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University of Cologne
Geographical Institute
Graduate School of Geosciences

Session H23V: Urban Heat, Vegetation, and Water Dynamics: Emerging Research for Management and Equity in Cities,
Poster, H23V-1850, Tuesday, 12 December 2023, Poster Hall A-C - South (Exhibition Level, South, Moscone Center)

# High-Resolution Microclimate Modelling to Evaluate Urban Heat Mitigation Potentials of Rainfed Climate Change Adaptation Measures on Buildings under Various Climatic Conditions

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## Motivation:

- Due to global warming, **heat stress** is becoming a major challenge in urban areas.
- An intensification of the urban heat island effect is observed and expected.
- **Climate change adaptation measures** are needed to mitigate heat stress and health risks, and should cool down indoor and outdoor conditions.
- Measures like **green, blue or blue-green roofs** are a promising scalable approach aiming to substitute sensible and wall heat flux by latent heat flux.
- Cooling effects of evapotranspiration-based measures are **limited by water availability**.
- Coupling **rainfed water storage systems** e.g. cisterns with PV-driven pumping systems for green/blue roofs holds the potential to mitigate drought, heat as well as reduce floods.
- A parameterization of wet roofs in urban microclimate models is currently not available.

## Research Goals:

**(1)** Development of a **new parameterization for wet roofs** in ENVI-met.
**(2)** **Simulation** of rainfed nature-based solutions on buildings using the physically-based microclimate model ENVI-met for an urban high-density area in Cologne/Germany.
**(3)** **Evaluation of scenario analyses** (green & blue roofs) to quantify **potential cooling effects**.

## Methods:

### 1) ENVI-met Model Setup: (*2 X 2 X 2 meter spatial resolution, 1 second temporal resolution*)

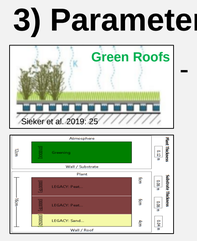
- 3D gridded **16 ha model domain** of an urban high-density area in the city of Cologne/Germany.
- **Parameterized** using field measurements and remote sensing.
- Model driven by a setup research-grade meteorological station in the study area.
- **Simulation** of a **20-year heat event** in summer 2022: 18th-20th July (72 hours).

### 2) Model Calibration and Validation:

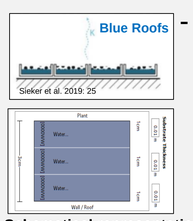
- Model validated using **quality-controlled, densely-distributed microclimate sensor network.**
  - **59 NETATMO sensors** measuring in 5 min. resolution: Temperature, humidity, wind speed.
  - Accuracy of sensors regularly checked by **re-calibrations under laboratory conditions** and direct comparisons with research-grade meteorological sensors in the field.
  - High long-term stability and consistency: **RMSE = 0.059 °C** and 1.41 % rel. Humidity.
  - **Good significant model fit** between measurements and ENVI-met outputs: **NSE = 0.94**

**Model Validation: NETATMO sensors, installed under uniform controlled conditions in the study area with radiation protection and mounts (50cm).**

### 3) Parameterizations of Blue and Green Roofs:



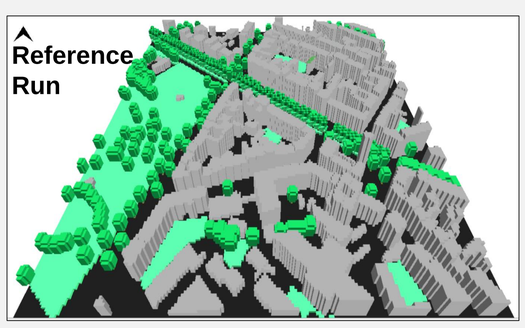

- **Green Roof:** 4 cm sand and 12 cm peat as a roof greening substrate: Emissivity = 0.95, Albedo 0.30, Water Coefficient of Substrate to Plant 1.00, Air Gap to Wall 0.01 m, fully-irrigated. 12 cm dense gras, LAI 1.5, Leaf angle distrib. 0.5.



