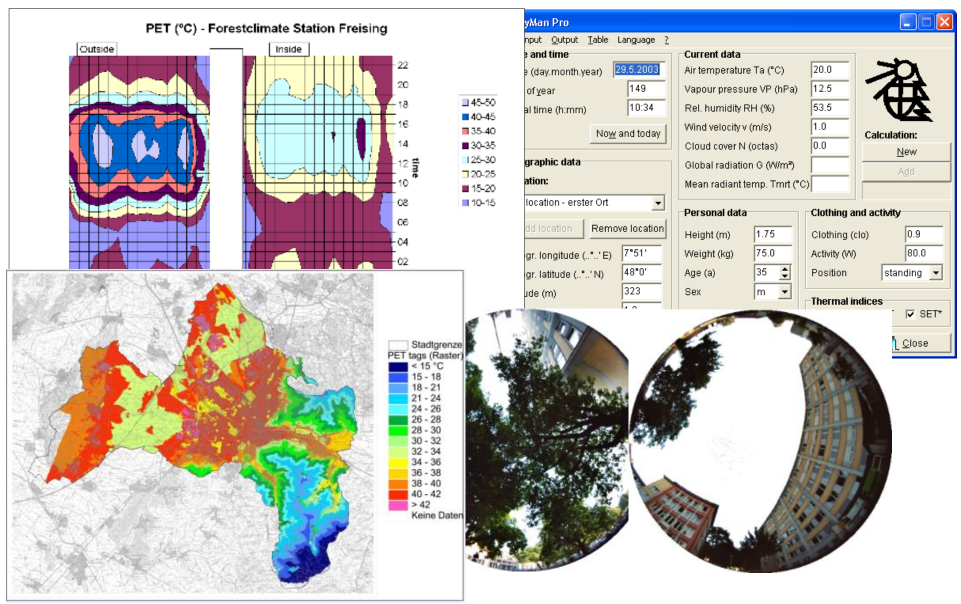
Estimation of urban bioclimate by micro scale models for the development of adaptation possibilities in cities



Prof. Dr. Andreas Matzarakis
Research Center Human Biometeorology
Deutscher Wetterdienst, Freiburg

Outlook/Questions

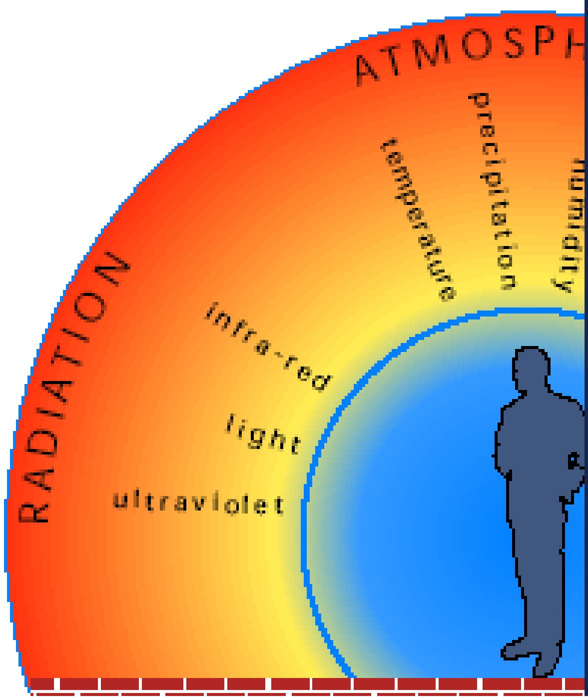
- ➔ Quantification of climate for cities
  - ➔ Air temperature? – Equivalent temperature (thermal indices)
- ➔ Measurements and simulations
  - ➔ Micro scale models
- ➔ Quantification of urban spaces
  - ➔ Long term analysis
  - ➔ Hot spot analysis
  - ➔ Climate change data/simulations
- ➔ Data visualization and transfer

Target: Human / Method

Models

Application and examples

Effect of the thermal atmosphere



Assessment of effects of climate

- Not only air temperature
- Air humidity
- Wind
- **Radiation**
- **Thermo-physiology (activity and clothing)**
- Energy balance of humans

- Physiologically Equivalent Temperature
- **Thermal index**

(Matzarakis, 2007)

Human energy balance

Under stationary conditions due to priciples of thermodynamics:
total of input energies = total of output energies

$$H + Q^* + Q_H + Q_L + Q_{Sw} + Q_{re} = 0$$

H: internal heat production (metabolic heat production - heat loss due to physical (mechanical) work)

Q^*: net radiation (radiative heat flux)

Q_H: turbulent flux of sensible heat (convection heat flux), interchange of sensible heat between the surface of the body and the ambient air

Q_L: turbulent flux of latent heat due to water vapour diffusion through the skin into the ambient air

Q_{Sw}: turbulent flux of latent heat due to sweat evaporation

Q_{re}: heat flux due to respiration (heating and humidification of respired air)

(VDI, 1998, Matzarakis, 2001)

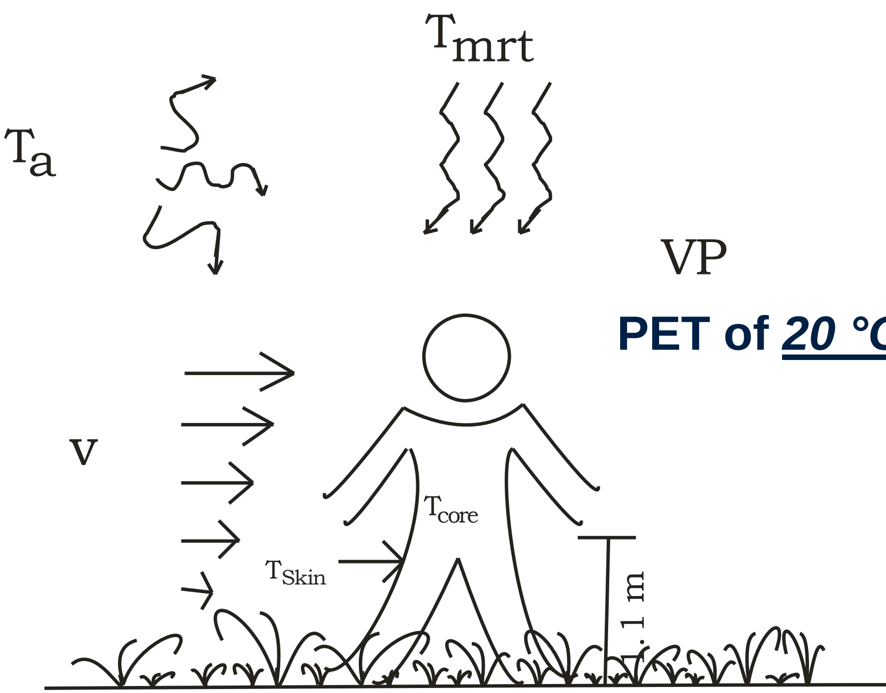
Modern Thermal Indices

(derived thermal indices: PMV, PET, SET*, PT, UTCI)

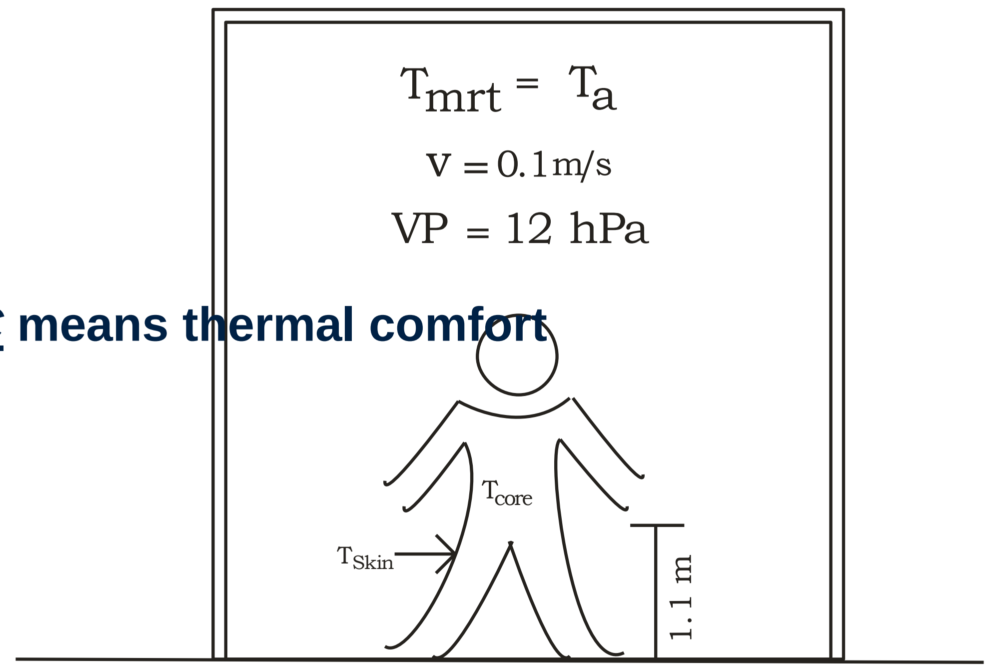
Physiologically Equivalent Temperature (PET):

Definition:

M_{work} = 80 W
I_{cl} = 0.9 clo



PET of *20 °C* means thermal comfort



Thermal indices – Assessment scale

PET	Thermal Sensitivity	Grade of Physiological Stress
	very cold	extreme cold stress
4 °C		
	cold	strong cold stress
8 °C		
	cool	moderate cold stress
13 °C		
	slightly cool	slight cold stress
18 °C		
	neutral (comfortable)	*no thermal stress*
23 °C		
	slightly warm	slight heat stress
29 °C		
	warm	moderate heat stress
35 °C		
	hot	strong heat stress
41 °C		
	very hot	extreme heat stress

Thermal indices (PMV, PET),
Thermal perception,
Physiological stresss

Threshold values of thermal indices PMV and PET for different grades of thermal sensitivity of human beings and physiological stress on human beings

(according to Matzarakis and Mayer, 1996)

Adjustment of scale (new):

