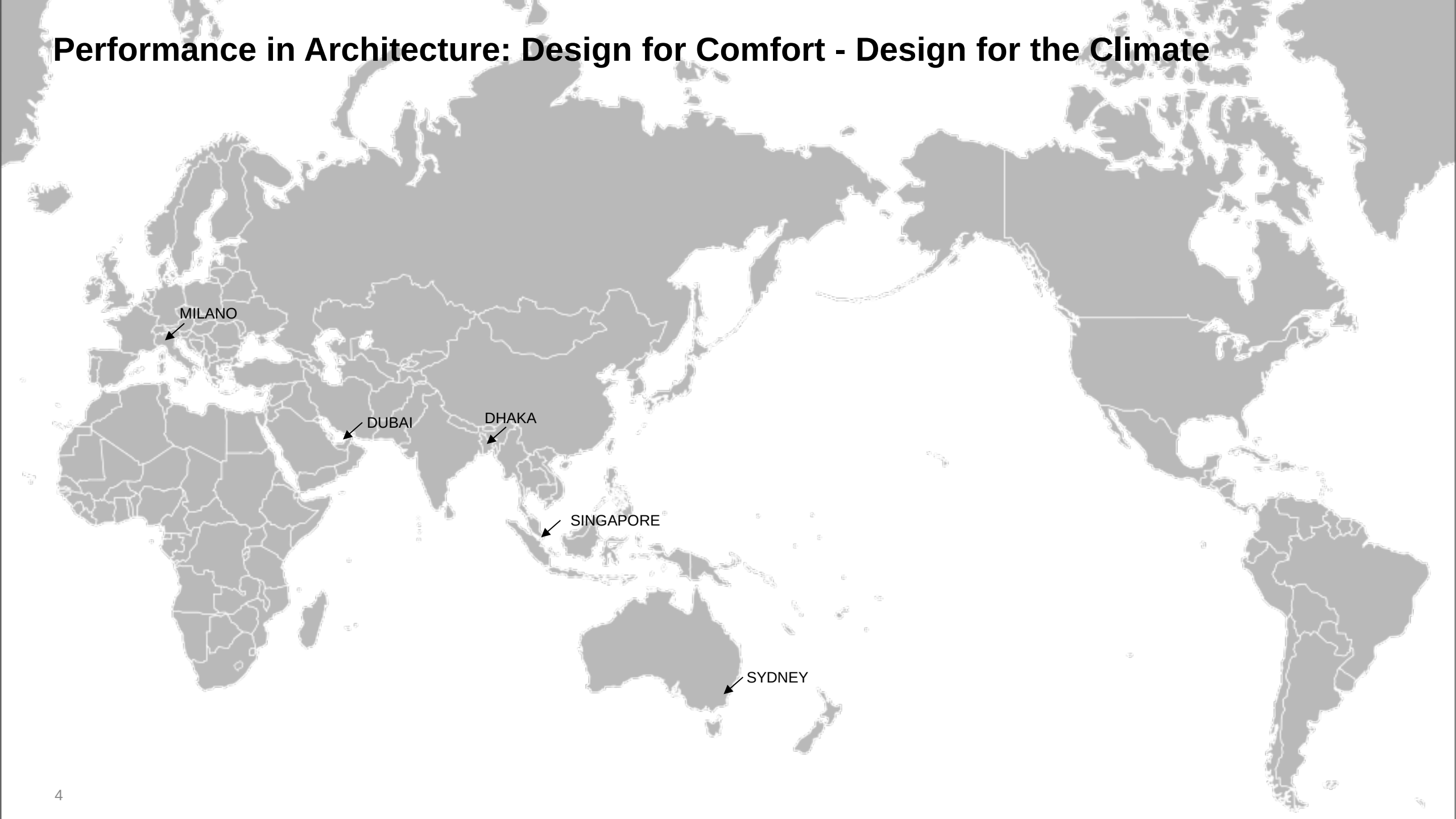
Klima im Wandel

Protect and Adapt



Transsolar KlimaEngineering

Performance in Architecture: Design for Comfort - Design for the Climate



CREATING COMFORT IN THE TROPICS

Client
NParks, Singapore

Gardens by the Bay
Landscape: Grant Associates, Bath

Cooled Conservatories
Architect: Wilkinson Eyre, London

Façade Engineering
A1 London; ARUP Singaproe

MEP
A10, London; CPG, Singapore

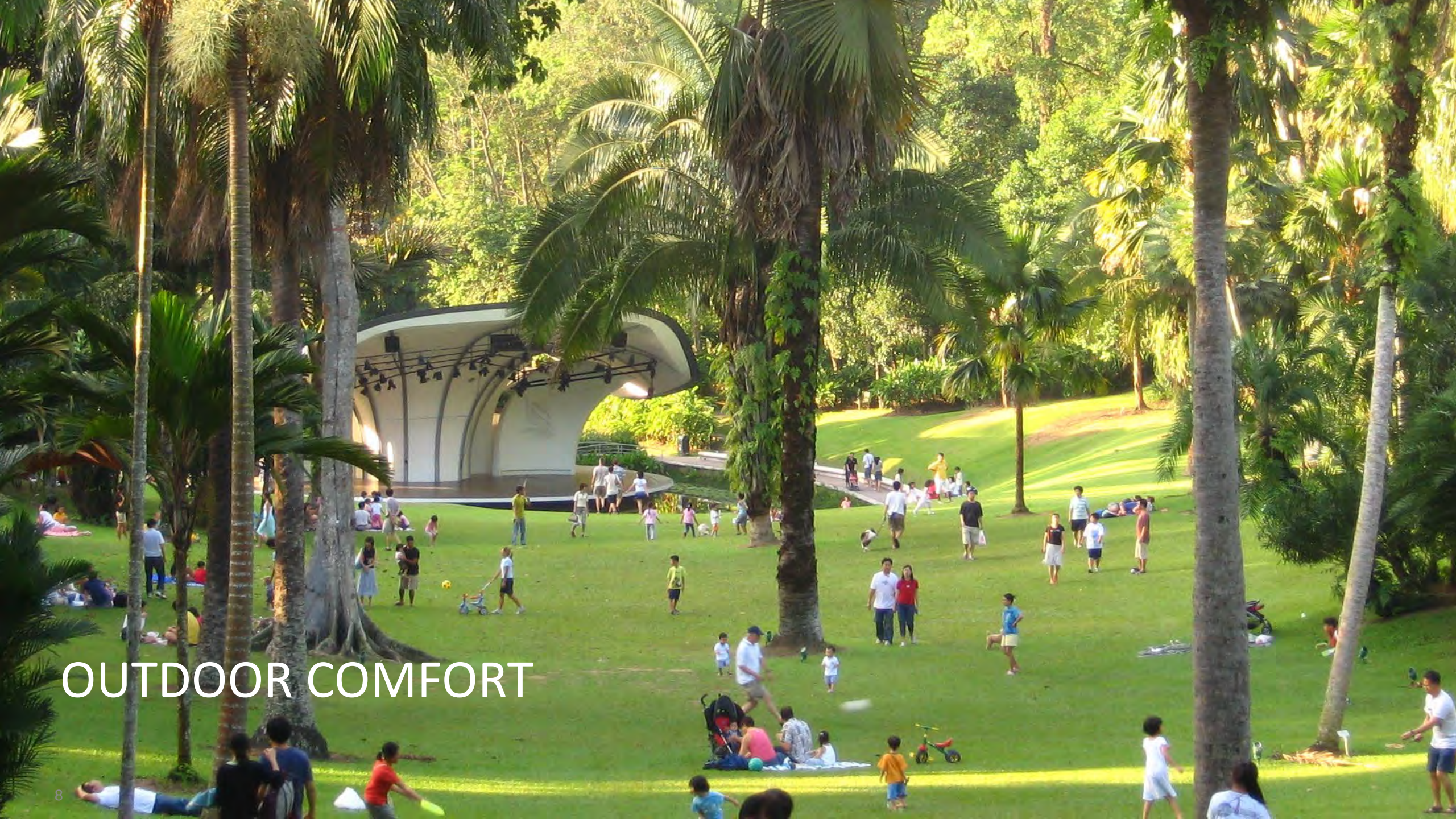
Credits: Grant Associates

COOL MOIST BIOME

Credits: Grant Associates

COOL DRY BIOME

Credits: Grant Associates



OUTDOOR COMFORT

Kuala Lumpur, es ist tropisch warm und feucht.
Was soll Wassernebel hier bewirken?


