Center for Innovation and
Science on Building
Greening

# Urbanes Klima und Hitzestress - Möglichkeiten zur Quartiersmodifikation -

## Warum, wann, für wen und wo?

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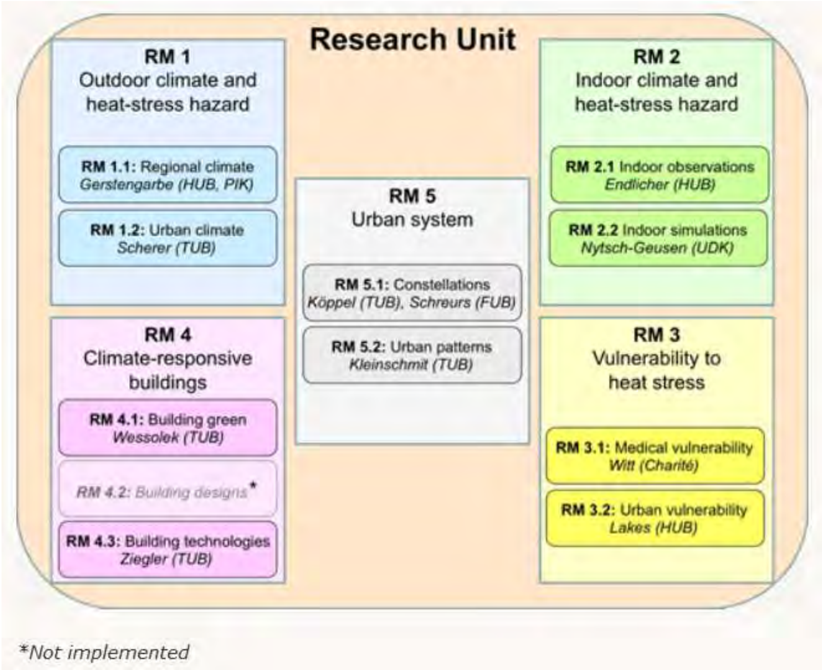
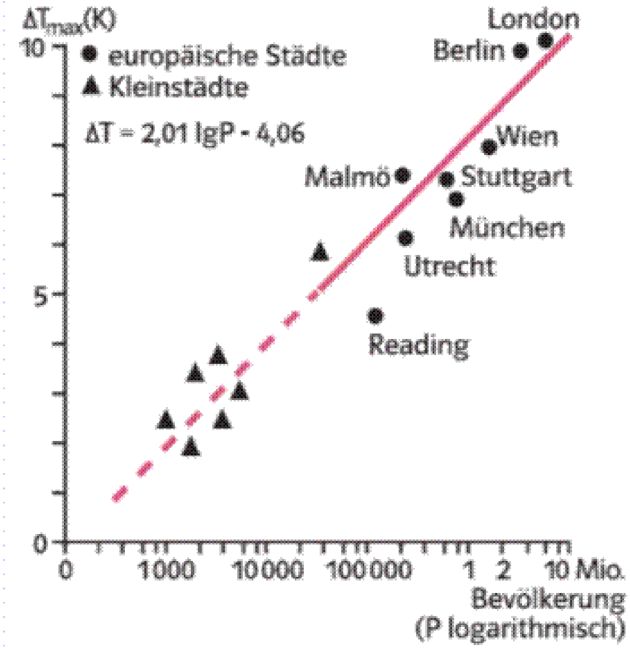
# Gliederung

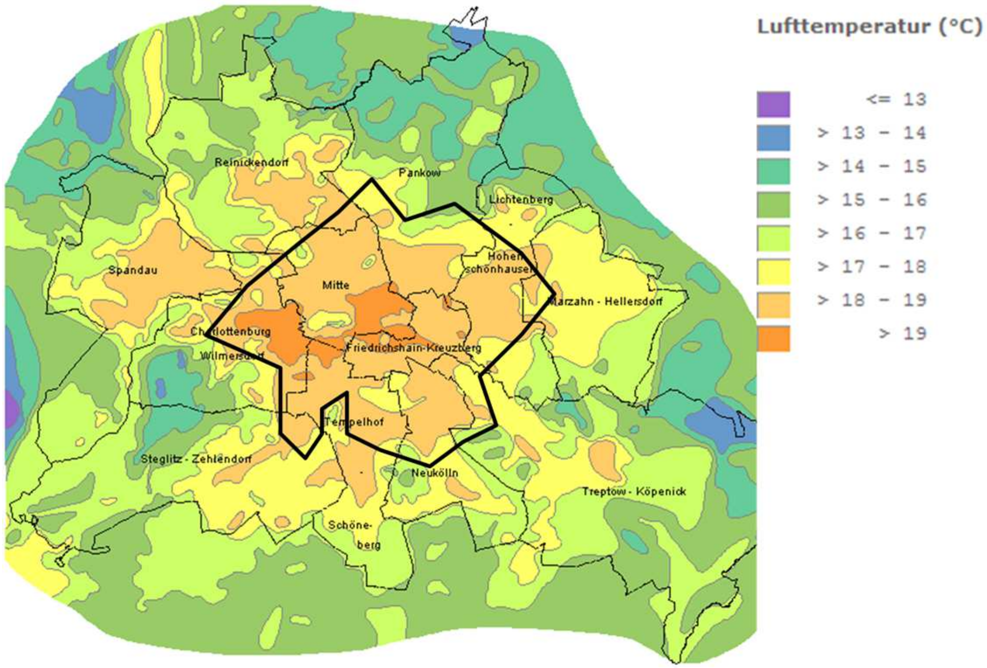
1. Ursachen für die Ausbildung der urbanen Hitzeinsel
2. Hitzestress, wann, für wen, wo?
3. (sinnvolle) Möglichkeiten zur Quartiersmodifikation