Taiwan, Israel, (Nigeria), Greece, Hungary, …

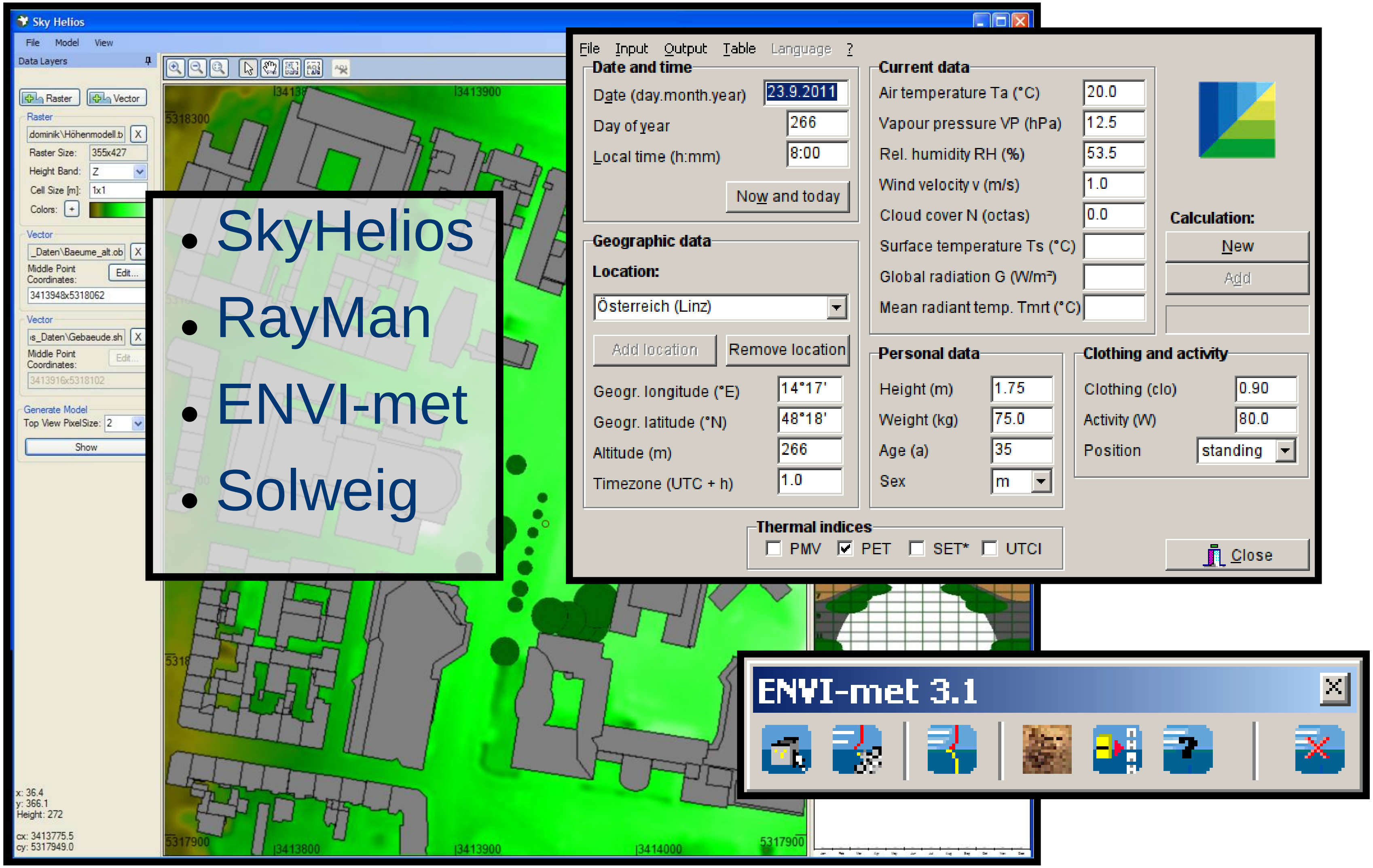
Target: Human / Method

Models

Application and examples

Micro scale models (free available)

- SkyHelios
- RayMan
- ENVI-met
- Solweig



RayMan Pro - A Tool for Applied Climatology

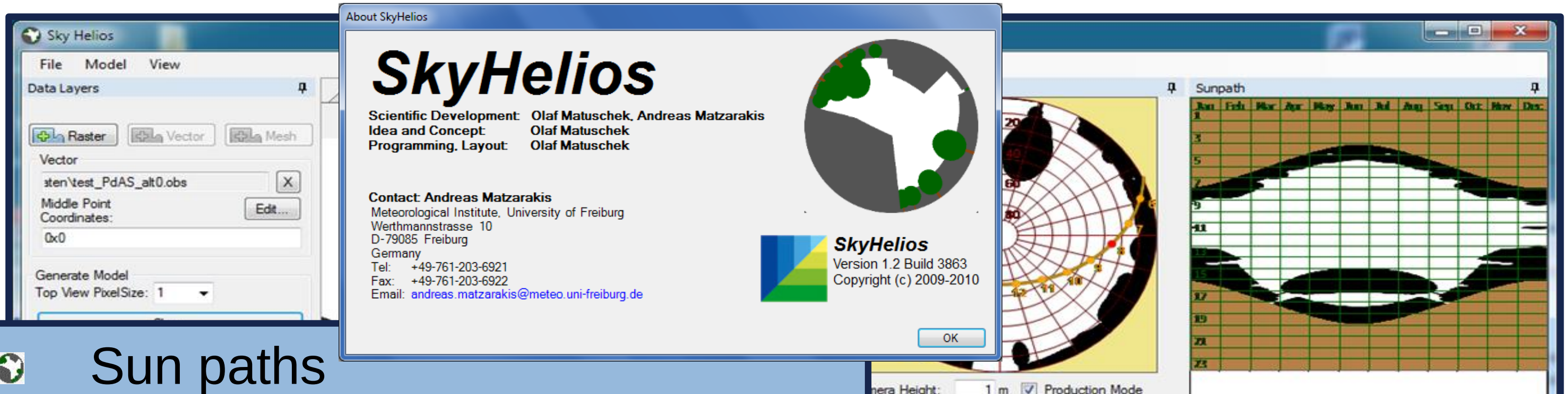
(urban climatology, human-biometeorology, tourism climatology, …)

- Sunshine duration
- Sun paths
- Shadow
- Global radiation
- Mean radiant temperature
- Predicted Mean Vote (PMV)
- Phys. Equiv. Temp. (PET)
- Stand. Effec. Temp. (SET*)
- Universal Thermal Climate Index (UTCI)
- Perceived Temperature (pT)
- new: mPET

- Simple environments
- Complex environments
- Topography
- Fish-Eye
- Hemisph. input/SVF
- Meteo data
- Climate data
- ....

RayMan Pro

SkyHelios



- Sun paths
- Sun duration/diagram
- Shade
- Sky view factor(s)
- Roughness
- Local climate zones (partially)
- Global radiation
- Mean radiant temperature
- Wind speed and direction
- PET and UTCI

- Vector and grid data
- Google Earth implementation
- Interfaces and outputs for RayMan
- Interface/Output for Climate Mapping Tool

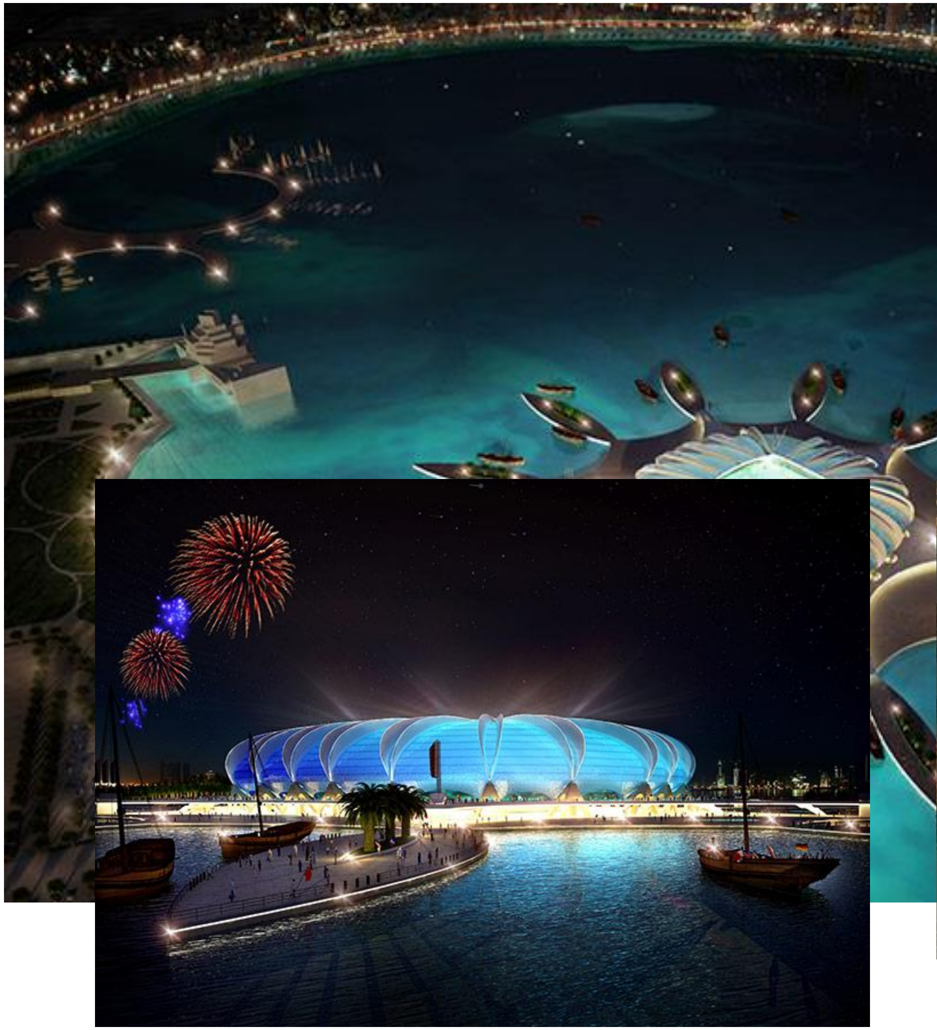
Target: Human / Method

Models

Application and examples

- Events (popular examples)