Interssant ist:
Wir wissen viel aber
wir verstehen nicht viel
von Komfort

KOMFORT IM FREIEN

WORAUF KOMMT ES AN?

Komfort im Außenraum?

Ziel im Außenraum ist es, die thermische Belastung zu reduzieren.

Sehr hohe Hitzebelastung

Hohe Hitzebelastung

Moderate Hitzebelastung

Keine thermische Belastung

Leichte Kältebelastung

Moderate Kältebelastung

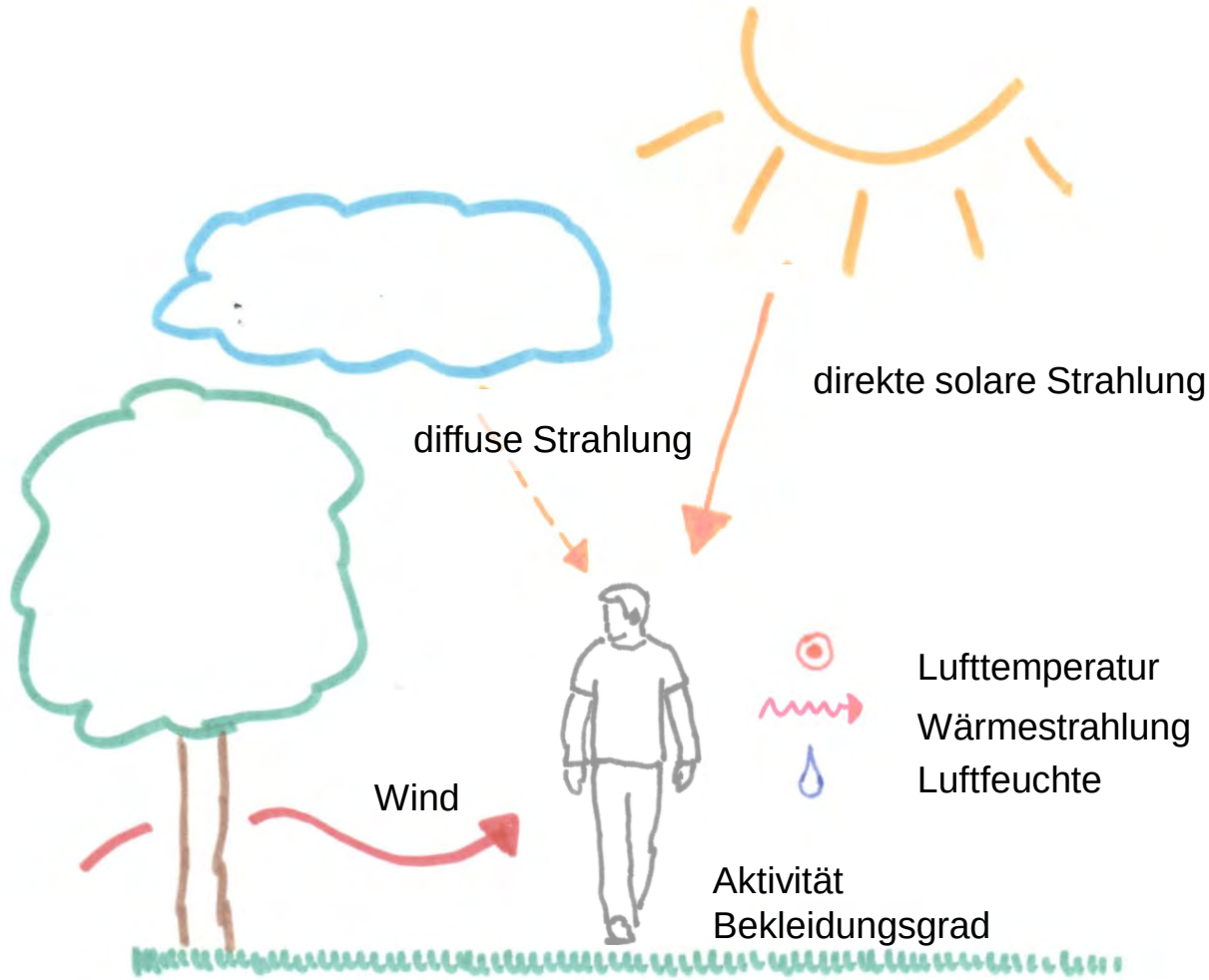
Hitzebelastung mindern

Reduce cold stress

Transsolar KlimaEngineering

Was ist Komfort?

Unser Körper produziert ständig Wärme. Wie gut wir diese Wärme loswerden, bestimmt unsere thermische Belastung.



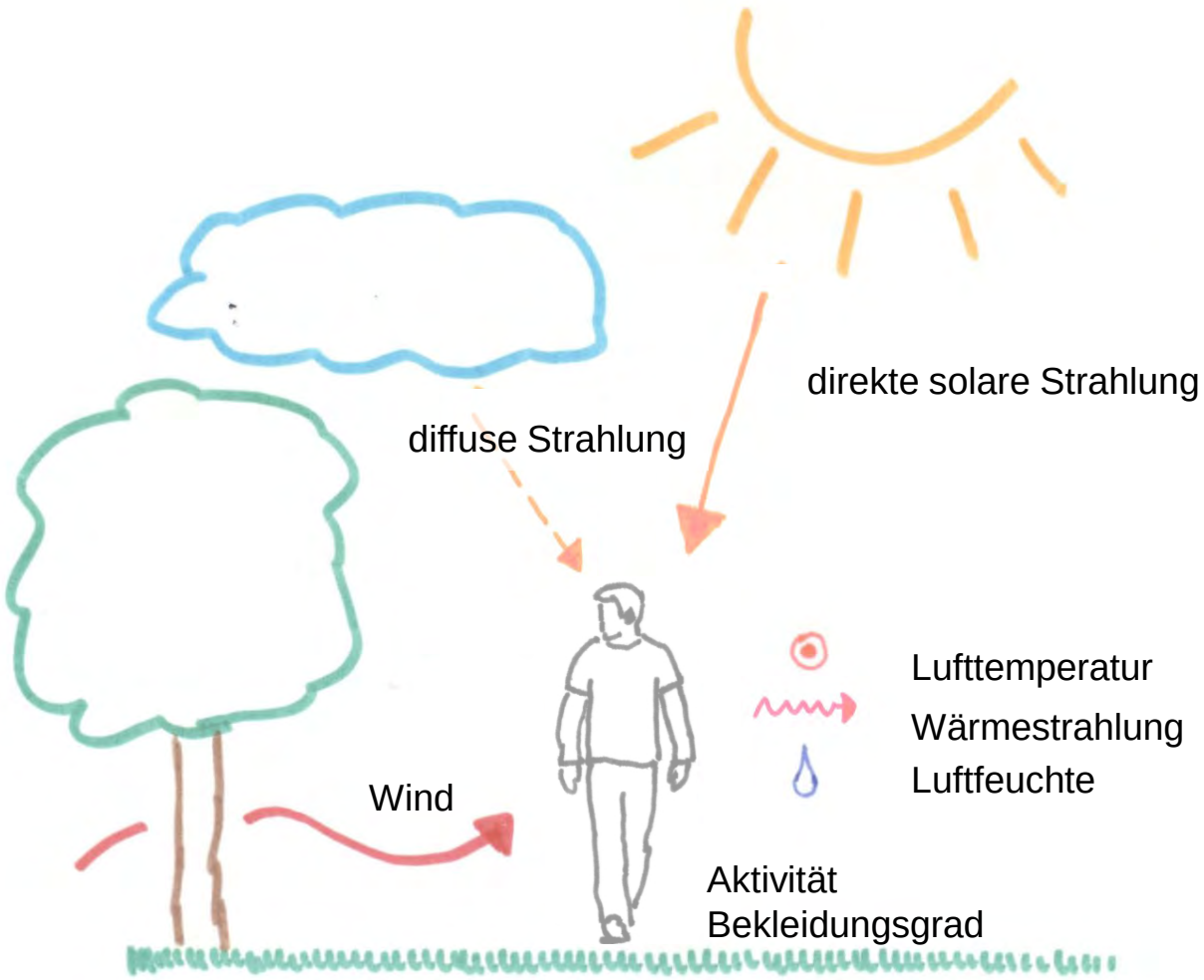
8 bioklimatische Parameter beeinflussen, wie wir uns thermisch fühlen.