www.ucahs.org



# 1 Die urbane Hitzeinsel…



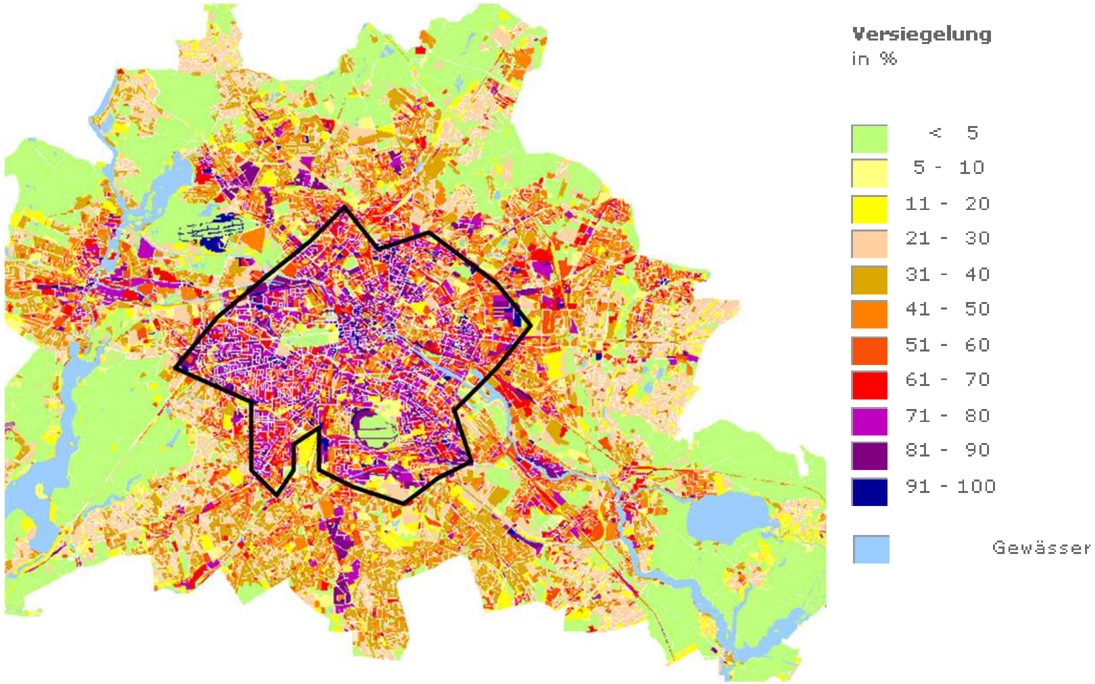



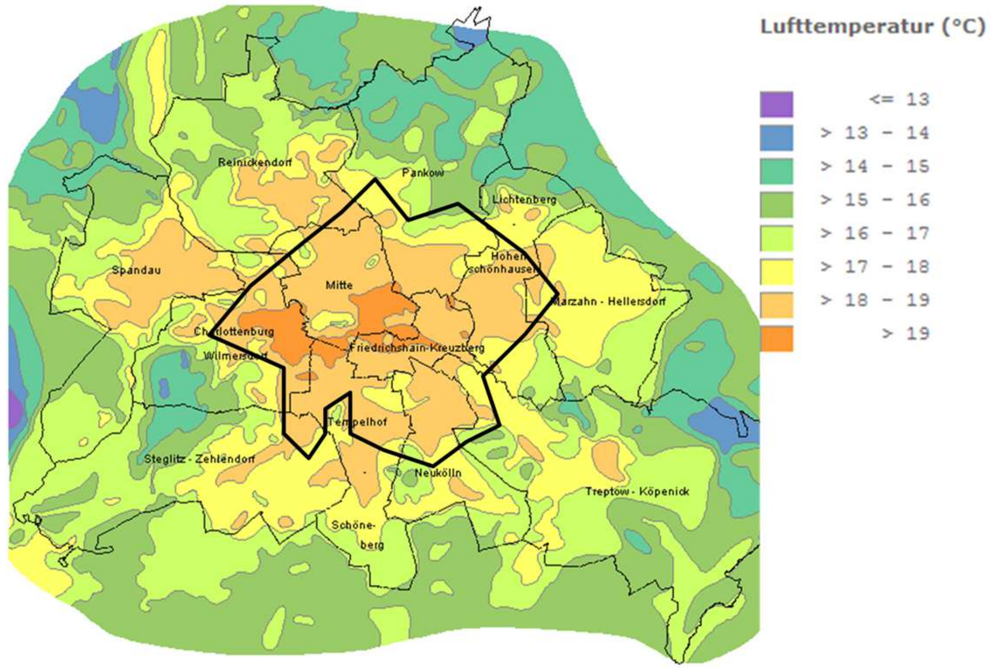

…ist ein Großstadtphänomen

*Mittelwerte maximaler Temperaturdifferenzen zwischen Stadt und Umland in Europa.*
*(Oke 1973, Danzeisen 1983)*

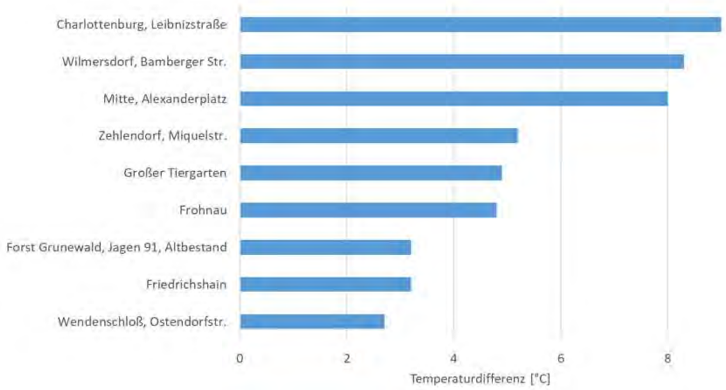
*Mehrjähriges Mittel der Lufttemperaturverteilung in austauscharmen Strahlungsnächten*
*(http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/iinhalt.htm)*

# 1 Die urbane Hitzeinsel




Berlin: 1/3 versiegelt, davon:
1/3 bebaut versiegelt,
2/3 unbebaut versiegelt




Temperaturdifferenzen von Stationen zur kältesten Station Dahlemer Feld um 4:00Uhr an einem heißen austauscharmen Strahlungstag (8.Juli 1991)

*alle Abbildungen:*
*(http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/iinhalt.htm)*

# 1 Ursachen für die Ausbildung der urbanen Hitzeinsel

<u>Erwärmung:</u>

- Große absorbierende Oberfläche (Berlin 1:3, Manhattan 1:10)