Events – Sports



Images: the guardian

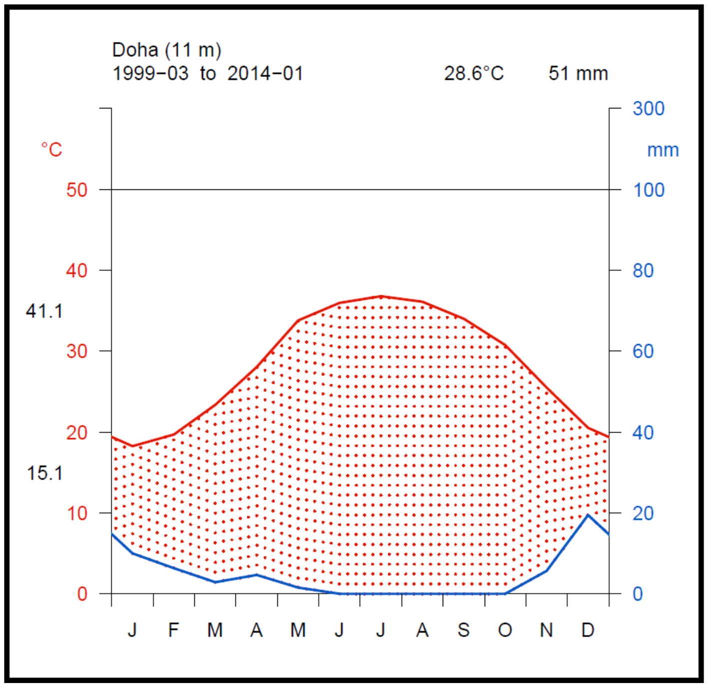
Exposition: Air condition

- HVAC
- Transfer/Transportation
- Adaptation humans

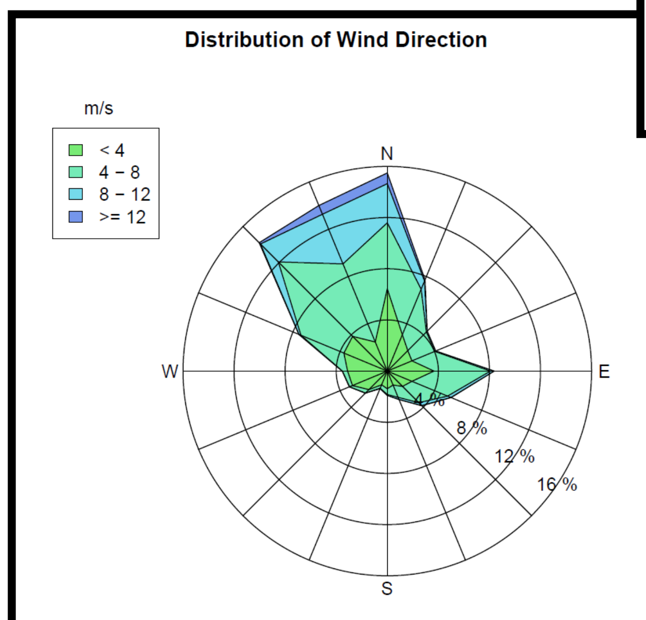
Images: the guardian

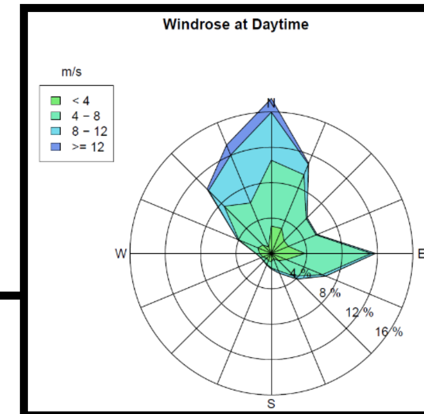
Climate data – Climate diagram

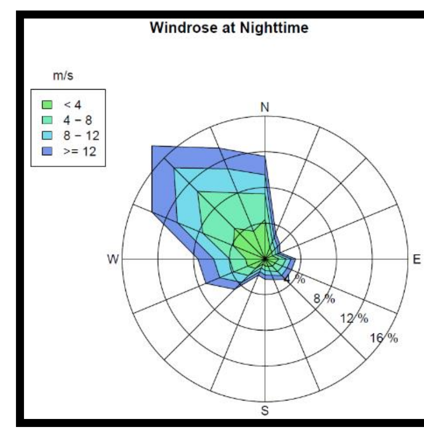
FIFA 2022



(Matzarakis and Fröhlich, 2015)







FIFA 2022

Science Now

Discoveries from the world of science and medicine

Scientific proof that a summer World Cup in Doha is too hot - for fans

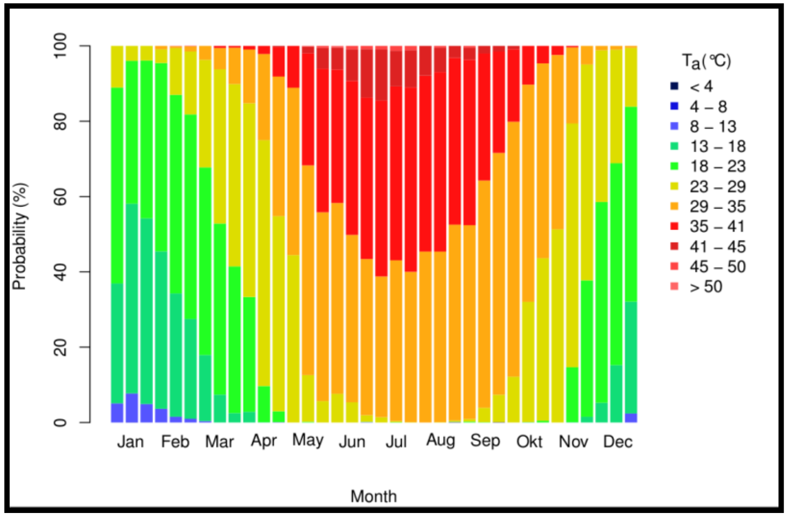
Fans support Argentina during the 2014 FIFA World Cup. A new study says that holding the 2022 tournament in Doha, Qatar, in the summer would be unbearable for most spectators. (Juan Mabromata / AFP/Getty Images)

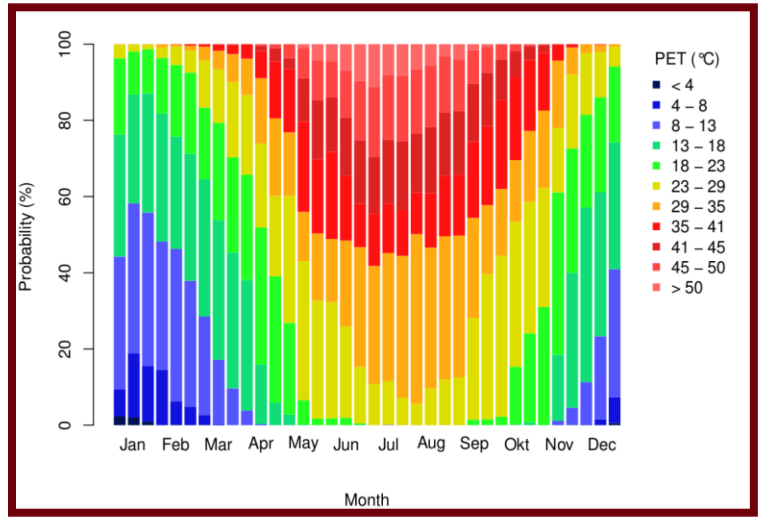
Los Angeles Time, 23. August 2014

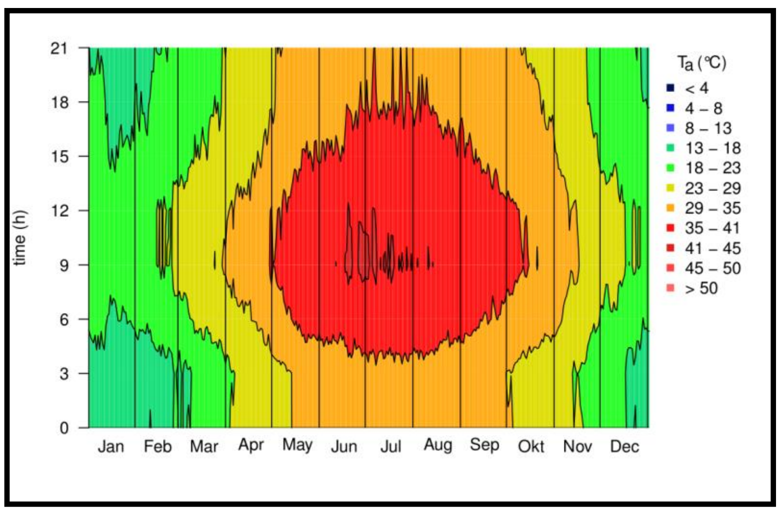
Doha, Ta, PET

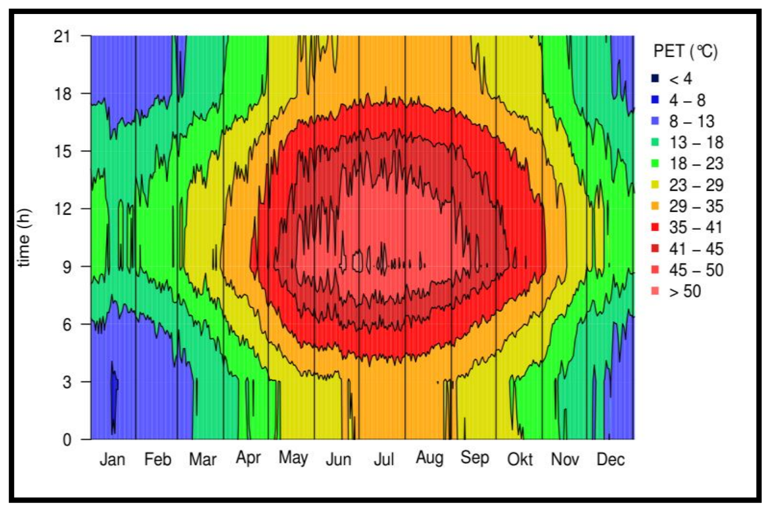
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

FIFA 2022









- < 4
- 4 – 8
- 8 – 13
- 13 – 18
- 18 – 23
- 23 – 29
- 29 – 35
- 35 – 41
- 41 – 45
- 45 – 50
- > 50

Period: March 1999 to Jan 2014

(Matzarakis and Fröhlich, 2015)

Controverse

A World Cup in Qatar's heat won't be safe for players – or even spectators

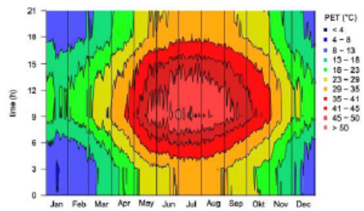
August 2014 — Qatar is currently scheduled to host the FIFA World Cup in the summer of 2022. There are many reasons why this is a terrible idea, but for now, let's just focus on one of them: the heat.

The average summer temperature in Qatar is 106 degrees Fahrenheit. In sweltering heat like that, nobody should be in direct sunlight for very long, let alone playing soccer at a world-class level for ninety minutes. But don't worry, the Qataris have a plan for reducing the pitch temperature to a less frightening 87 degrees in all of their open-roof stadiums: giant fans... lots of them. Good luck with that, wealthy oil tycoons.

The simple fact is that playing soccer outdoors in a Qatari summer isn't safe for players, and, according to a new report in the *International Journal of Biometeorology*,* it might not even be safe for spectators.

Researchers Andreas Matzarakis and Dominik Fröhlich of Albert-Ludwigs University in Freiburg, Germany gathered weather data for Doha – Qatar's capital and the designated home for 6 of the 13 World Cup stadiums – and distilled the collection into a metric called physiological equivalent temperature (PET). PET takes variables like wind, humidity, and solar radiation into account to produce what's essentially an estimated indoor temperature. For example, on an 80-degree day with copious amounts of sunlight and high humidity, the PET might be 95 or higher. Walking around outside would feel like

The 2022 FIFA World Cup in Qatar will be outlandishly, mind-bogglingly, barbeque-liciously hot. And that's putting it mildly. Check out this figure showing the calculated PET by time of day for Doha over the course of a year.



You're reading that graph correctly. Between 7 A.M. and 2:30 P.M. during the time of the World Cup, the average PET will be between 45 and 50 degrees Celsius or higher. Converted to Fahrenheit, that's between 113 and 122 degrees! At PETs like that, heat stroke, where the body's temperature rises above 104 degrees Fahrenheit, can occur in a manner of hours or less, Matzarakis says, depending on factors like age, clothing, and alcohol intake. Heat stroke can result in permanent organ damage

- Suggestion: Winter
- Contra: we can cool everything
- FIFA: now in Winter
- Diverse reactions and perceptions

18–23	Comfortable	No thermal stress
23–29	Slightly warm	Slight heat stress
29–35	Warm	Moderate heat stress
35–41	Hot	Strong heat stress
41–45	Very hot	Extreme heat stress

And here are the two levels added in order to fit a Qatari summer:

45–50	Very hot	Extreme heat stress
>50	Very hot	Extreme heat stress

sult of bribery, and a report assessing those allegations is due this fall. If claims of bribery are substantiated, it is highly likely that the 2022 World Cup will be relocated to the second place country, the United States.

— *By Ross Pomeroy at* www.realclearscience.com

* Matzarakis A, Fröhlich D. (2014) Sport events and climate for visitors – the case of FIFA World Cup in Qatar 2022. *Int J Biometeorol*. DOI 10.1007/s00484-014-0886-5

Counterpoint: Cooling open-air sports venues is not science fiction

September 2014 — There is often an element of fantasy linked to the idea of cooling outdoor football stadiums for the 2022 FIFA World Cup in Qatar.