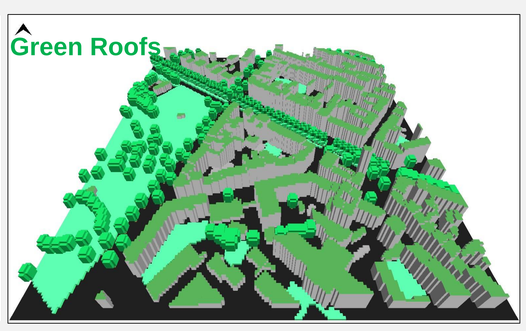

- **Wet Roof:** 3 cm water body as a natural roof greening substrate: Emissivity 0.95, Albedo 0.50, Water Coefficient of Substrate 1.00, Air Gap to Wall set to 0.01 (minimum value to approx. 0). Roof greening removed by seasonal LAD = 0.00.

**Schematical representations of a green roof (top) as well as a blue roof (below), and its implementation in the ENVI-met model parameterizations.**

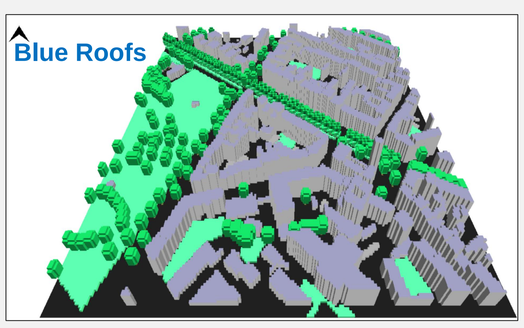
### 4) Szenario Design:




**Reference Run:** 3D ENVI-met model domain of the area (status-quo)

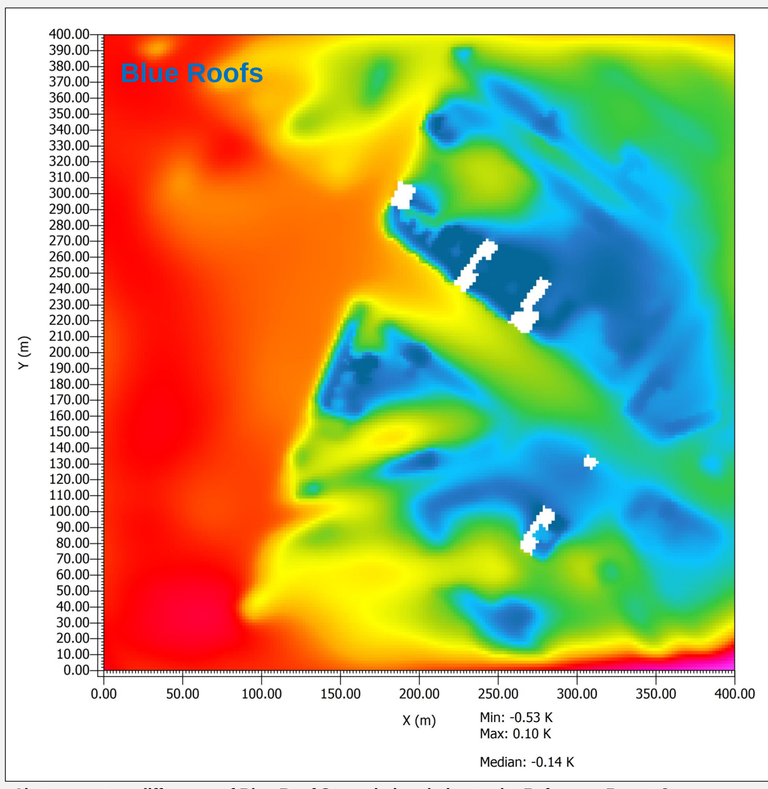



Szenario 1: **Green Roofs** on all building roof terraces (fully-irrigated)