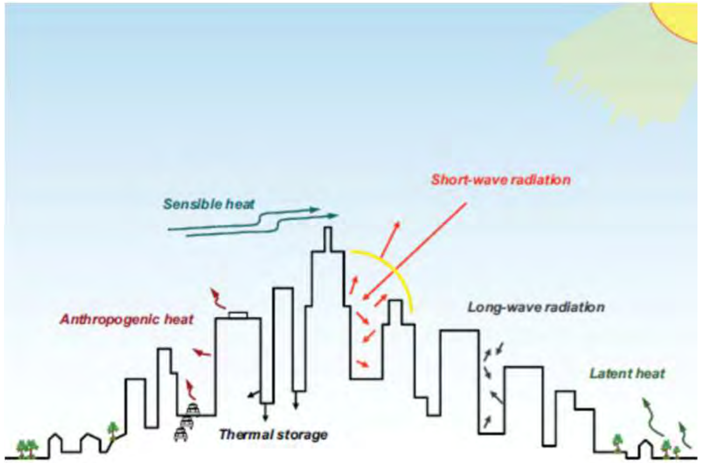
- Gemäßigte Breiten hoher Energieeintrag über senkrechte Flächen ca. 110 $Wm^{-2}$ (Sommer: 300-1000, Winter: 50-500 $Wm^{-2}$)

- Anthropogene Abwärme: Sommer 30 $Wm^{-2}$, Winter 100 $Wm^{-2}$

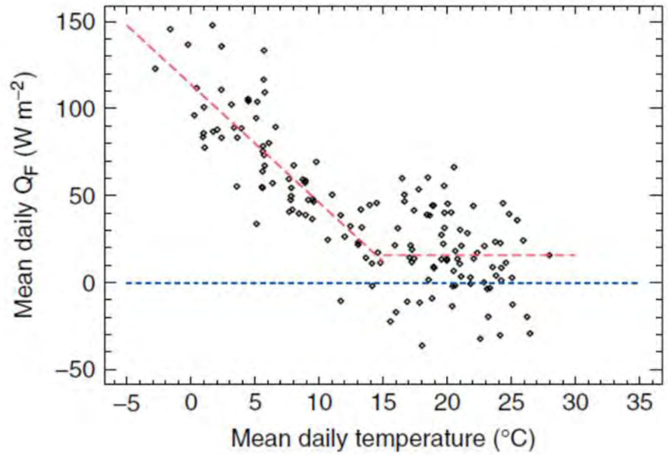
<u>fehlende Abkühlung:</u>

- behinderter turbulenter Austausch mit Umland

- Wenige Pflanzen (Beschattung, Transpiration) stattdessen trockene Versiegelung

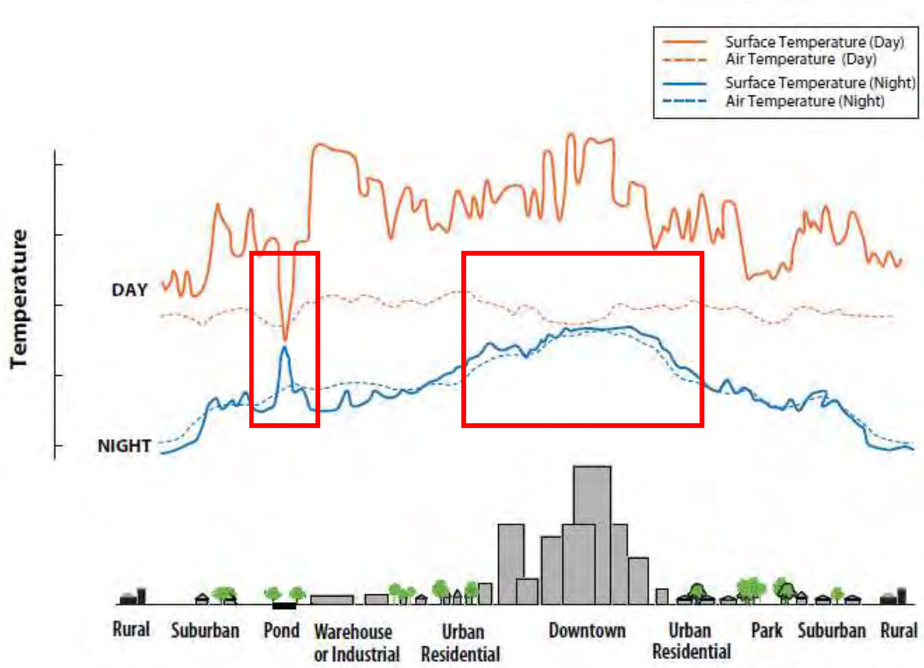



***EPA, online***




***Pigeon et al., 2007***

# 1 Ausbildung der (nächtlichen) urbanen Hitzeinsel




Strahlungseigenschaften: α, ε
thermische Eigenschaften: ρ, c

Konvektion, Pufferung

keine kurzwellige Einstrahlung

wenn kein Wind

Tag: Stadt mitunter kühler als Umland
Nacht: Fast immer höhere Temperaturen in der Stadt

***EPA, online***

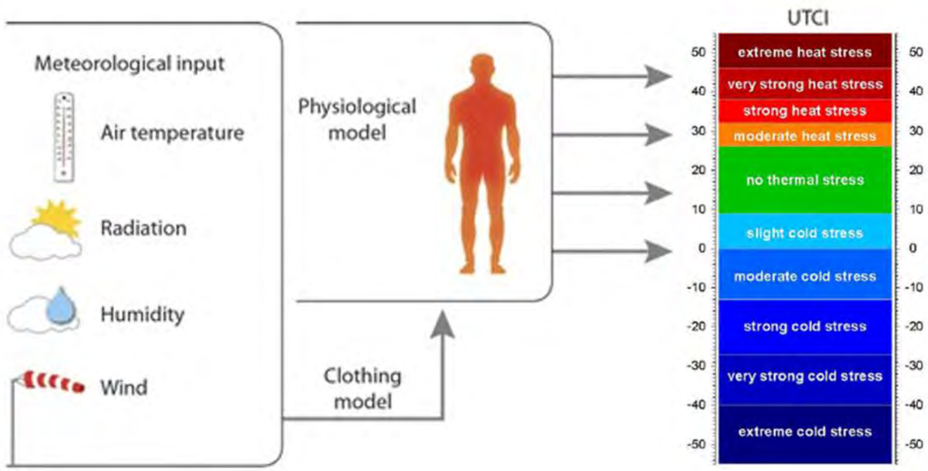
Eignung bzw. Nicht –Eignung von Oberflächentemperaturen für Klimaanalysen, z.B. fehlende Aussagen zu Gebäudeoberflächen