Almost four years on from when I joined the Qatar 2022 Bid Committee and Qatar winning the rights to host the 2022 FIFA World Cup, people still ask me if it is possible to play football here in the summer. My answer is always the same: yes.

I was motivated to work for the Qatar 2022 Bid Committee because Qatar didn't shy away from challenges, they embraced them. As an architect, one always dreams of working on projects that can cause a paradigm shift in the field. After all, Qatar could simply build a retractable roof on a stadium to make things simpler, but then there wouldn't be any need for innovation.

To begin with, Qatar's Al Sadd Stadium, where Real Madrid and Spain legend Raúl González Blanco most recently plied his trade for two seasons, has had fully-functioning outdoor cooling systems working since 2008. Valves around the pitch and below each seat blow cool air into the arena, using traditional power generators. I took CNN International's Becky Anderson to a training session there last fall.

In September 2010, FIFA's technical inspectors attended a Qatar Stars League match at the same stadium between Al Sadd and Al Rayyan – the local derby – when the on-field and spectator tribune temperature was 19 degrees Celsius. And, that wasn't the only cooled venue FIFA visited in Qatar.

In 2010, I oversaw the project to build a prototype, 500-seat version of a proposed FIFA World Cup venue, to showcase specifically to FIFA how the state-of-the-art air cooling systems could be powered using solar energy work. We were able to lower the ambient air temperature to 23 degrees Celsius, when it was in the low 40s outside. FIFA was impressed on both counts.

We want players to have the best conditions for football. I used to live in Miami before coming to the Middle East and I remember watching Mexico play Ireland on television during the 1994 FIFA World Cup in the heat of Orlando (mind you, not uncommon summer weather for many cities across the Northern Hemisphere). Our concept will make sure all teams play comfortably in the same, safe conditions – creating a level playing field.

People then usually ask me: What about the fans?

This summer at a beach in Qatar, we tested our cooling systems in an open-air, custom-built fan zone for the 2014 FIFA World Cup in Brazil. The temperatures inside the fan zone were on average 12 degrees Celsius lower inside the venue.

Our bid was based on the sole intent of hosting the 2022 FIFA World Cup in the summer. We are offering solutions to keep players and fans comfortable – and developing those solutions to ensure that they are environmentally sustainable.

My team of technical and sustainability experts have worked with international climate specialists to analyse the reality of conditions likely to be experienced at the time of the tournament. Every firm who has been appointed to design one of our stadiums has been asked to demonstrate how they plan to cool the pitch to an optimal 26 degrees Celsius and shaded spectator stands to between 24 and 28 degrees Celsius.

This is well below the temperature of 32 degrees Celsius when FIFA requires a cooling break to be taken – as we witnessed at the Estádio Castelão in Fortaleza this summer during the Mexico vs. Netherlands round of 16 match.

Passive and active cooling in outdoor areas will connect stadiums to Qatar's transportation network. As spectators approach a stadium, the average temperature will slowly lower from approximately 32 degrees Celsius, to 26 degrees Celsius (± 2).

We will forge ahead implementing and developing this technology. Our commitment to this is grounded in the legacy it will offer for Qatar and countries with similar climates. It will enable sport to be played 12 months of the year. And, the application of this technology is not limited to stadiums or sport venues. It can be applied in public spaces, so people can enjoy outdoor activities all year round.

We understand the scepticism and respect the work that has gone into the study authored by Professors Andreas Matzarakis and Dominik Froehlich. However, we believe the experts currently developing these groundbreaking technologies will mitigate any concerns for players or spectators visiting Qatar in the summer, where the Qatar Stars League began playing official matches last week.

As with any innovative technology, doubts remain of whether we can deliver, but I believe we are beginning to demonstrate that cooling open-air sport venues is science fact and not science fiction.

— *Dario Cadavid is the Technical Assurance & Integration Senior Manager for the Supreme Committee for Delivery & Legacy, the Qatari government entity in charge of leading the country's preparations to host the 2022 FIFA World Cup Qatar. Source:* http://www.gulf-times.com/opinion/189/details/410296/cooling-open-air-sport-venues-is-no-science-fiction

Target: Human / Method

Models

Application and examples

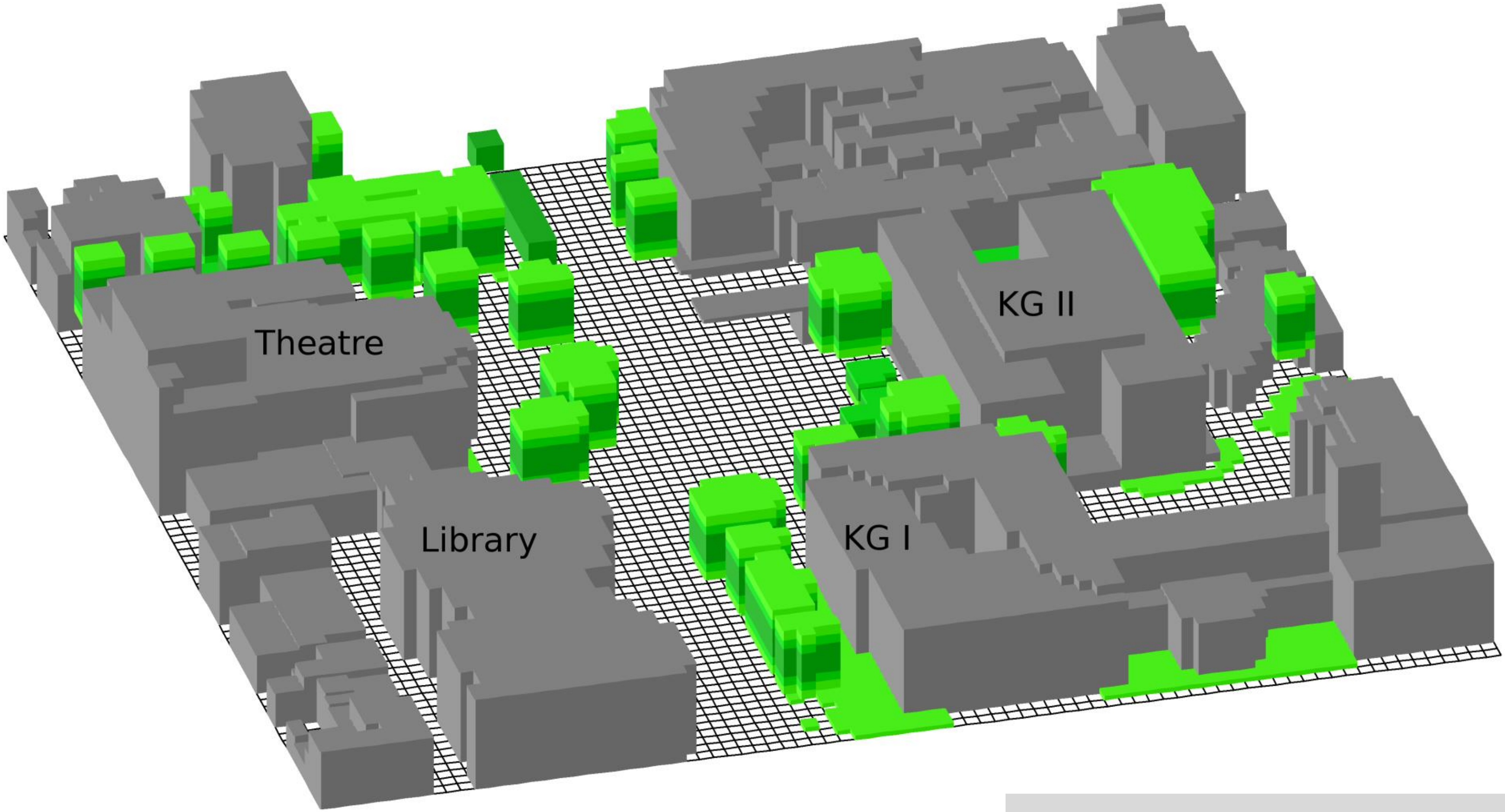
- Political pressure (Freiburg)

Environmental pressure (pop, politics)

Badische Zeitung

Ein ziemlich heißes Pflaster

ENVI-met



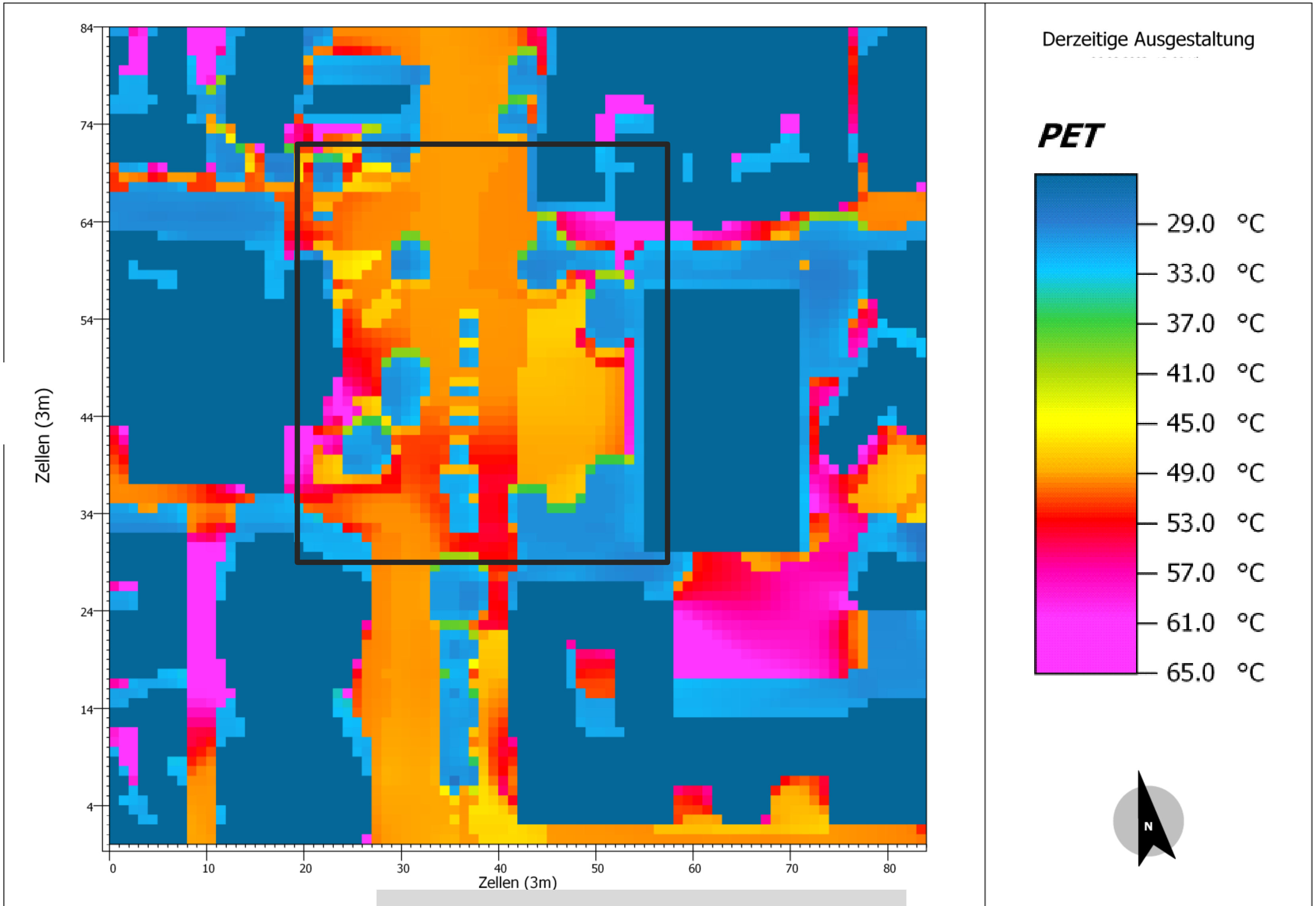
Results: ENVI-met

Fröhlich and Matzarakis, 2012

ENVI-met

Day 3 (13:00)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Meteorologisches Institut Freiburg, 06.08.2010