Transsolar KlimaEngineering

Wir sind Sensoren

Drei Umweltparameter bestimmen im Wesentlichen, wie wir Wärme und Kälte empfinden.

Ihr Einfluss verschiebt sich mit der Lufttemperatur.



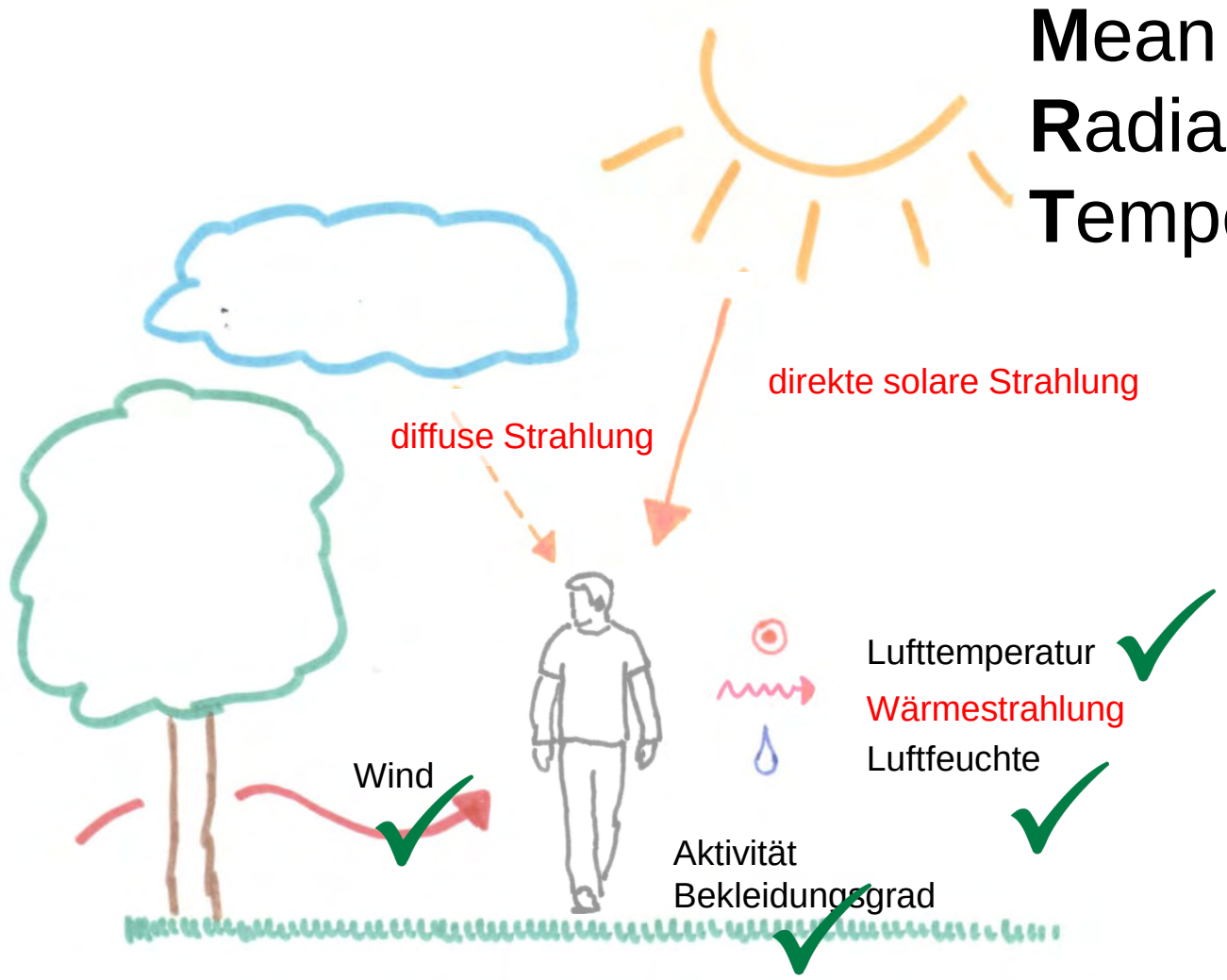
1. **Lufttemperatur**
   Sommer / Winter / Jahreszeiten
2. **Mittlere Strahlungstemperatur**
   Sonne / Schatten / Wärmestrahlung
3. **Wind**
   Luftbewegung / Windchill
4. **Luftfeuchtigkeit**
   Verdunstung / Transpiration

Transsolar KlimaEngineering

MITTLERE STRAHLUNGS-TEMPERATUR

Mean Radiant Temperature - mittlere Strahlungstemperatur

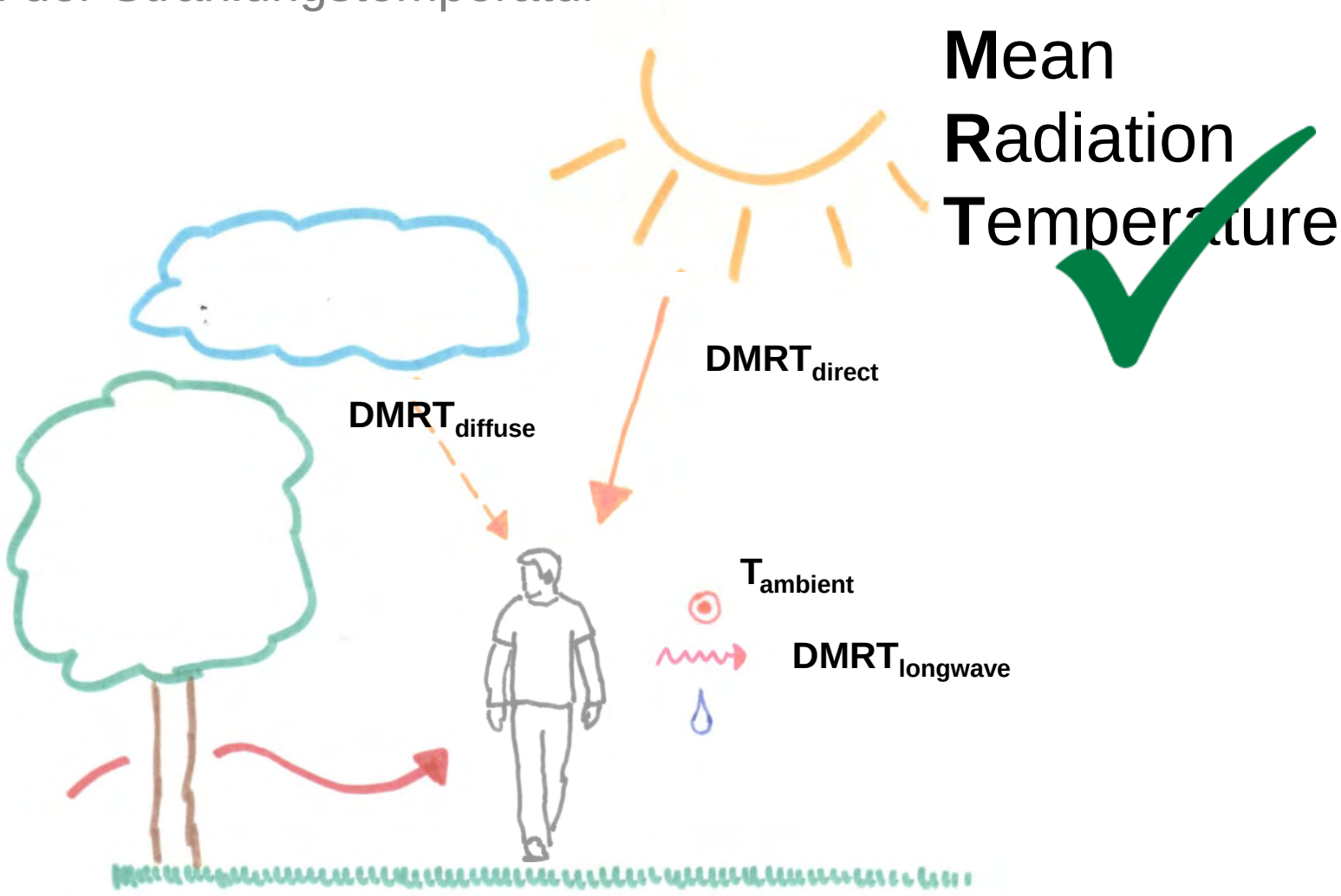
Wie bekommt man schnell ein Gefühl für die mittlere Strahlungstemperatur?