# 2. Thermisches Optimum und Hitzestress

- Menschen haben relativ universelles thermisches Optimum
- kann beschrieben werden für den Außenraum: Universal Thermal Climate Index (UTCI)
- unterhalb/oberhalb des Optimums:

unbehaglich (Laune/Psyche) → störend (Leistungsfähigkeit) → bedrohlich…(Tod)

- Hitzewelle 2003: 30.000 zusätzliche Tote in Europa, Lehren:
  - → Hitzestress betrifft vor allem Kleinkinder, ältere und "vorbelastete" Menschen
  - → hauptsächlich Herz-Kreislauf System, Atemapparat
  - → Vulnerabilität steigt z.B. bei der Altersgruppe 65+




*DWD, online*

# 2. Nächtliche Urbane Hitzeinsel und Hitzestress

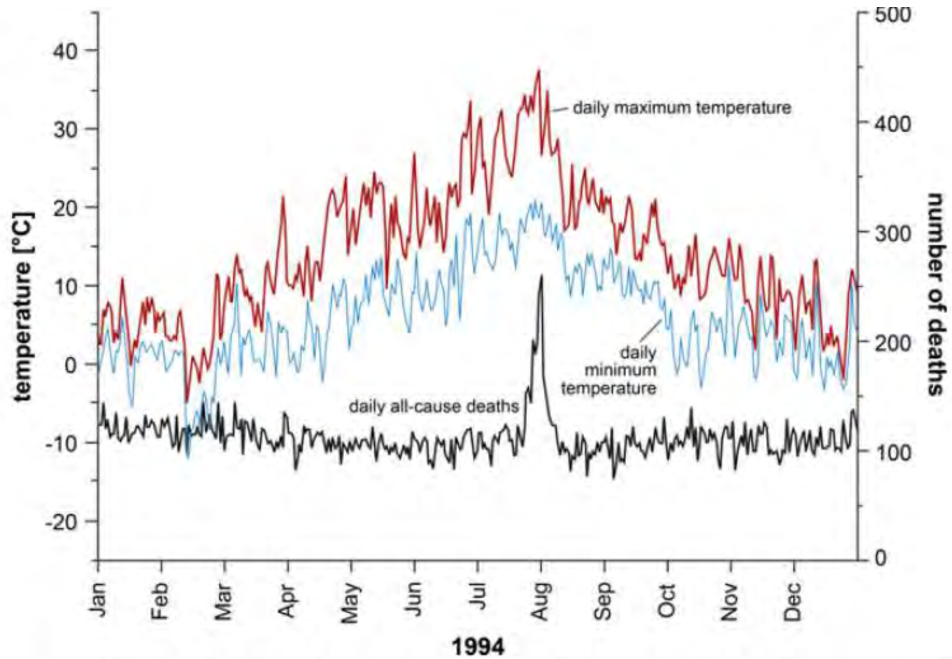



**Fig. 3.** Daily maximum and minimum temperatures, together with daily mortality rates for Berlin during 1994 [Data: German Meteorological Service, Statistical Services of Berlin and Brandenburg].

***Gabriel and Endlicher, 2011***

- höchste tägliche Temperaturen $T_{max}$ erklären nicht gut die zusätzliche Mortalität → tagsüber: Anpassung, Kühlung
- geringste tägliche Temperatur $T_{min}$ erklärt zusätzliche Mortaliät besser → nachts: Anpassung eher schwierig
- je länger die Hitzewelle, desto höher $T_{min}$ , wenn Hitzewelle eine bestimmte Länge überschreitet, wird sie gefährlich

# 2. Nächtliche Urbane Hitzeinsel und Indoor Hitzestress

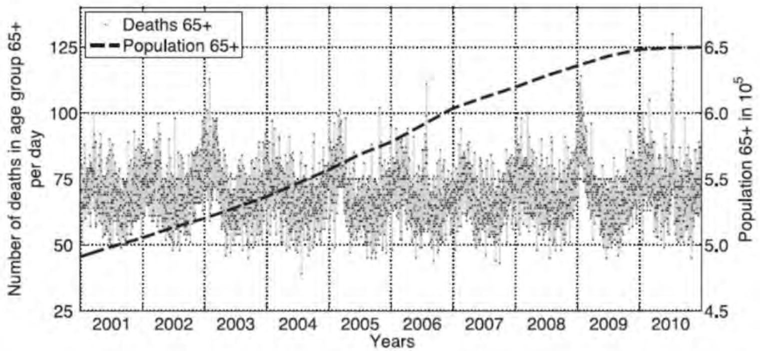
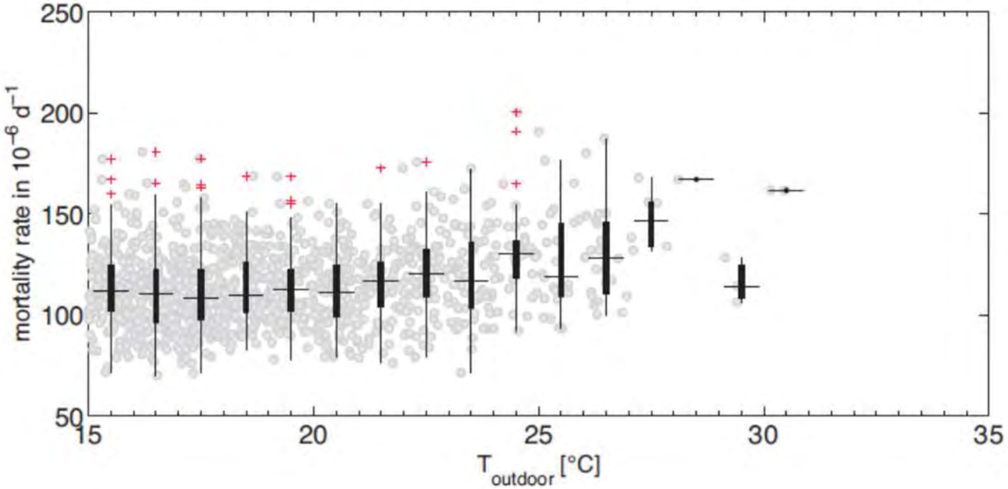
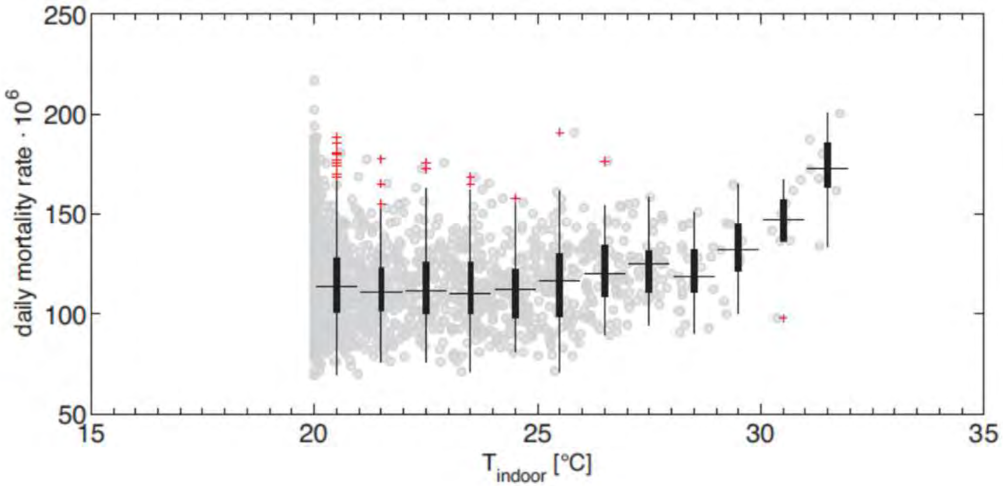