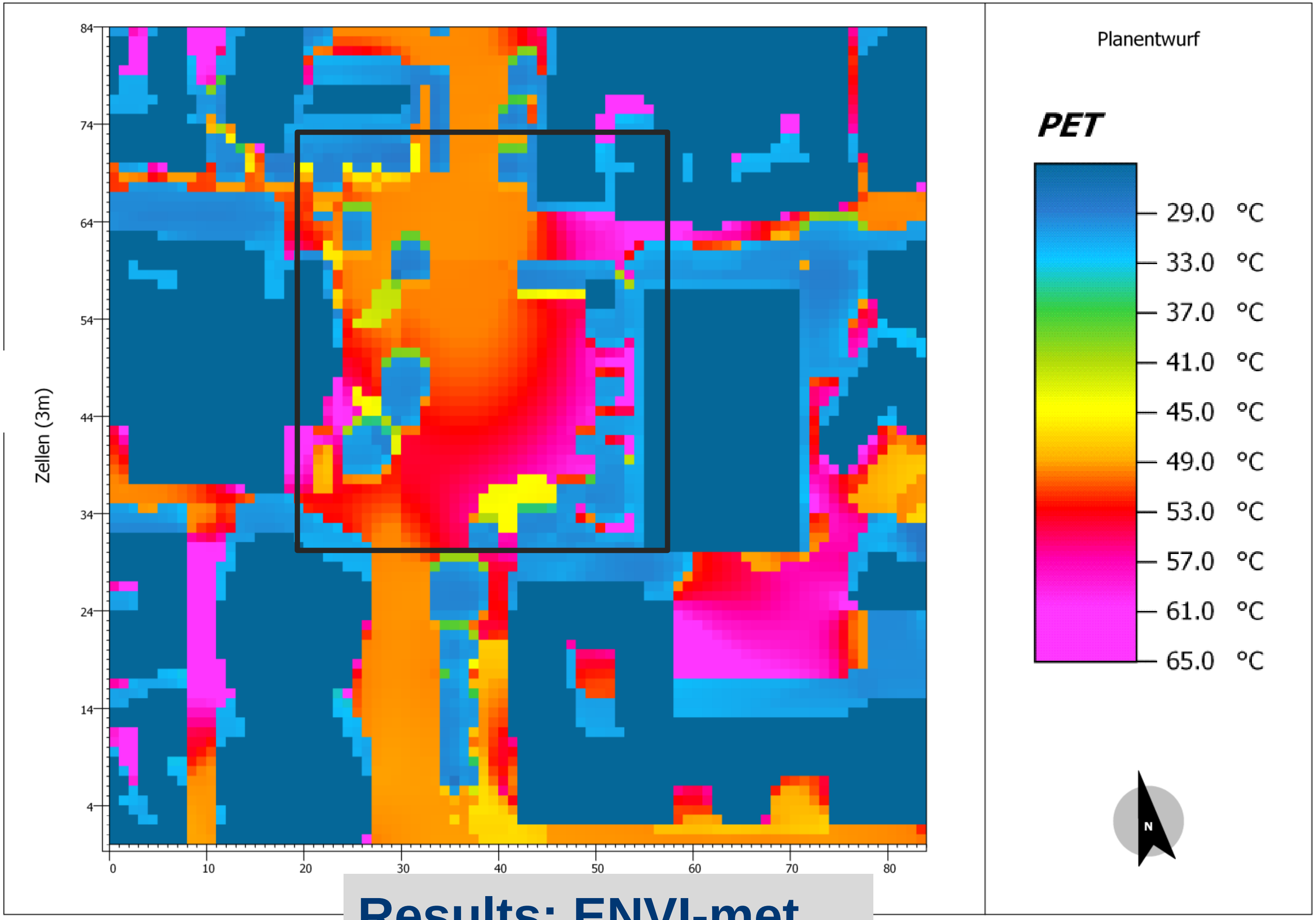
Dominik Fröhlich

Results: ENVI-met

Fröhlich and Matzarakis, 2013

ENVI-met

After reconstruction

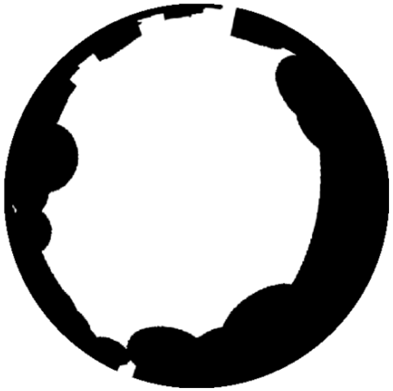


Results: ENVI-met

Fröhlich and Matzarakis, 2013

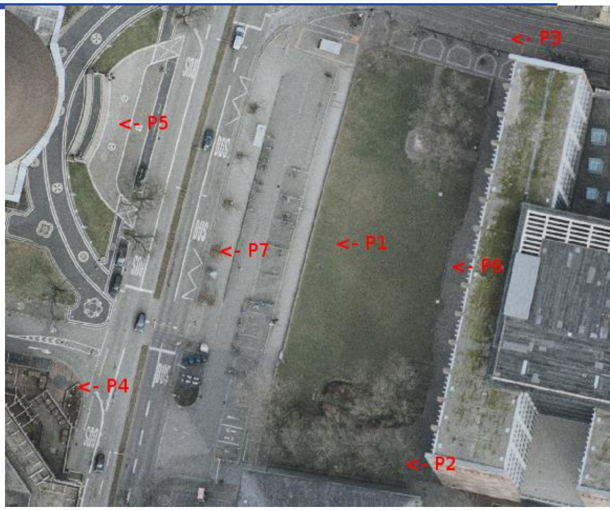
SVF before

MP1
Green area



MP2
KG I - North

MP3
KG II - North



MP4
UB - Northeast

MP5
Theatre

MP6
KG II - Middle

MP7
Bus stop

Fröhlich and Matzarakis, 2013

SVF after - Place of Old Synagogue

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

MP	PET35	PET35a	Δ (h)
1	348.1	338.1	-10
2	196.2	207.2	11
3	322.4	329.1	6.7
4	302.6	273.5	-29.1
5	313.9	313.3	-0.6
6	275.9	218.1	-57.8
7	204.4	330.2	125.8

MP1
Green area

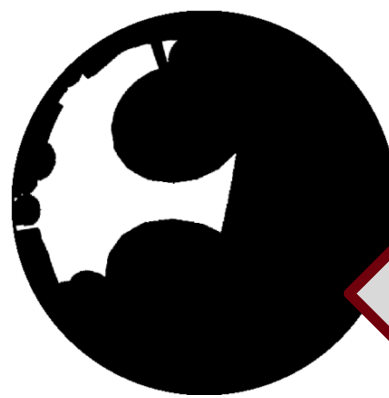
MP2
KG I - North

MP3
KG II - North

MP4
UB - Northeast

MP5
Theatre

MP6
KG II - Middle



MP7
Bus stop

SVF

Effect: wind and Tmrt

Results: RayMan Pro/SkyHelios

Fröhlich and Matzarakis, 2013

Target: Human / Method

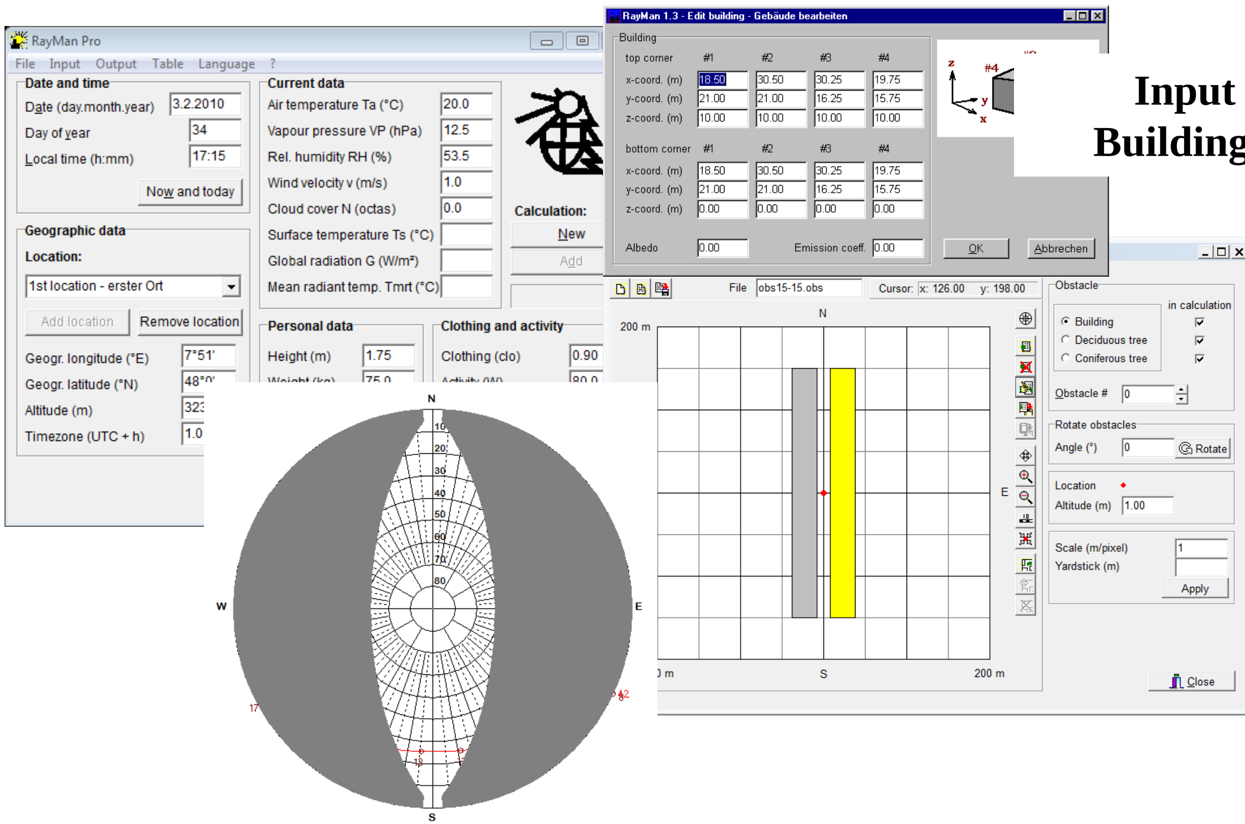
Models

Application and examples

- Fundamental studies (aspect ratio, orientation)