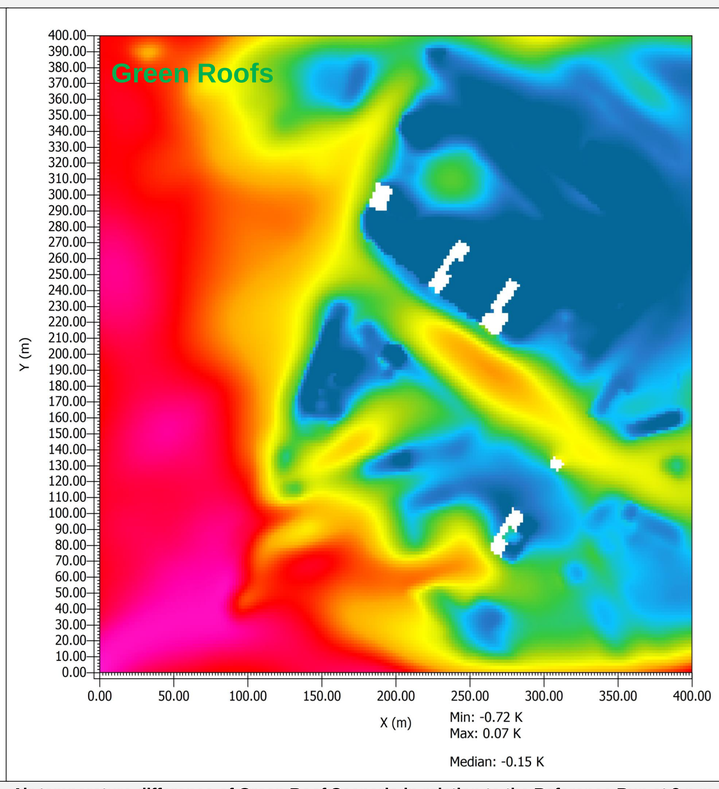



Szenario 2: **Blue Roofs** (water bodies) on all building roof terraces

## Modelling Results:



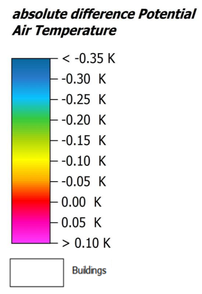

**Air temperature difference of Blue Roof Scenario in relation to the Reference Run at 2 p.m..**



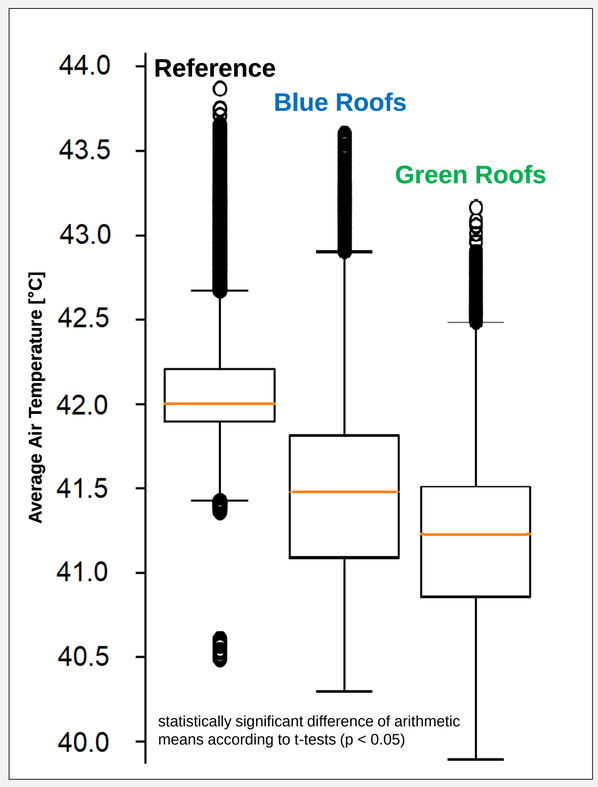

**Air temperature difference of Green Roof Scenario in relation to the Reference Run at 2 p.m..**

**Simulated Air Temperature Differences (Blue/Green Roof Scenario – Reference Run) at 2 p.m. on 18 th July 2022**

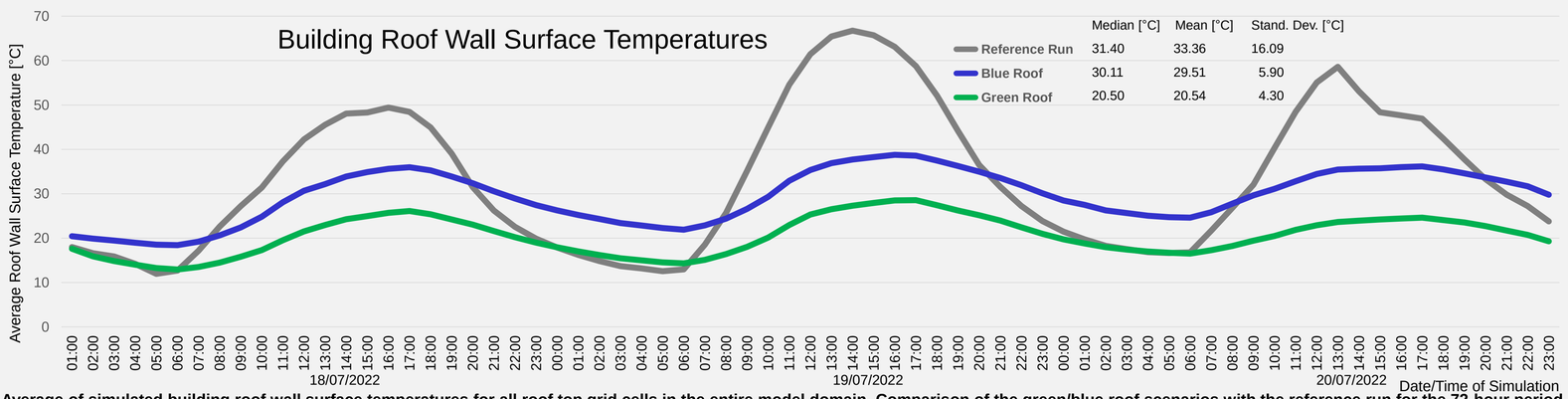
**View plane height: 25 m above ground level**




Meteorological driver conditions:
Wind: 1.07 m/s


**Average of Air Temperature for all adjoining grid cells 1m above roof tops in the model domain for the hottest hour of the day (4 p.m. at 19th July).**




**Average of simulated building roof wall surface temperatures for all roof top grid cells in the entire model domain. Comparison of the green/blue roof scenarios with the reference run for the 72-hour period.**

## Conclusion and Discussion:

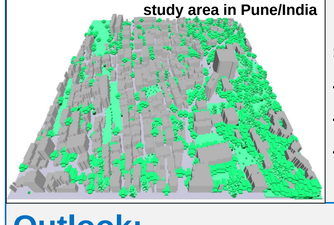
**(1)** New blue roof parameterization shows expected results.
**(2) High accuracy of setup ENVI-met model** validated with quality-controlled densely-distributed ground measurements.
**(3) Statistically significant cooling effects** found on average:
  a) Blue Roofs: Temperature difference to reference run:
  - Air 1m above rooftops: **-0.52 K** and up to -2.67 K