**Fig. 2.** Number of deaths and population for the group of people in the age of 65 years and older in Berlin from 01.01.2001 to 31.12.2010.

komplexes Gebäudemodell, verarbeitet u.a. Außentemperaturen




***Buchin et al, 2015***

→ Innenraumtemperatur beste Vorhersagevariable (Prädiktor) für Mortalität in Gruppe 65+ (2001-2010)

# 2. Hitzestressrisiko – räumliche Verteilung

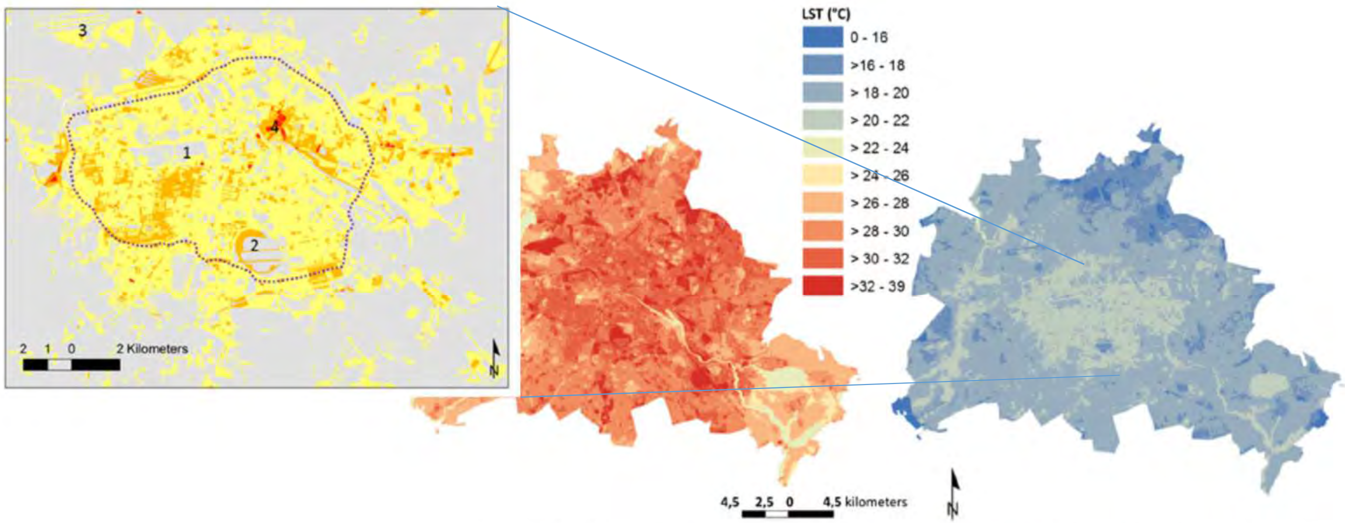



Fig. 2. Land surface temperature (LST) in °C in August for Berlin at 10 am (left) and 10 pm (right).

Classification and calculation method for the indicators used for the estimation of the potential heat stress related risk.

| Indicator/potential risk factor | | Value | Signification | Calculation method | Comment |
|---|---|---|---|---|---|
| Potential demographical vulnerability | Population density per block | 0 | Relatively negligible density | Population density < 85th percentile ⟺ 129 inh./ha | The average density in Berlin is 57 inh./ha |
| | | 1 | Relatively low density | Population density > 85th percentile ⟺ 129 inh./ha | |
| | | 2 | Relatively medium density | Population density > 90th percentile ⟺ 211 inh./ha | |
| | | 3 | Relatively high density | Population density > 95th percentile ⟺ 326 inh./ha | |
| | Vulnerable inhabitants per block | [0-1] | Percentage of vulnerable inhabitants (*i.e. younger than 6 and/or older than 65*) at block- level divided by 100 | The Concentration of vulnerable inhabitants is multiplied by the inhabitants density to give more importance to the absolute amount of vulnerable inhabitants | The average amount of vulnerable inhabitants per block in Berlin is 20% |
| | Concentration of vulnerable inhabitants in a block | 0 | Not problematic concentration | Weighted concentration < 0.3 ⟺ max. concentration of vul. ihn. of 30% if Pop. dens. = 1 | The weighted concentration ranges from 0 to 3 with a mean value of 0.08 and a standard deviation of 0.20 |
| | | 1 | Quite problematic concentration | Weighted concentration > 0.3 ⟺ max. concentration of vul. ihn. of 30% if Pop. dens. = 1 | |
| | | 2 | Problematic concentration | Weighted concentration > 0.6 ⟺ max. concentration of vul. ihn. of 60% if Pop. dens. = 1 | |
| | | 3 | Highly problematic concentration | Weighted concentration > 0.9 ⟺ max. concentration of vul. ihn. of 90% if Pop. dens. = 1 | |
| Potential climatic hazard | Distribution of air temperatures | 0 | Negligible potential hazard | Air temperature < 85th percentile ⟺ Temp(06 am) = 16.54 °C | The mean modeled air temperature in the summer in Berlin is of 14.41 °C with a standard deviation of 2.42 °C |
| | | 1 | Low potential hazard | Air temperature > 85th percentile ⟺ Temp(06 am) = 16.54 °C | |
| | | 2 | medium potential hazard | Air temperature > 90th percentile ⟺ Temp(06 am) = 16.74 °C | |
| | | 3 | high potential hazard | Air temperature > 95th percentile ⟺ Temp(06 am) = 16.92 °C | |