Urban canyon – basic analysis

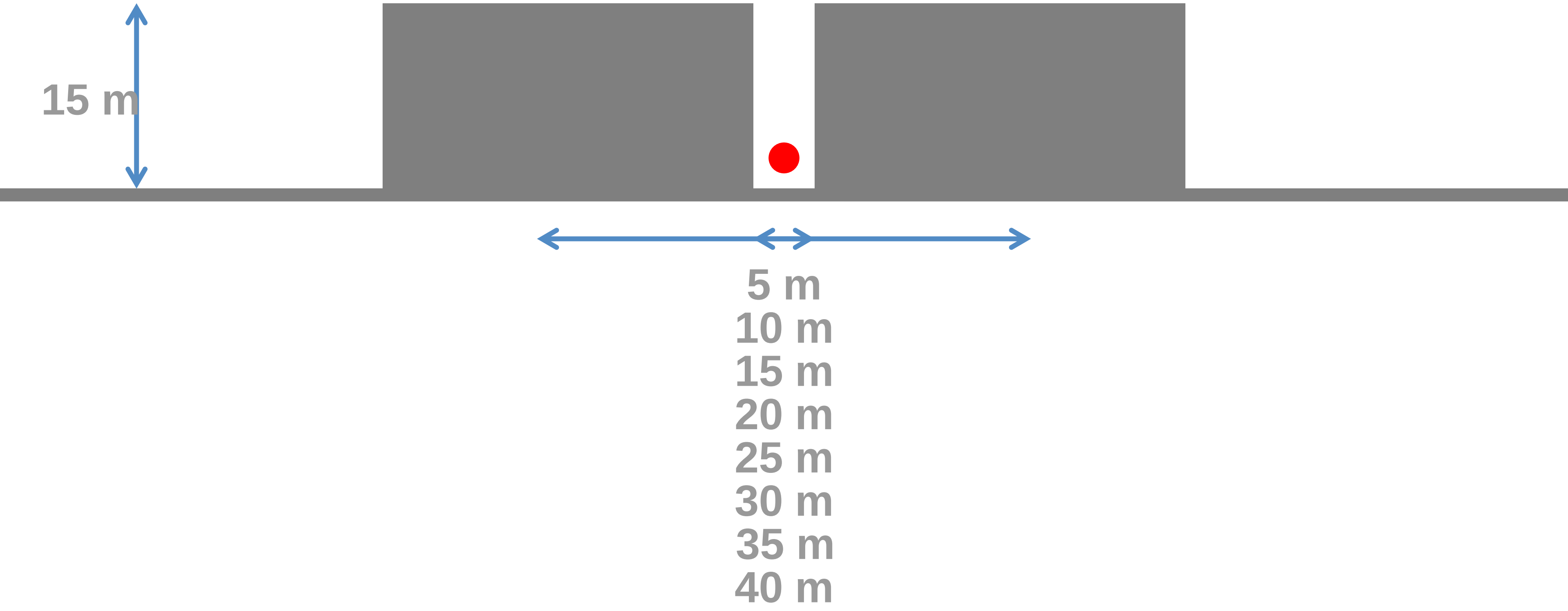
Typical urban canyons in Freiburg
Rotation of canyons



Input Co-ordinates
Buildings/solid surfaces

Urban canyon – street variability

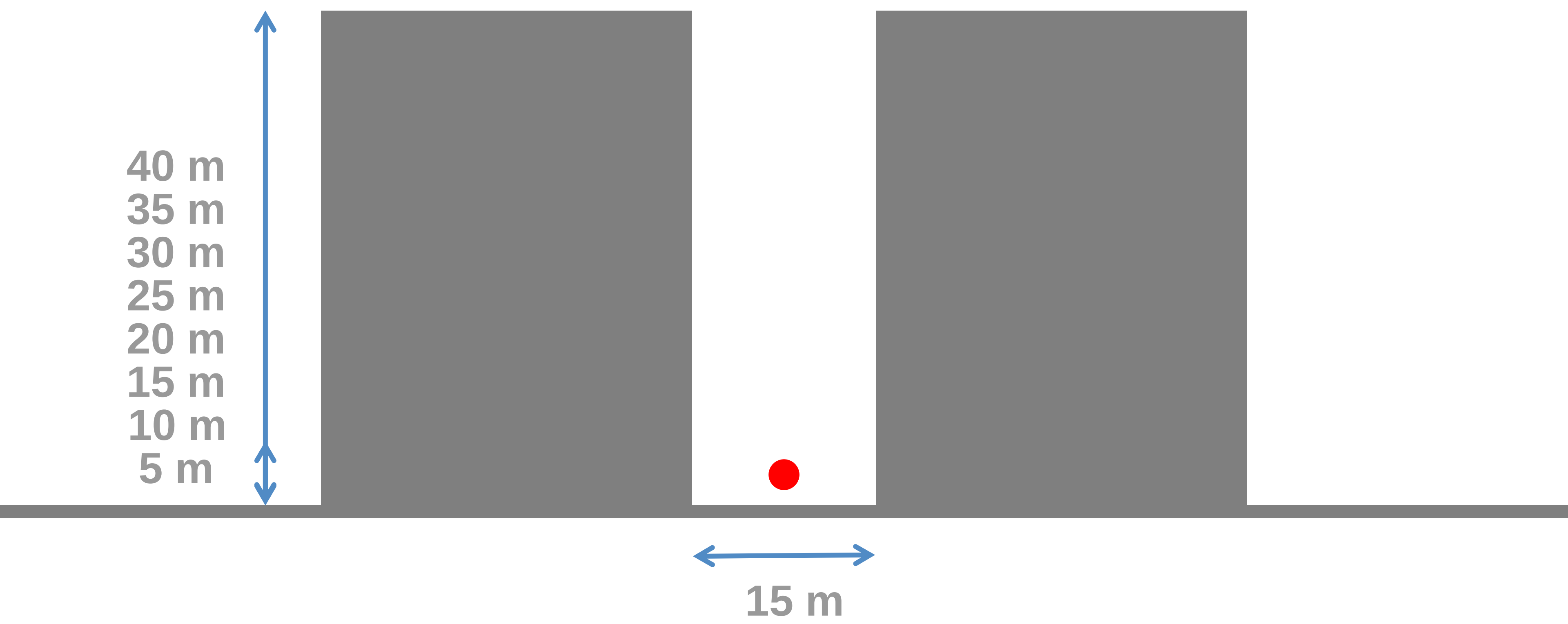
Building: 15 m, variable street width



Matzarakis and Herrmann, 2011

Urban canyon – building height variability

Street width 15 m, variable building height

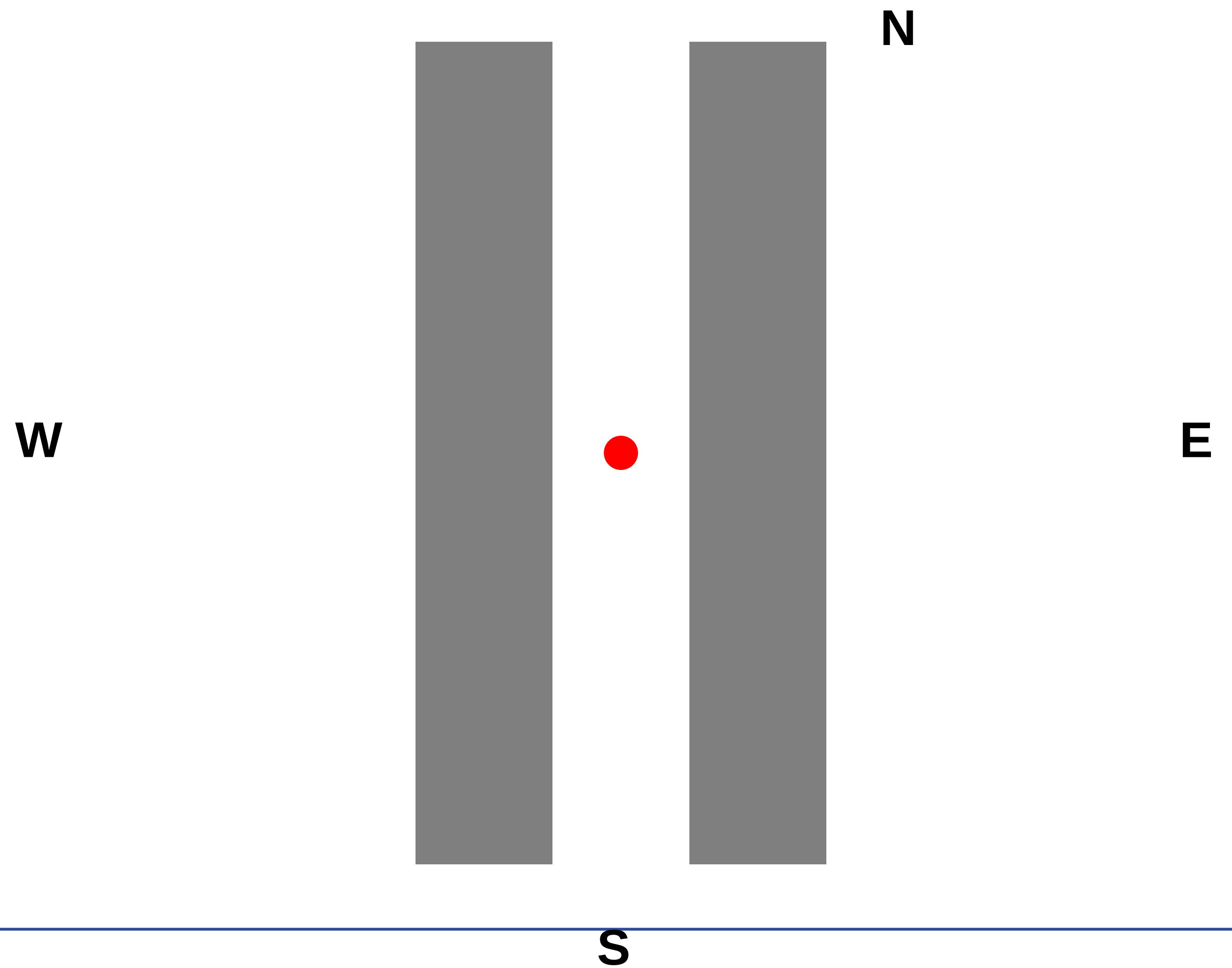


Matzarakis and Herrmann, 2011

Urban canyon – orientation

Street width 15 m, Building height 15 m, Rotation

0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°
180°



Matzarakis and Herrmann, 2011

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Adaptation measures – Street canyon