Transsolar KlimaEngineering

Mean Radiant Temperature - mittlere Strahlungstemperatur

Die drei Komponenten der Strahlungstemperatur

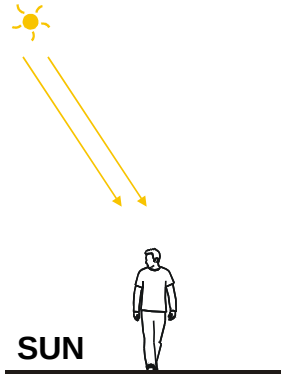


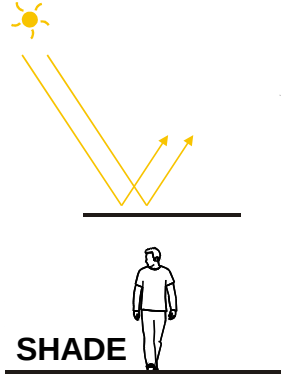
$$MRT = T_{ambient} + (DMRT_{diff} + DMRT_{dir} + DMRT_{lw})$$

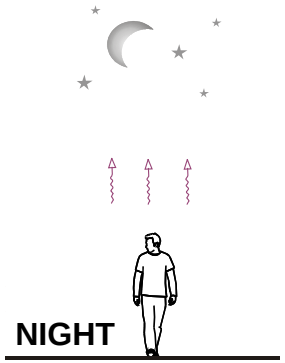
Transsolar KlimaEngineering

Mean Radiant Temperature - mittlere Strahlungstemperatur

Strahlungstemperatur – drei typische Bereiche: Sonne, Schatten, Nacht







MRT = T_{amb} + 20 Grad sonniger Tag, leichte Wolken
+ 30 Grad unverschattet, heißer dunkler Boden
heiße Hauswände

MRT = T_{amb} + 5 Grad gut verschattet durch Gebäude

MRT = T_{amb} unter Bäumen, umgeben von gut gewässerter Vegetation

MRT = T_{amb} - 10 Grad klarer Nachthimmel

Transsolar KlimaEngineering

Mean Radiant Temperature

Want to know more?

PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany 10-12 September 2013

The Human Bio-Meteorological Chart

A design tool for outdoor thermal comfort

WOLFGANG KESSLING, MARTIN ENGELHARDT, DANIEL KIEHLMANN

Transsolar Energietechnik GmbH, Munich, Germany

ABSTRACT: A simplified method is proposed to estimate human outdoor thermal comfort for a given situation using hourly climate data of ambient temperature and humidity. This so called human bio-meteorological chart is overlaid on the psychrometric chart and can be used to study and compare very quickly the effect of outdoor comfort strategies such as sun exposure, shading, sky cooling or wind protection on thermal comfort. To calculate human comfort indices, typically 8 parameters need to be known. In particular the calculation of the long wave mean radiant temperature and the complex effect of the direct and diffuse radiation on the mean radiant temperature (MRT) is time consuming and requires detailed modeling of the radiant field. The simplifications to estimate the MRT and to reduce the numbers of parameters are justified in the second part of this paper. The simplification can be used for any kind of comfort index where the MRT is required as input.

Keywords: outdoor comfort, perceived temperature, mean radiant temperature, climate data analysis

INTRODUCTION

In an outdoor situation people have many adaptive opportunities and they can adjust their thermal requirements according to the weather conditions. However there is a lack of design tools that provide analysis of outdoor thermal comfort strategies, design tools especially for a quick statistical analysis of the strategies are in need.

There are typically 8 major parameters which define the comfort perception in outdoor situations: direct and diffuse solar radiation, long wave radiation, air temperature and humidity, wind velocity, activity and clothing (see *Figure 1*). When designing for outdoor comfort these parameters need to be analyzed with thermal dynamical simulation tools such as TRNSYS 17 3D which consider building materials, 3D geometry, hourly climate data, etc.. Modeling and simulating an open outdoor space e.g. a plaza can be time consuming.

To reduce the complexity and to quickly identify opportunities of the urban design to enhance outdoor comfort, the number of parameters can be reduced. It was found that with reasonable accuracy the local outdoor comfort can be qualified with a human bio-meteorological chart and design options can be