Risiko = Gefährdung * Anfälligkeit

→ Hitzestress nachts → nachts Oberflächentemp. als Gefährdungsmaß anwendbar, siehe vorn

→ Vulnerabilität: u.a. Einwohnerdichte, Anteil Bevölkerung jünger 6 / älter 65

→ Identifikation von Gebieten mit besonders hohem Risiko

***Dugord et al 2015***

# 2. Hitzestressrisiko – räumliche Verteilung

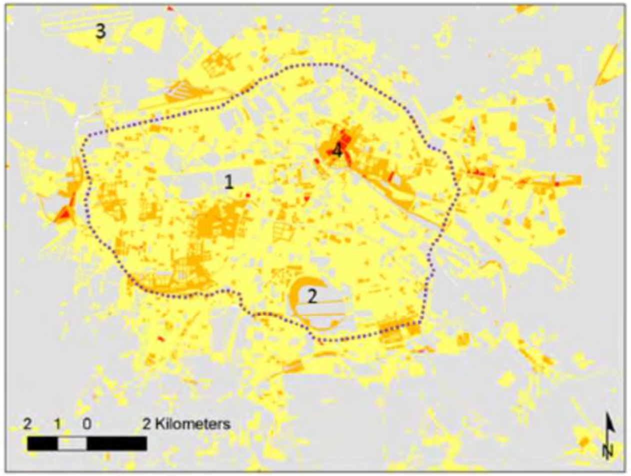




**Fig. 6.** Risk map, valuing the potential heat-stress risk per block; Special sites: 1: The central park Tiergarten, 2: TV Tower on the Alexander Platz, 3. The urban park on the former Tempelhof airport, 4. Western part of the district Lichtenberg, 5: Neighborhood of Friedenau.

→ Identifikation von Gebieten mit besonders hohem Risiko, Einfluss der Vulnerabilität sehr hoch

***Dugord et al 2015***

# 3. Möglichkeiten zur Quartiersoptimierung

- Gebäude oder Außenraum, oder beides? → Mensch mit einbeziehen, Wohnung, Gebäude, Gebäudeverband

- Ein Ziel oder mehrere?
(Kühlung im Raum vs. Klimaschutz im Quartier, wassersensitive Stadt, grüne Stadt, Ästhetik, Biodiversität, essbare Stadt…)

- Kriterien und Strategien? (Energieeinsatz, Ökobilanz, Effizienz allein (Suffizienz? Konsistenz?))

- Ressourcen: Zeit (eine oder mehrere Legislaturperioden), Energie (grün?), Wasser, Platz, (Bewohner/Nutzer), ~~Geld,~~ Kompetenz, Organisation

→ end-of-pipe vermeiden, integrierte, nachhaltige Lösungen (ökonomisch, ökologisch, sozial), systemische Ansätze bevorzugen, Mehrfachnutzen anstreben

→ Übertragbarkeit innerhalb der Stadt u.U. gering, zwischen Städten u.U. nicht gegeben (Systeme verschieden) → das ist gut! es fördert angepasste Lösungen und Vielfalt in den Lösungsansätzen

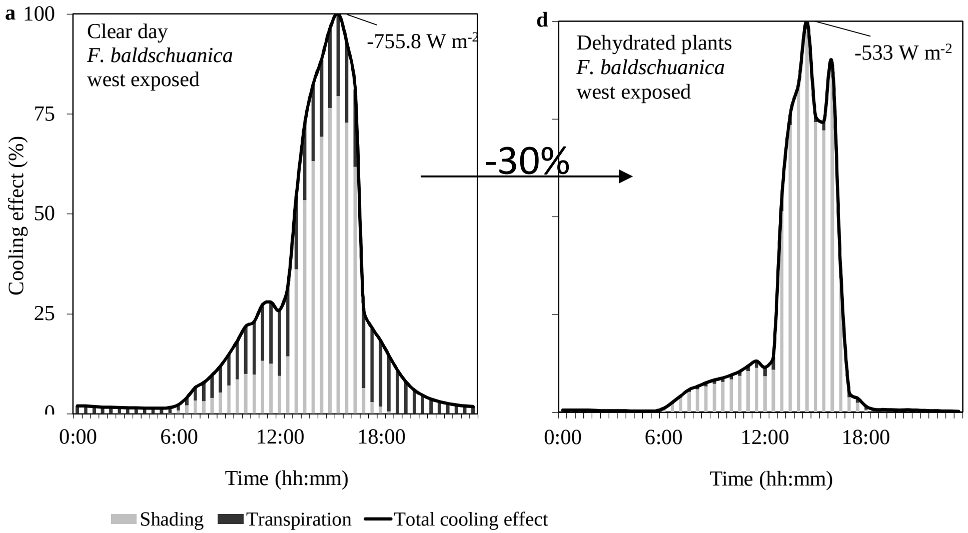
→ Fehlertoleranz erhöhen, Fehler zulassen und daraus lernen, Prozess betonen (eine Stadt ist sowieso niemals fertig!),

# 3. Möglichkeiten zur Quartiersoptimierung

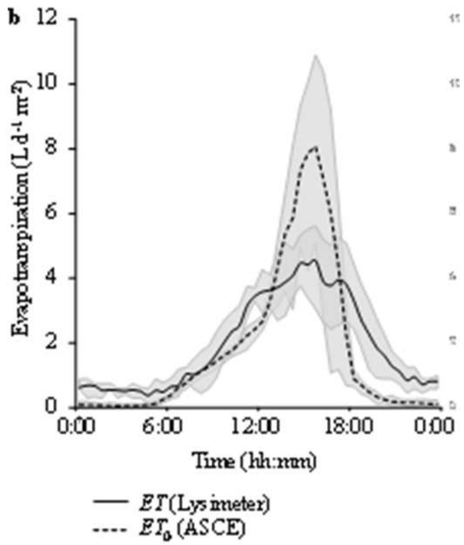
- Lösungsansätze:
Klimaanlagen, Gebäudedämmung, Dachbegrünung, Jalousien etc. siehe Buchin et al. 2015