thermal comfort/ street orientation		0 °	15 °	30 °	45 °	60 °	75 °	90 °	105 °	120 °	135 °	150 °	165 °
0,5	heat stress	26,5	26,6	26,8	27,0	27,1	27,2	27,2	27,1	26,9	26,7	26,5	26,4
	th. comfort	50,2	50,1	49,8	49,6	49,0	48,5	48,5	49,0	49,3	49,9	50,1	50,2
	cold stress	23,4	23,4	23,4	23,4	23,9	24,3	24,3	24,0	23,7	23,4	23,4	23,3
1,0	heat stress	24,3	24,4	24,5	24,7	24,8	24,9	25,0	24,8	24,6	24,4	24,3	24,2
	th. comfort	54,1	54,1	54,2	54,3	54,3	54,1	53,6	53,6	54,0	54,2	54,2	54,4
	cold stress	21,6	21,5	21,3	20,9	20,9	20,9	21,4	21,6	21,4	21,4	21,5	21,4
1,5	heat stress	23,4	23,4	23,6	23,7	23,9	23,9	23,9	23,8	23,8	23,6	23,6	23,4
	th. comfort	56,1	55,9	56,2	56,1	56,0	56,3	56,2	55,7	55,6	55,8	56,1	55,8
	cold stress	20,5	20,6	20,2	20,2	20,1	19,8	19,9	20,5	20,6	20,5	20,3	20,8
2,0	heat stress	22,9	23,0	23,1	23,2	23,3	23,4	23,3	23,2	23,2	23,2	23,1	23,0
	th. comfort	56,8	57,0	56,9	56,9	57,0	57,1	57,1	56,8	56,6	56,5	56,7	56,8
	cold stress	20,3	19,9	20,0	19,9	19,7	19,6	19,6	20,0	20,1	20,3	20,3	20,3
2,5	heat stress	22,7	22,7	22,8	22,9	23,0	23,1	23,1	22,9	23,0	22,9	22,8	22,7
	th. comfort	57,2	57,7	57,4	57,5	57,5	57,4	57,7	57,3	57,2	57,3	57,4	57,7
	cold stress	20,1	19,5	19,8	19,6	19,5	19,5	19,3	19,8	19,8	19,8	19,8	19,6
3,0	heat stress	22,5	22,4	22,5	22,6	22,7	22,8	22,8	22,6	22,7	22,6	22,5	22,4
	th. comfort	57,9	58,1	57,8	58,0	58,0	57,8	58,0	57,9	58,0	57,7	57,7	58,1
	cold stress	19,6	19,4	19,7	19,4	19,3	19,4	19,2	19,5	19,4	19,7	19,7	19,5
3,5	heat stress	22,3	22,3	22,4	22,5	22,6	22,6	22,7	22,5	22,5	22,4	22,4	22,2
	th. comfort	58,3	58,3	58,1	58,2	58,2	58,0	58,1	58,1	58,2	58,1	58,0	58,3
	cold stress	19,4	19,4	19,5	19,4	19,2	19,3	19,2	19,4	19,3	19,5	19,6	19,4

Ketterer & Matzarakis, 2014

object: middle of a street canyon
model: RayMan
data: 2000 -2010

cold stress	PET < 13 °C
heat stress	PET > 29 °C
thermal comfort	13.1 °C < PET < 29 °C