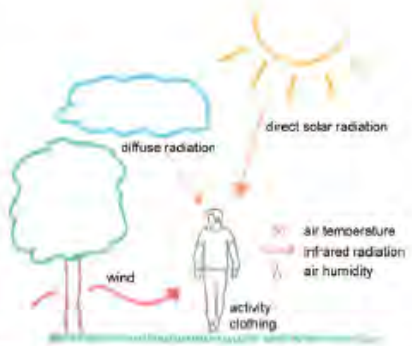


Figure 1: 8 major parameters to characterize outdoor comfort

EVALUATION OF HUMAN BIO-METEREOLOGICAL PARAMETERS

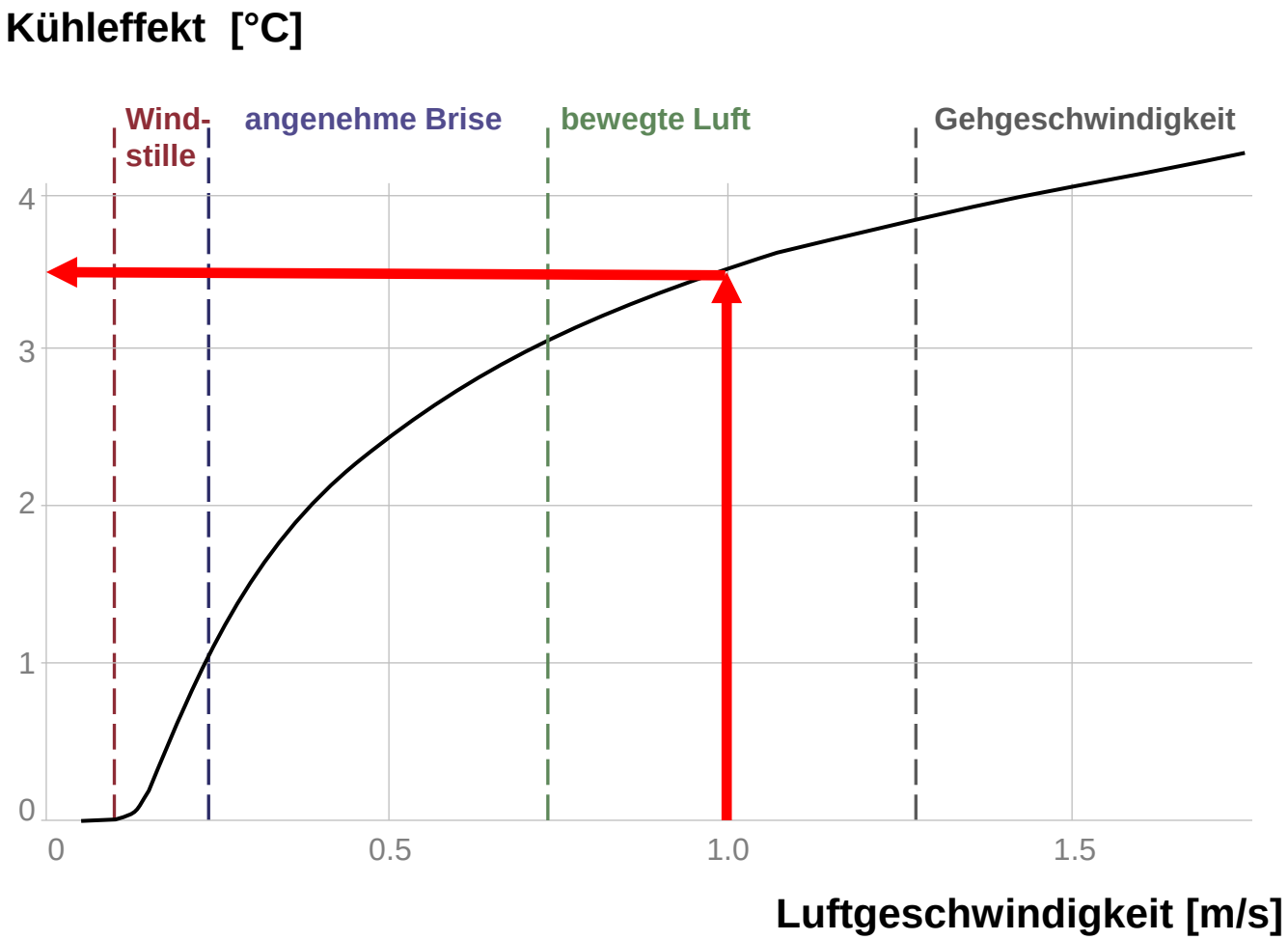
The German guideline VDI 3787 [1] is intended to provide evaluation methods linking together human biometeorology and overall physical planning. The first part of the guideline describes human bio-meteorological factors (comfort parameters). The

Download for free &
www. transsolar.com >> Publications

Transsolar KlimaEngineering

LUFTBEWEGUNG

Der Kühleffekt von Luftbewegung



Credits: Cooling Effect of Elevated Air Speed by Raftery & Douglass-Jaimes, 2020

Transsolar
KlimaEngineering

Wie beschreibt man Komfort im Freien?

Wie beschreibt man Komfort im Freien?

Bewertungsindex – UTCI

EINFLUSSFAKTOREN

Solarstrahlung
Infrarotstrahlung
} Mittlere Strahlungs-temperatur (MRT)

Lufttemperatur

Luftfeuchtigkeit

Windgeschwindigkeit

Bekleidungsgrad

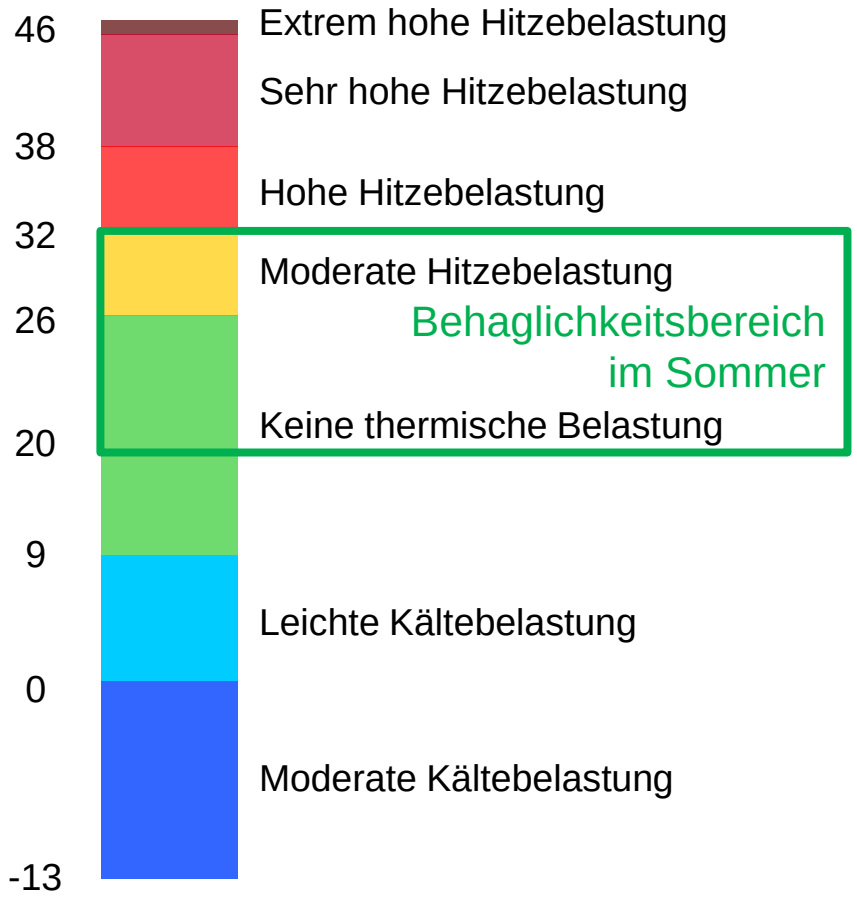
Stoffwechselrate

MODEL

UTCI

UNIVERSELLER THERMISCHER KLIMAINDEX [°C]

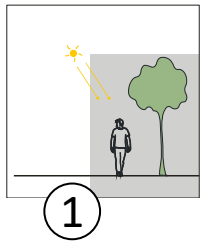
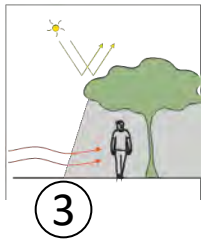
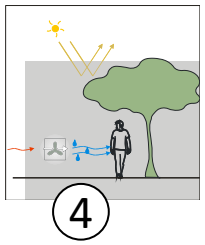
BEHAGLICHKEITSSTUFEN

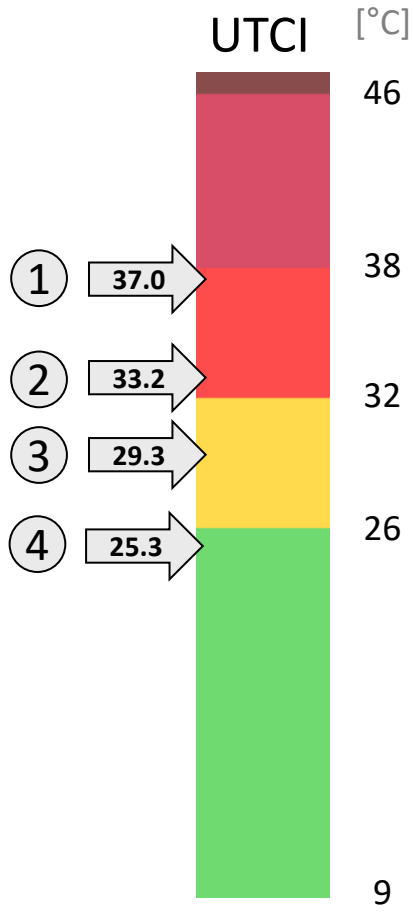


Transsolar KlimaEngineering

Was ist Komfort?