- systemischer Lösungsansatz: Beschattung und Verdunstungskühlung (funktioniert immer!)
bodengebundene Vertikalbegrünung (Innenraum) & kleine Straßenbäume (Außenraum)
→ Beschattung, Transpiration, Isolierung für das Gebäude – keine Aufheizung für die Straße
dazu Zusatznutzen und Herausforderungen,
- gestalterische, technische, organisatorische Lösungen → Akzeptanz + Rentabilität

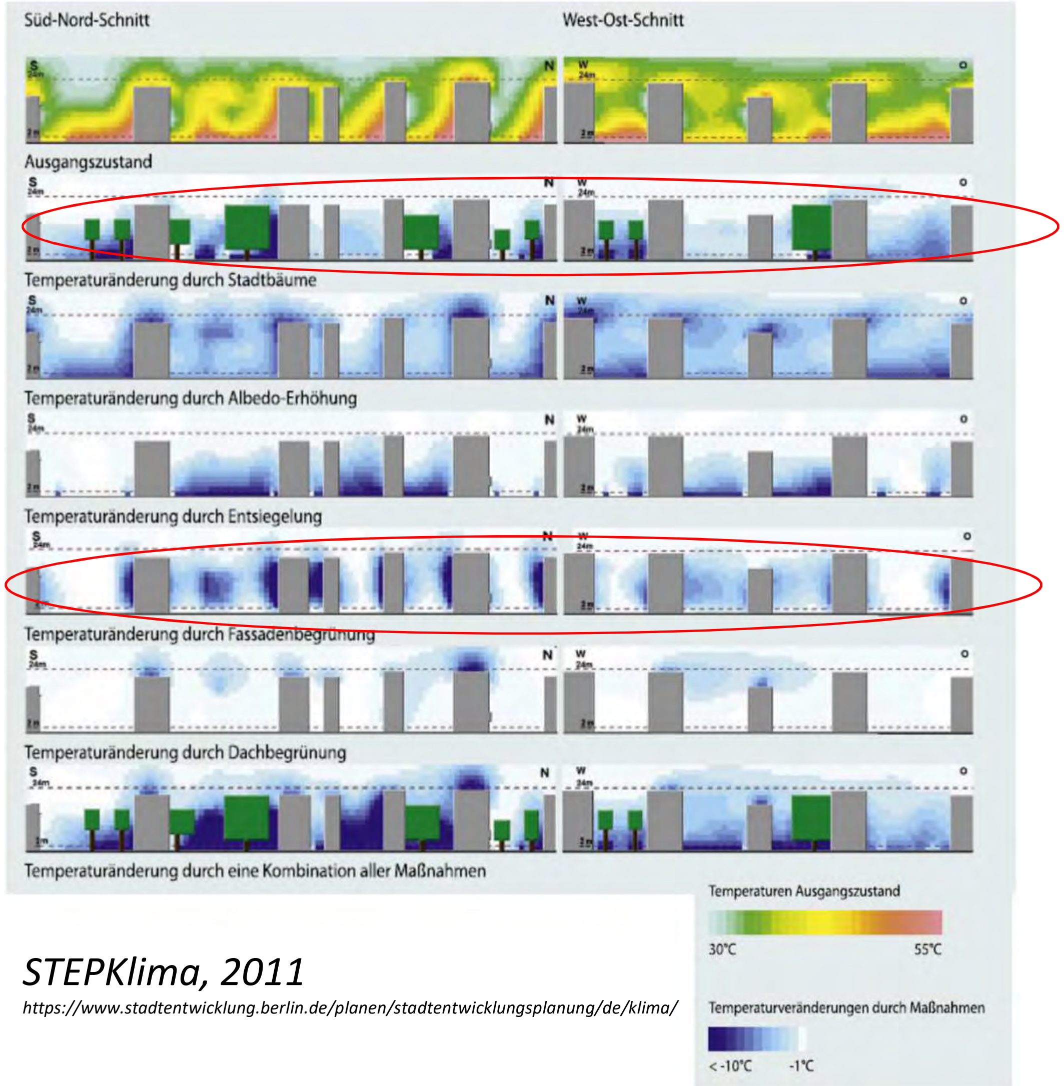
*Hölscher, 2016*




15th July 2014 at about 18:40



# 3. Möglichkeiten zur Quartiersoptimierung




*STEPKlima, 2011*

*https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/de/klima/*

**Table 1**
Classification of countermeasures to UHI, levels: (+) small, (++) medium, (+++) high, (0) no, and (–) negative effectiveness. Abbreviations: (HW) during heat wave, (e) electric energy, (h) heat, (w) water.

| Measures | Hazard reduction potential | | Resources |
|---|---|---|---|
| | Outdoors | Indoors (HW) | |
| *City scale (pavement and urban green)* | | | |
| Cool pavements | + | + | |
| Trees | ++ | + | w |
| Grass | + | 0 | w |
| *Building scale (roof and façade)* | | | |
| Cool roof | + | + | |
| Green roof | + | + (0) | w |
| Green façade | + | + | w |
| *Room scale (passive and active cooling)* | | | |
| Overhangs and shutters | 0 | ++ | |
| Curtains | 0 | + | |
| Night ventilation | 0 | ++ (+) | |
| Vapour compression AC | – | +++ | e |
| Absorption based AC | – | +++ | h |
| Evaporative cooling | 0 | ++ | w |

*Buchin et al. 2016*

# 3. Möglichkeiten zur Quartiersoptimierung

**Table 1**
Classification of countermeasures to UHI, levels: (+) small, (++) medium, (+++) high, (0) no, and (–) negative effectiveness. Abbreviations: (HW) during heat wave, (e) electric energy, (h) heat, (w) water.

| Measures | Hazard reduction potential | | Resources |
|---|---|---|---|
| | Outdoors | Indoors (HW) | |
| *City scale (pavement and urban green)* | | | |
| Cool pavements | + | + | |
| Trees | ++ | + | w |
| Grass | + | 0 | w |
| *Building scale (roof and façade)* | | | |
| Cool roof | + | + | |
| Green roof | + | + (0) | w |
| Green façade | + | + | w |
| *Room scale (passive and active cooling)* | | | |
| Overhangs and shutters | 0 | ++ | |
| Curtains | 0 | + | |
| Night ventilation | 0 | ++ (+) | |
| Vapour compression AC | – | +++ | e |
| Absorption based AC | – | +++ | h |
| Evaporative cooling | 0 | ++ | w |