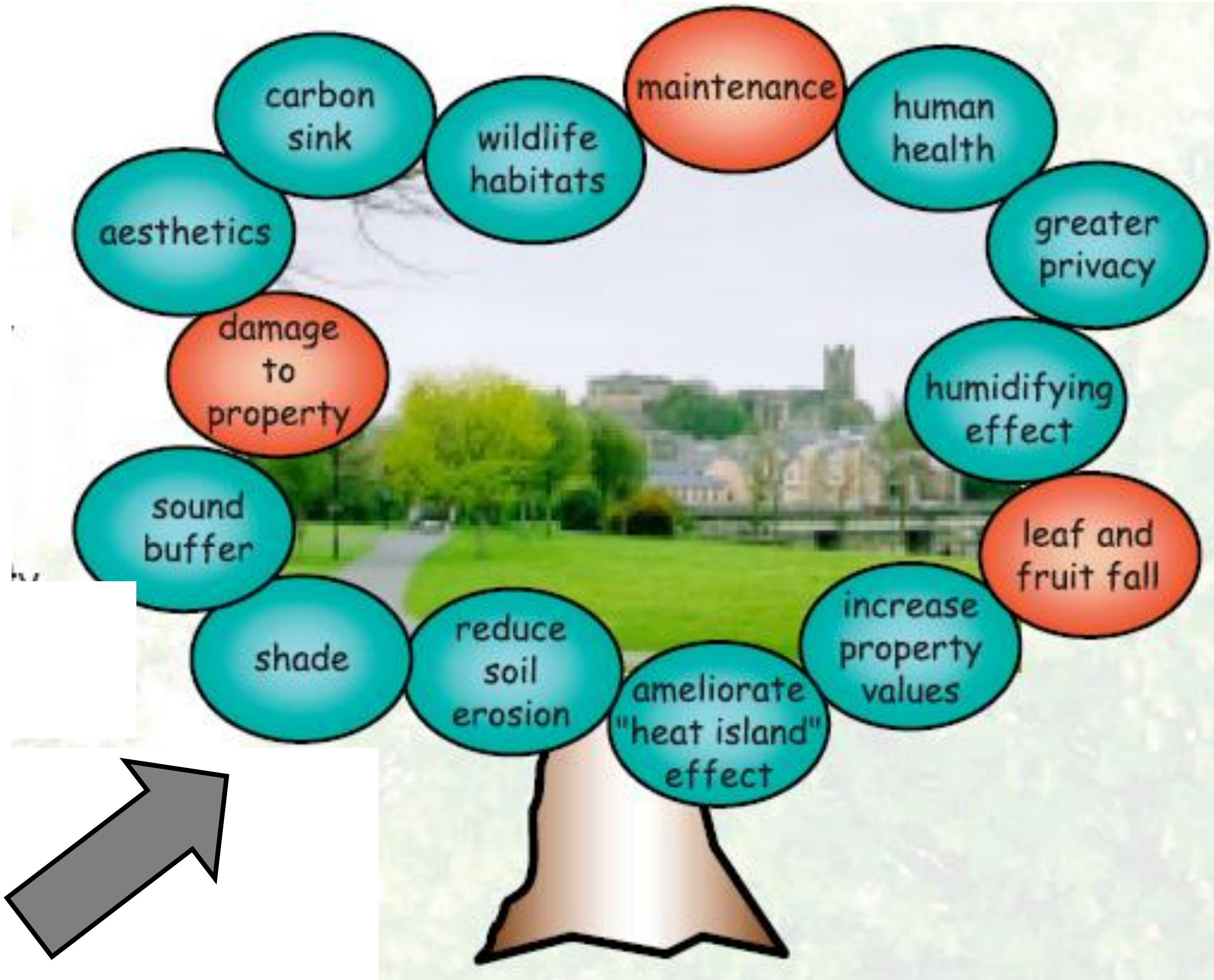
Target: Human / Method

Models

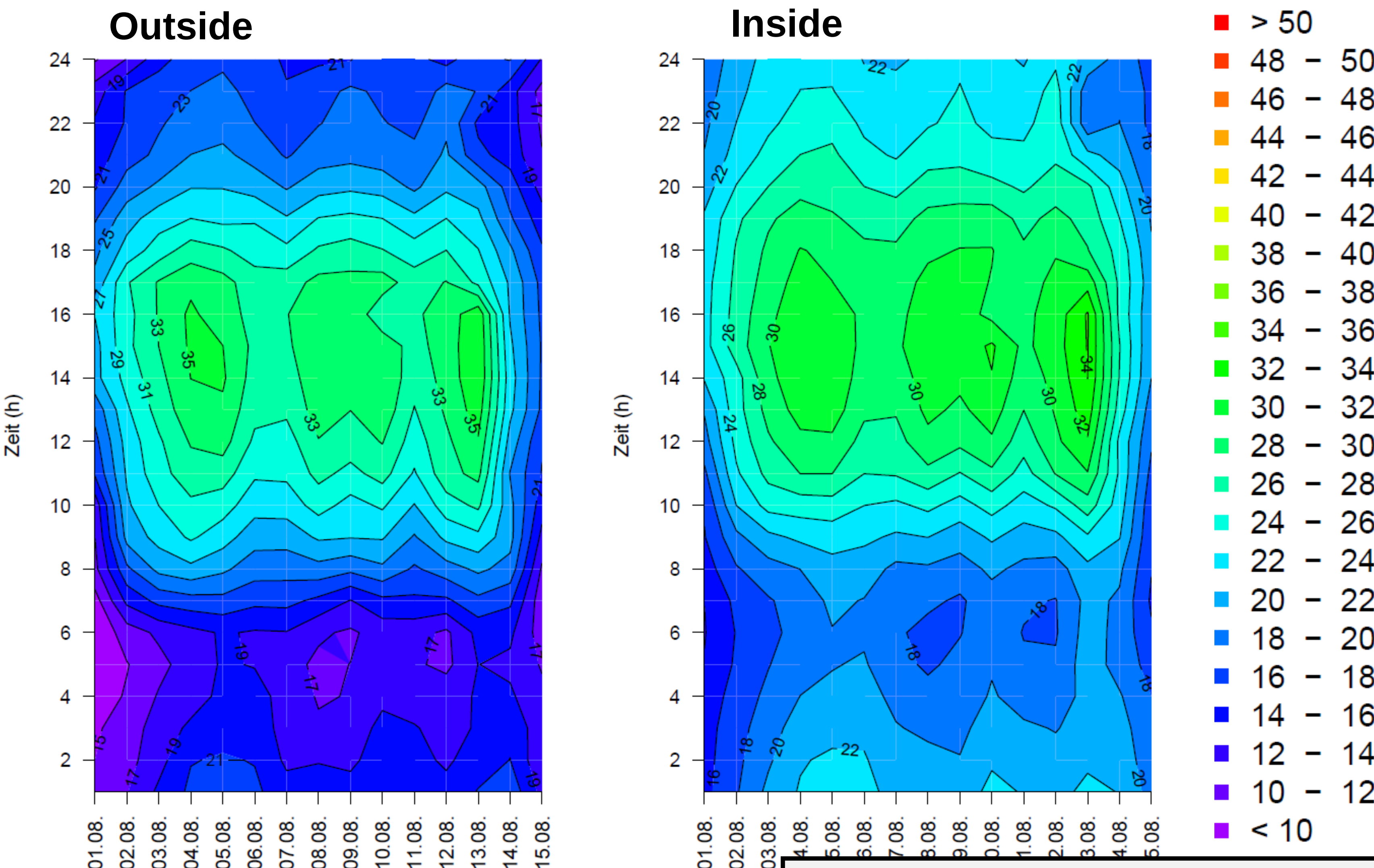
Application and examples

- Trees

Positive/Negative



Heat wave 2003 - Ta



Data: Landesanstalt für Wald und Forst, München,

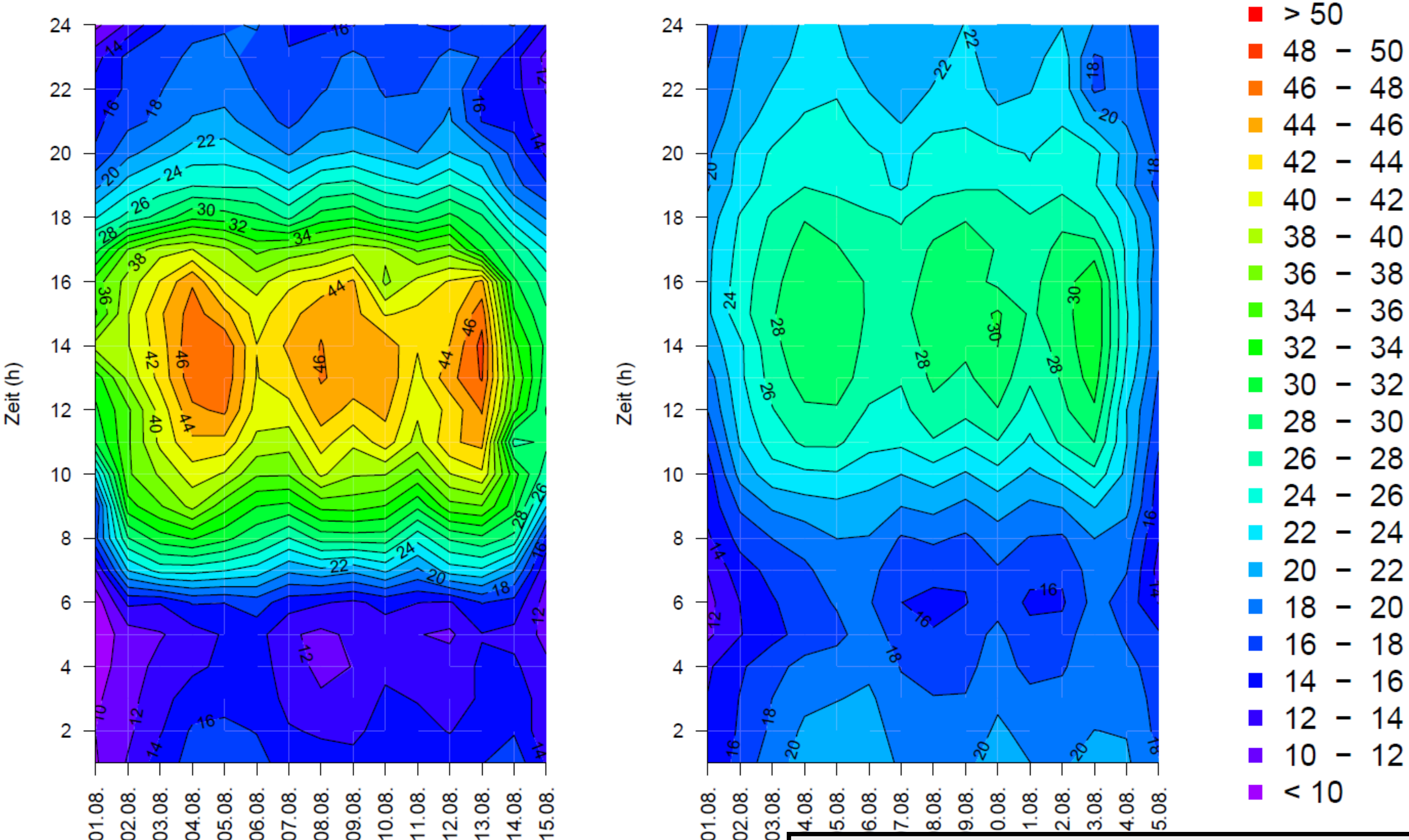
Question: Forests and bioclimate during heat waves ?

Heat wave August 2003 - PET

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Outside

Inside



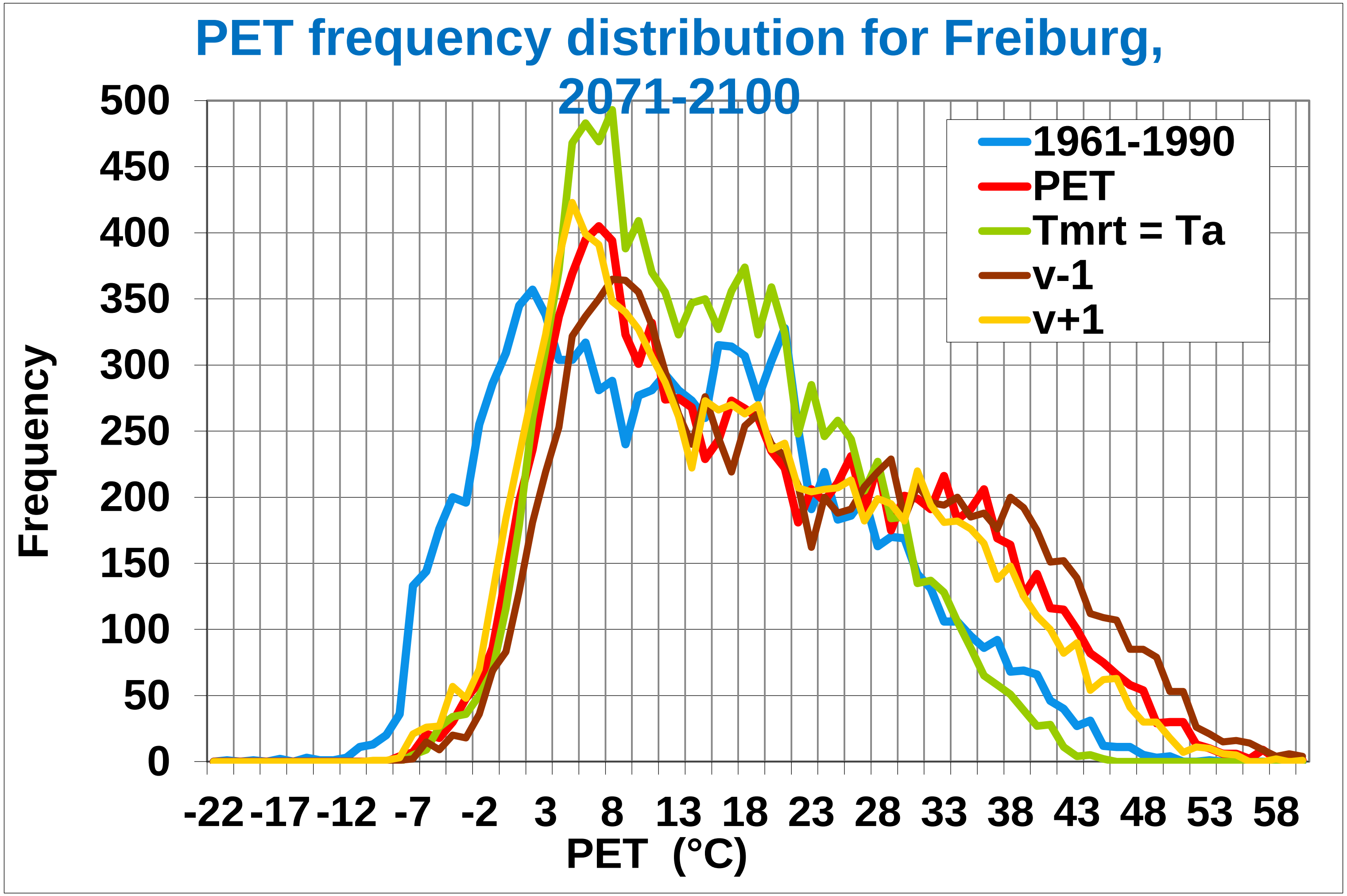
Data: Landesanstalt für Wald und Forst, München,

Question: Forests and bioclimate during heat waves ?

Climate change and adaptation (shade/wind)

Deutscher Wetter
Wetter und Klima aus ei
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung
klimazwei Risiken mindern · Chancen nutzen

< 1973
1973 - 2000
2002
Post 2002
2006-2009
2009
2010-2013
Future



(Matzarakis and Endler, 2010)

Target: Human / Method

Models

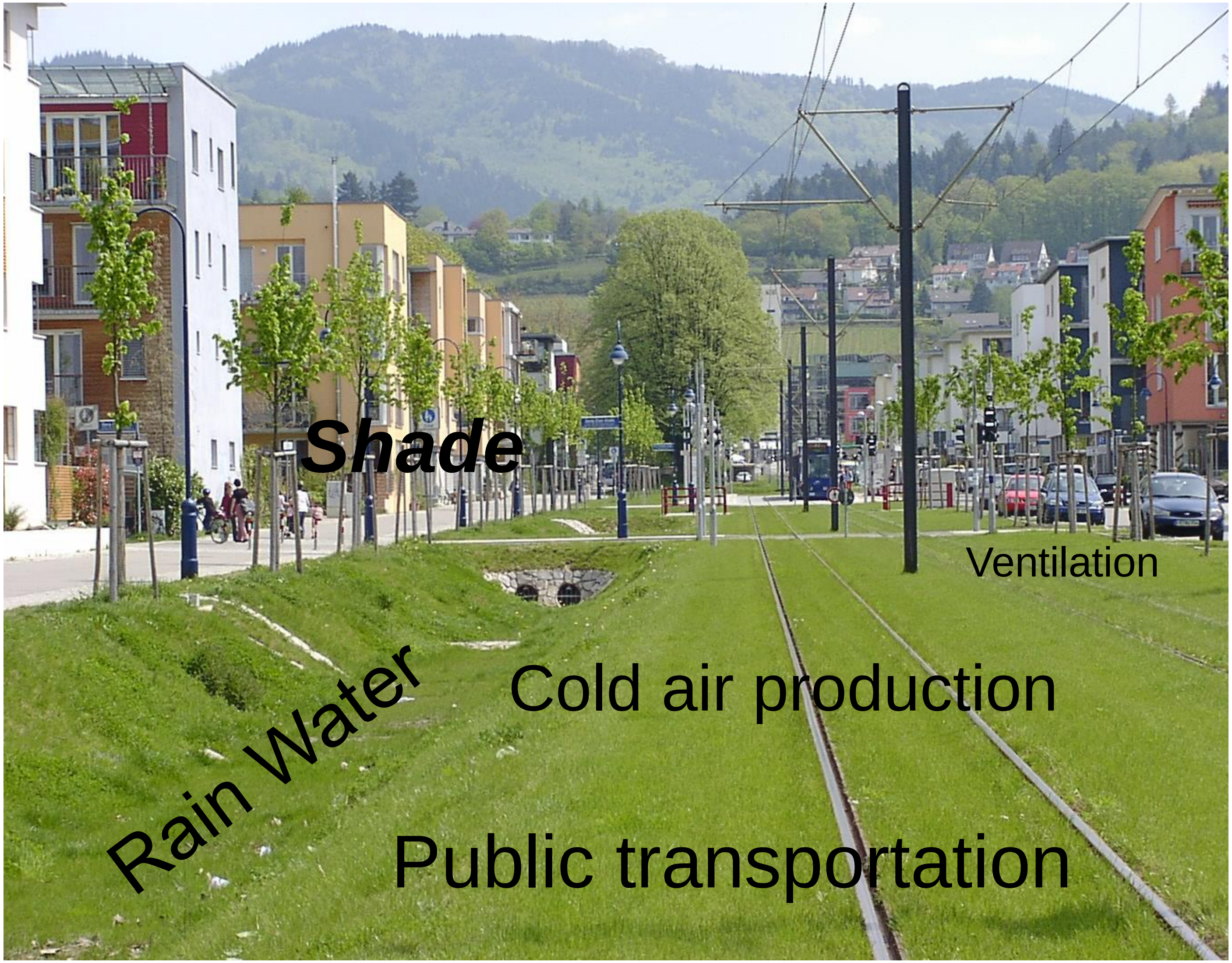
Application and examples

- Communication aspects

Data and information

- First level of information: qualitative
- Second level of information: quantitative
- Third level: way of transferring information
- Most important level: communication of information

Vision from an urban planner



(Sheet: Köhler, 2008)

Statements/Summary

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Not only air temperature – Human Biometeorology
- Appropriate data and information
- Measurements and simulations
- Urban areas - modelling
- Combination of methods/data
- No clickable solutions
- Less case studies – more long term (H/W)
- Models provide additional data: SD, Sun paths, …
- **Focus Radiation and wind**

- Recommendations to users of models
  - Validation
  - Consider possibilities and limitation – aim of development
  - **PLEASE: read/consider manual**