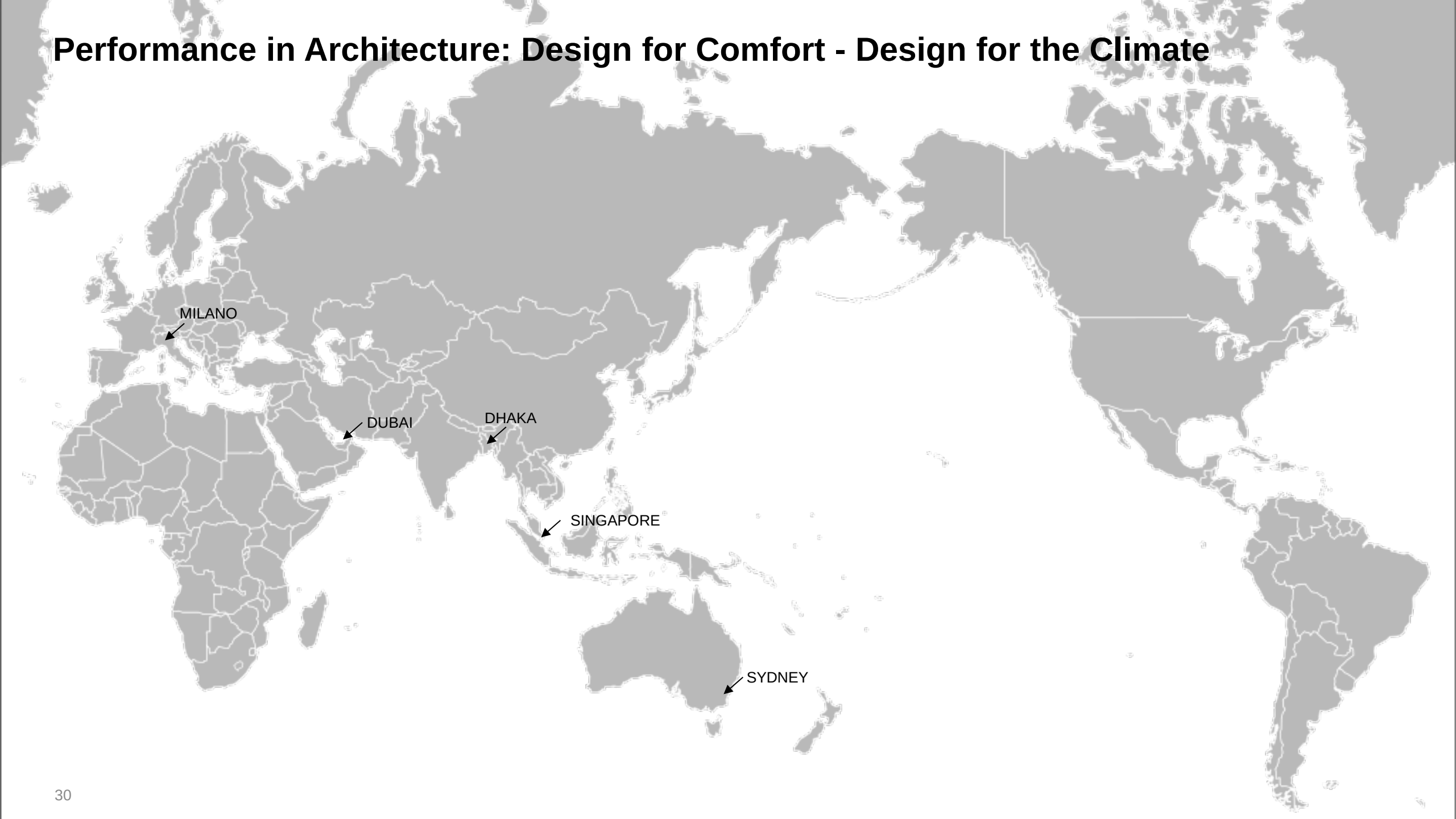
Strategien für den Außenkomfort

	SONNE KEIN WIND	SCHATTEN KEIN WIND	SCHATTEN BRISE	SCHATTEN DRY MIST
	 1	 2	 3	 4
Lufttemperatur	30°C	30°C	30°C	**26.5°C**
Luftfeuchtigkeit	17.2 g/kg	17.2 g/kg	17.2 g/kg	**18.6 g/kg**
Mittlere Strahlungstemp.	**50°C**	**35°C**	35°C	35°C
Windgeschwindigkeit	windstil	windstil	**Brise**	**Brise**
Bekleidungsgrad	0.5	0.5	0.5	0.5
Aktivitätsgrad	135 W/m²	135 W/m²	135 W/m²	135 W/m²