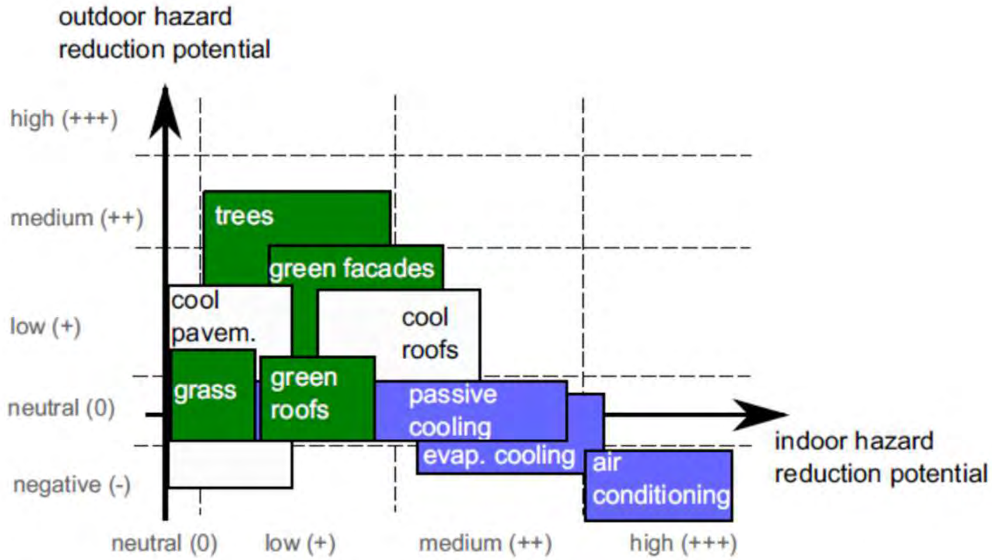



**Fig. 7.** Hazard reduction potential of countermeasures to UHI and active and passive cooling measures on the room scale.

*Buchin et al. 2015*

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# Land use patterns, temperature distribution, and potential heat stress risk – The case study Berlin, Germany

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Climate change
Berlin

ABSTRACT

In western societies, the combined effects of climate warming, proceeding urbanization, and demographic change (e.g. population aging) increase the risk of city populations to be subjected to heat-related stress. To provide a scientific fundament for city-wide and spatially explicit adaptation planning, urban heat distribution and the population at risk need to be studied at small spatial scale. This study pursued to (a) investigate the land surface temperature (LST) distribution with regard to underlying effects of urban land use patterns, and to (b) identify areas at potential risk towards heat stress based on temperatures distribution and demographic vulnerability. We used LST maps as derived from two Landsat thermal satellite images for 10 pm and 10 am at two subsequent summer days and examined land use patterns through land use types, landscape metrics, and structural parameters via statistical and GIS analysis. Using linear regressions we obtained the degree of soil sealing to be the best predictor of LST-variations. However, under certain conditions, NDVI, distance to city center and floor area ratio (FAR) were better predictors. Water bodies had beneficial effects at 10 am and inverse effects at 10 pm, vice versa for arable land. The cooling effects of green areas were more significant in the morning than in the evening. Residential uses were among the most heat affected land use types at 10 pm, with different intensities according to their density level. For the identification of risk areas at the building scale, we introduced a matrix to combine simulated air temperature with population age and density. Results showed higher potential risk in central inner-city areas of dense residential uses, in particular for areas with high amounts of elderly residents, and for two major residential building types. The identified building blocks of specific heat stress risk provide urban planners with useful information to mitigate adverse effects caused by future heat waves.

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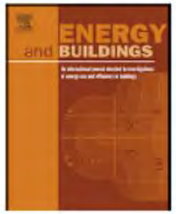


# Quantifying cooling effects of facade greening: Shading, transpiration and insulation

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Insulation
Building
Urban context

ABSTRACT

Facade greening is expected to mitigate urban heat stress through shading, transpiration cooling and thermal insulation. This study quantifies cooling effects of facade greenings for the building and the street canyon and distinguishes between transpiration and shading effects. Additionally it discusses insulation effects.

Outdoor experiments were conducted during hot summer periods on three building facades in Berlin, Germany.

We determined transpiration rates (sap flow) and surface temperatures of greened and bare walls as well as of plant leaves (temperature probes) of three climbing plants: *Parthenocissus tricuspidata*, *Hedera helix* and *Fallopia baldschuanica*. Furthermore, air temperature, relative humidity and incoming short-wave radiation were measured.

No cooling effect was detectable for the street canyon. Surface temperatures of the greened exterior walls were up to 15.5 °C lower than those of the bare walls, while it was up to 1.7 °C for the interior wall (measured during night-time). The cooling effects mainly depended on shading, whereas a lower proportion was due to transpiration. Insulation of the direct greenings reduced radiation during night-time. We conclude that greening can be an effective strategy to mitigate indoor heat stress as long as the plants are sufficiently irrigated with up to 2.5 L $m^{-2}$ $d^{-1}$ per wall area.

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# Evaluation of the health-risk reduction potential of countermeasures to urban heat islands

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Cool pavement
Urban green
Passive building design
Air-conditioning

ABSTRACT

Traditional assessment of heat-related health risks neglects the influence of the building physics as outdoor conditions are used as predictor variables. Data on heat-related mortality from Berlin, Germany and from the US are evaluated with a risk concept which differentiates between outdoor and indoor hazards. Such, the influence of non-linear building physics on heat-related risks can be considered and the impact of adaptation strategies can be examined.

The number of heat-related deaths in the age-group 65+ for Berlin is expected to double with each 1 K increase in ambient temperature. It can be reduced by 50% with a mean ambient air-temperature reduction of 0.8 K. Countermeasures to urban heat islands are evaluated according to their reduction potential on hazards, both indoors and outdoors. The analysis shows that classic UHI countermeasures, which are effective in reducing air-temperatures outdoors, do not necessarily reduce the indoor hazard. Regarding indoor heat-related hazards, trees, façade and roof greening, cool roofs and cool pavements have a low impact only. Measures at the building level, namely cool roofs and façade greening perform best, however, passive cooling and air-conditioning are most effective. To reduce the number of excess deaths in a changing climate, combined measures are necessary.