  - Building roof wall surface: **-3.85 K** and up to -29.03 K
  b) Green Roofs: Temperature difference to reference run:
  - Air 1m above rooftops: **-0.76 K** and up to -3.01 K
  - Building roof wall surface: **-12.82 K** and up to -39.45 K

- Cooling effects of green roofs on air temperature strongest during daytime and for **blue roofs strongest in the evenings**.
- Green roofs show small effects on roof surface temperatures during nighttime, while **blue roofs heat up walls in nighttime**.

=> *Suitable climate adaptation and flood mitigation pathways.*

- More **intensive roof greenings** show even stronger effects.
- **Sprayed wet roofs** (cistern pump cycle) reduce wall heating.
- Higher heat mitigation potentials when **combining** blue/green roofs with technical/nature-based solutions in street canyons.

**ENVI-met model domain for a similar study area in Pune/India**



## Outlook:

- In ongoing research, cooling effects of green/blue roofs are compared to a similar model setup for a study area in **Pune/India** to analyse different effects on thermal comfort.
- Heat mitigation potentials are stronger for Pune, but due to **water scarcity** in the Indian **pre-monsoon hot season**, actual cooling effects smaller than in Cologne/Germany.
- Rainfed measures can **rarely be operated** for extreme heat waves at the hot season end.

## Further Materials and References:

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