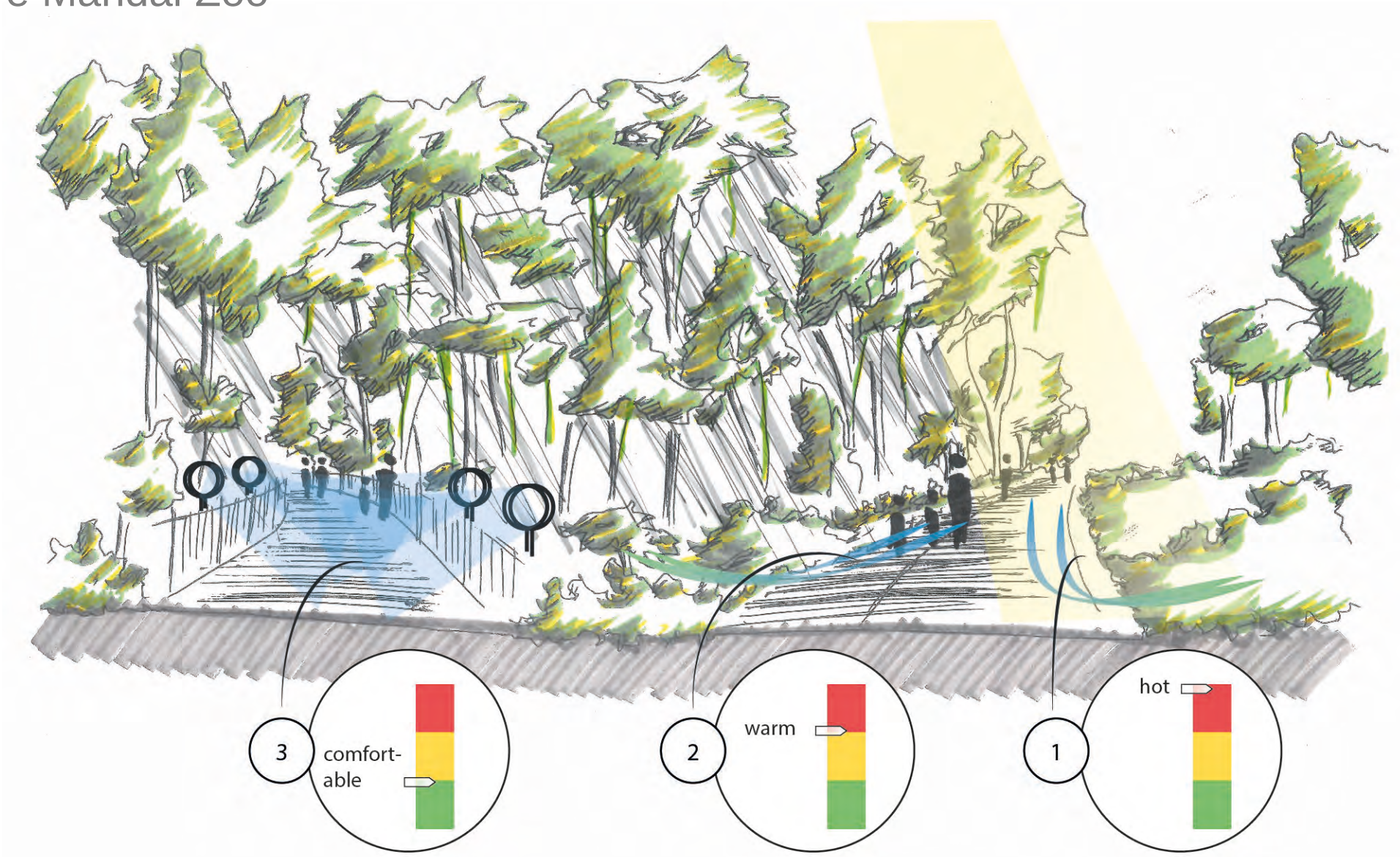
Transsolar KlimaEngineering

Performance in Architecture: Design for Comfort - Design for the Climate



Testing of Dry Mist

Singapore Mandai Zoo

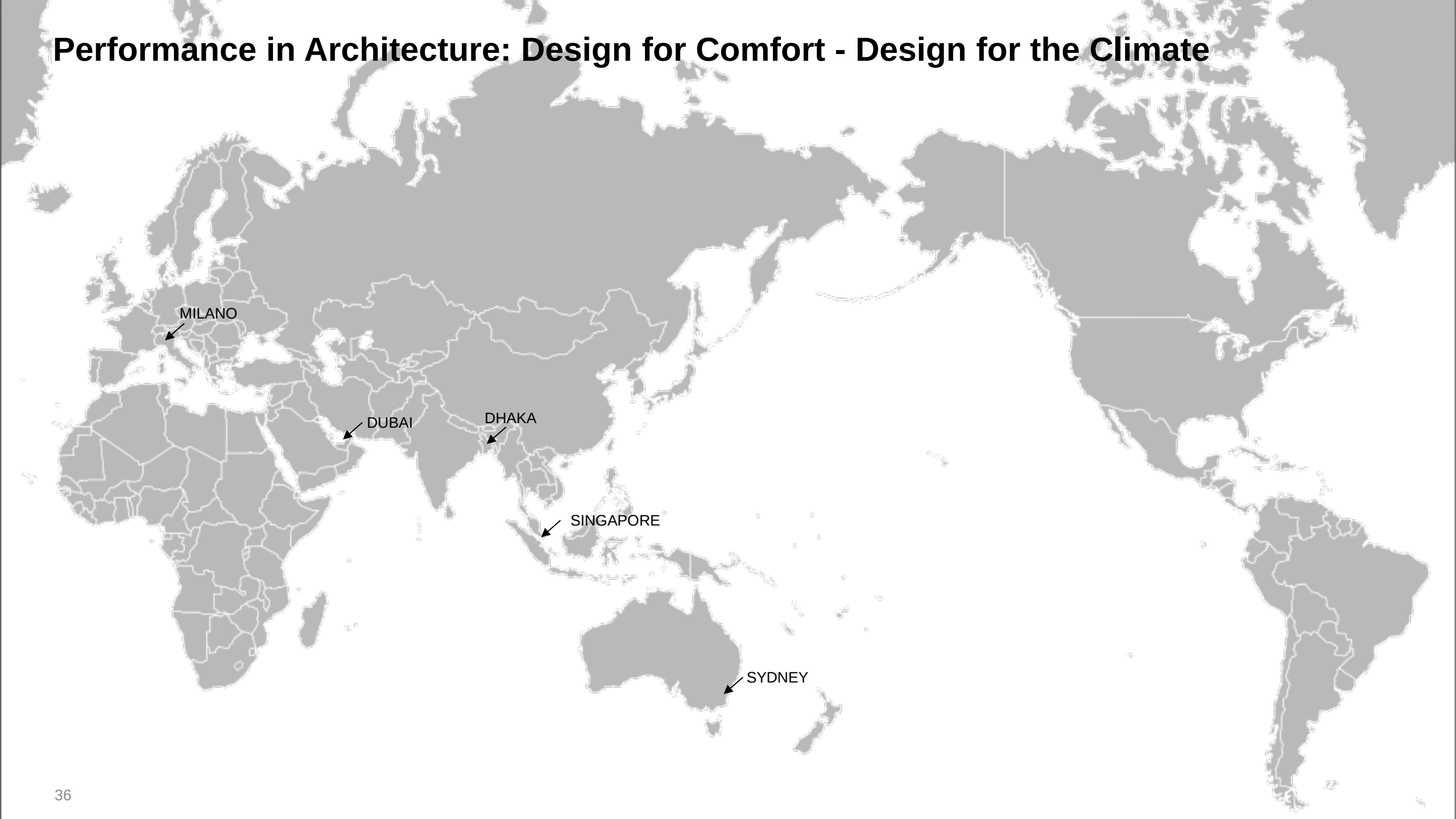


Transsolar
KlimaEngineering

DRY MIST

PEOPLE‘s RESPONSE

Performance in Architecture: Design for Comfort - Design for the Climate



Credits: Singapore Pavilion, Expo 2020 Dubai

Singaporean Pavilion EXPO Dubai, 2021

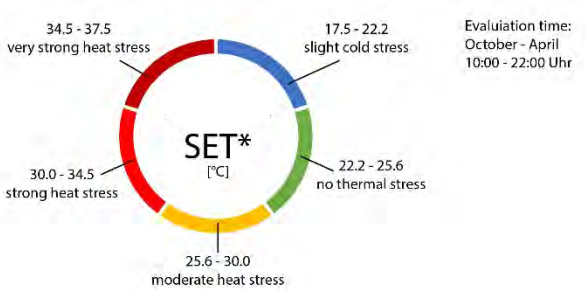
A green oasis in the coastal desert climate of Dubai

Client
URA, Singapore

Lead Architect and Creative
WOHA, Singapore

Climate and Energy concept

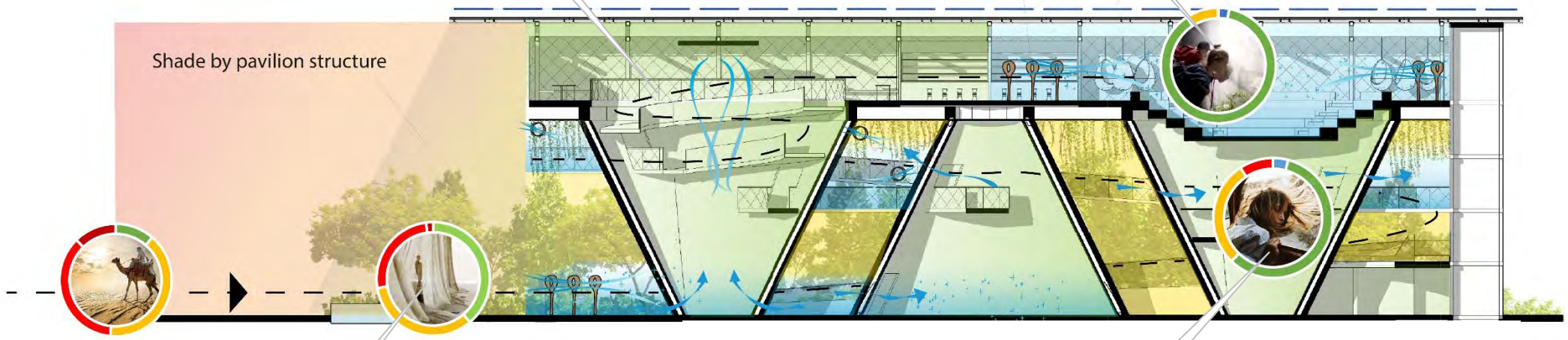
Creating a comfort story for visitors



Evaluation time:
October - April
10:00 - 22:00 Uhr

... enjoy staying in shade and vegetation...

... excellent comfort, linger and cool down...



...arriving in a protected area...

... breeze and comfort...

Transsolar KlimaEngineering

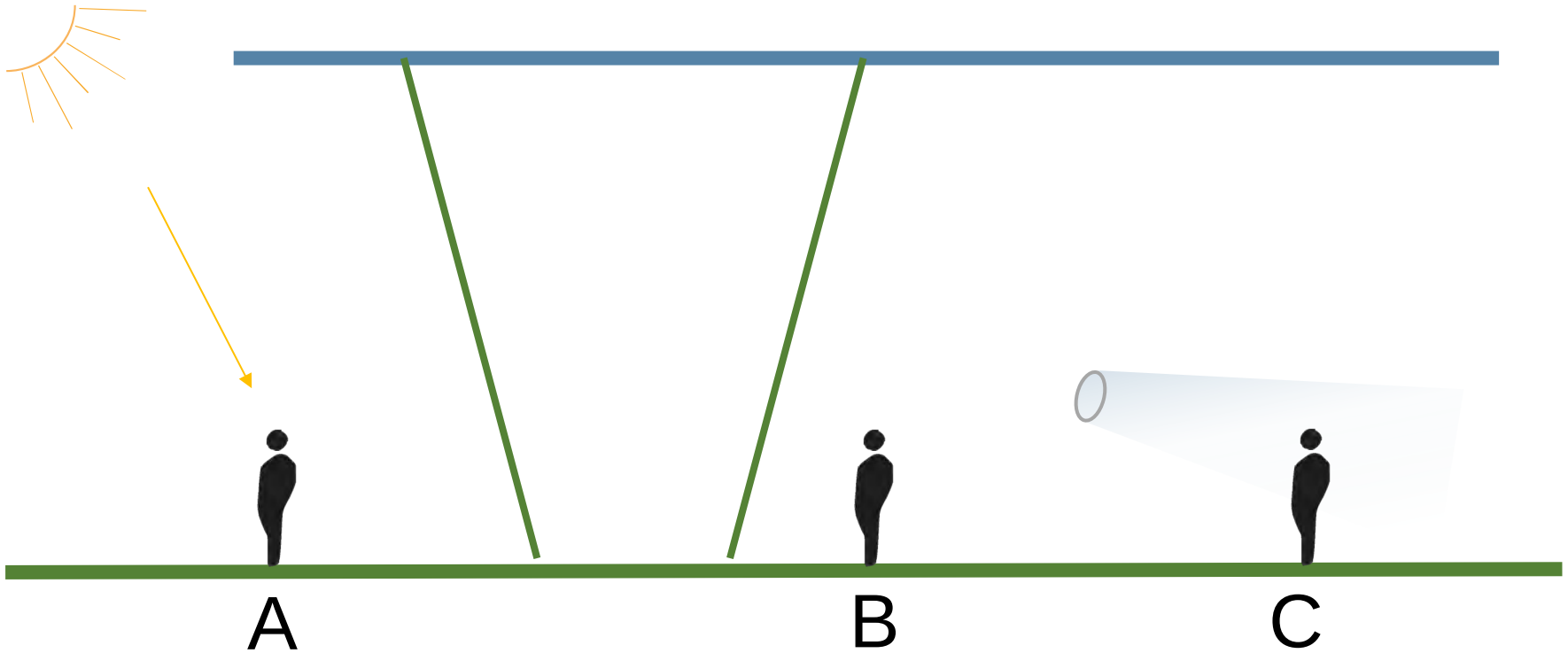
Credits: Singapore Pavilion, Expo 2020 Dubai

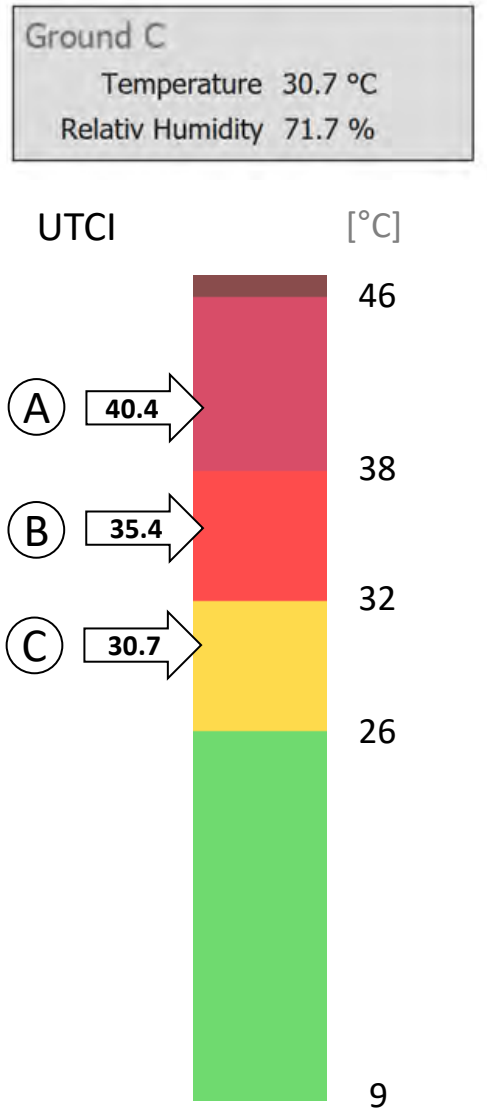

خروج
EXIT


Singapore

Performance of the Pavilion

Augmented with Dry Mist, the perceived temperature is reduced by about 10 degrees.





Unshaded in the sun, outside the pavilion

Shaded by the pavilion, surrounded by plants

Shaded by the pavilion in front of a Dry Mist Fan

Transsolar KlimaEngineering

Cool Plants and Comfortable Spaces

Want to know more?

Singapore Pavilion EXPO 2020 Dubai

TRANS SOLAR

Sustainable green in the desert sands

The Hanging Gardens of Semiramis, one of the seven wonders of the ancient world, were a testament to the extraordinary. Today, creating a sustainable green oasis in the desert doesn't require miracles, but rather ambitious and conscientious planning. This was demonstrated by the lush Singapore Pavilion at the Expo 2020 in Dubai. Transsolar from Munich was responsible for the environmental concept.

Expo in a Coastal Desert Climate
Dubai hosted Expo 2020, marking the first time an Arab country held a world exhibition. Despite a one-year delay due to the COVID-19 pandemic, the event attracted approximately 24 million visitors from across the globe with its theme of "Connecting Minds, Creating the Future." Throughout history, Expos have served as catalysts for innovative ideas, and Dubai's coastal desert climate presented a unique challenge. Typical new buildings are fully enclosed and air-conditioned - conditions that have come to be expected by locals. The aim was to design an open pavilion that could modify the existing climate without relying on air conditioning, creating a comfortable environment for visitors. The concept involved harnessing solar groundwater desalination to generate sufficient water for irrigation and implementing other measures to establish a locally pleasant climate.

Visitors at the Heart of the Design
Architecturally, an expo strives to showcase the extremes of possibility. However, the Singapore Pavilion was not solely created for artistic expression; it placed visitors at the center of its design.

The Munich-based Transsolar team focused on two fundamental questions: Could passive measures and extensive planting be employed to create pleasant outdoor spaces within an open pavilion that replicated the tropical environment of Singapore in Dubai's climate? Additionally, could the pavilion operate autonomously using only renewable energy and water resources?

Inspired by Singapore: Green "Climatecure"
The project was developed in collaboration with Singaporean firms WOHA Architects and Salad Dressing landscape architects. WOHA Architects is renowned for its sustainable and vegetation-centric approach to architecture and outdoor spaces, which effectively moderates local climatic conditions for enhanced comfort. At the heart of the Singapore Pavilion were three cone-shaped structures that supported multi-layered vertical and horizontal planting, symbolizing Singapore's vision of a city in harmony with nature. All the plants were sourced locally from nurseries in Dubai. The cones also served as platforms for the Sky Market, where visitors could experience various events and exhibitions. The pavilion's roof, adorned with an expansive photovoltaic system, provided shade for the Sky Market and supplied all the energy required for pavilion operations.

Cool Plants and Comfortable Spaces
After the completion of the pavilion, measurements confirmed that Transsolar's climate and comfort concepts, which were developed using digital models and simulation, translated effectively to reality. Visitors entering from the outside, where shade was scarce, experienced an immediate improvement in outdoor comfort as they ventured further into the pavilion.

Download for free &
transsolar.com/projects/singapore-pavilion-at-expo-2021 >> Paper

Transsolar KlimaEngineering


Am
Ende zählt,
wie wir uns fühlen

Transsolar
KlimaEngineering

Physik - Mikroklima gestalten
Thermischen Komfort planen

Dr. Wolfgang Kessling

Transsolar

Sommerorte die Wirkung zeigen,
Runge, BDLA, DAM, Frankfurt

26. August 2026