EGU General Assembly 2024, Vienna, Austria, 14-19 Apr 2024

University of Cologne
Geographical Institute

Session: CL2.5: Urban climate, urban biometeorology, and science tools for cities
Abstract: EGU24-9967

Comparison of heat mitigation effects of blue roofs and green roofs on building wall temperature and thermal outdoor comfort based on scenario analyses using 3D microclimate modelling for a dense urban district

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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*)

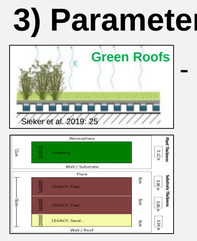
- 3D gridded **16 ha model domain** of an urban high-density area in the city of Cologne/Germany.
- **Parameterized** using field measurements and remote sensing.
- Model driven by a setup research-grade meteorological station in the study area.
- **Simulation** of a **20-year heat event** in summer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

2) Model Calibration and Validation:

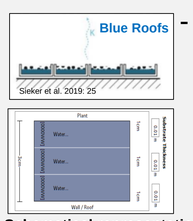
- Model validated using **quality-controlled, densely-distributed microclimate sensor network.**
  - **59 NETATMO sensors** measuring in 5 min. resolution: Temperature, humidity, wind speed.
  - Accuracy of sensors regularly checked by **re-calibrations under laboratory conditions** and direct comparisons 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:



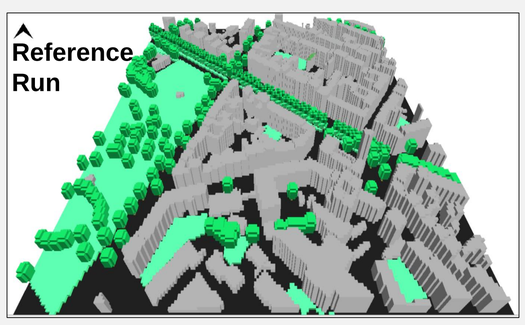
- **Green Roof:** 4 cm sand and 12 cm peat as a roof greening substrate: Emissivity = 0.95, Albedo 0.30, Water Coefficient of Substrate to Plant 1.00, Air Gap to Wall 0.01 m, fully-irrigated. 12 cm dense gras, LAI 1.5, Leaf angle distrib. 0.5.



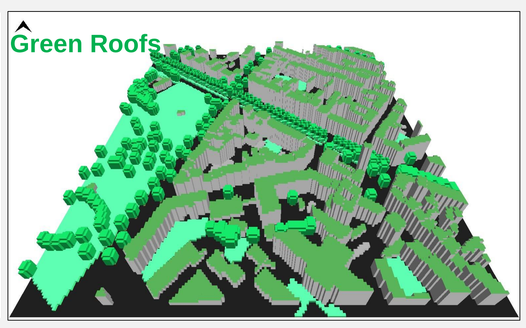
- **Wet Roof:** 3 cm water body as a natural roof greening substrate: Emissivity 0.95, Albedo 0.50, Water Coefficient of Substrate 1.00, Air Gap to Wall set to 0.01 (minimum value to approx. 0). Roof greening removed by seasonal LAD = 0.00.

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

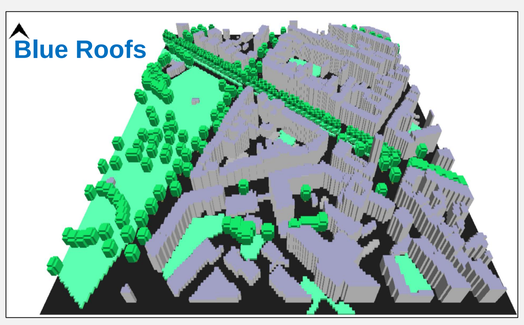
4) Szenario Design:



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

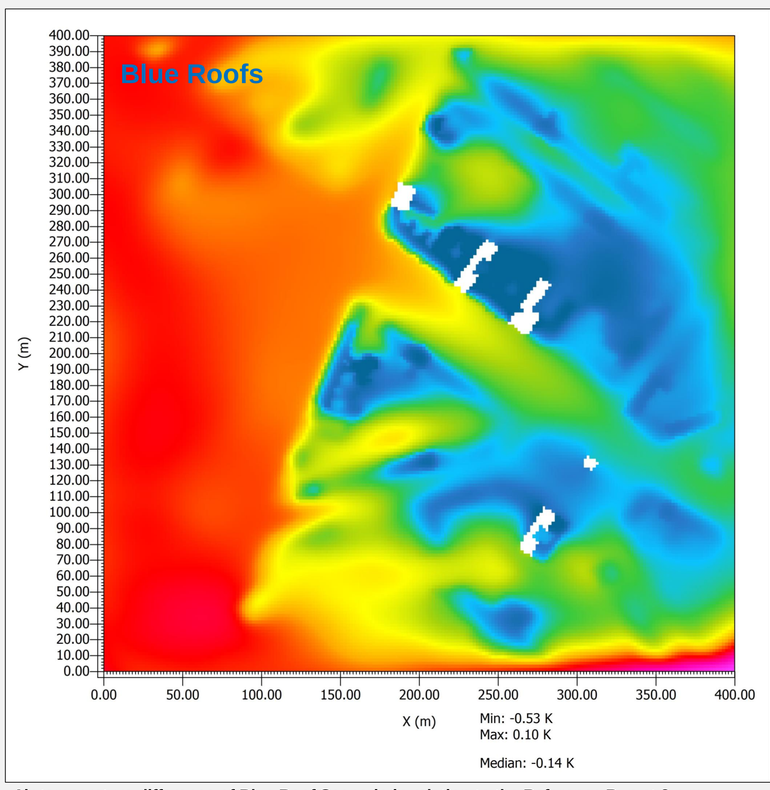


Szenario 1: **Green Roofs** on all building roof terraces (fully-irrigated)

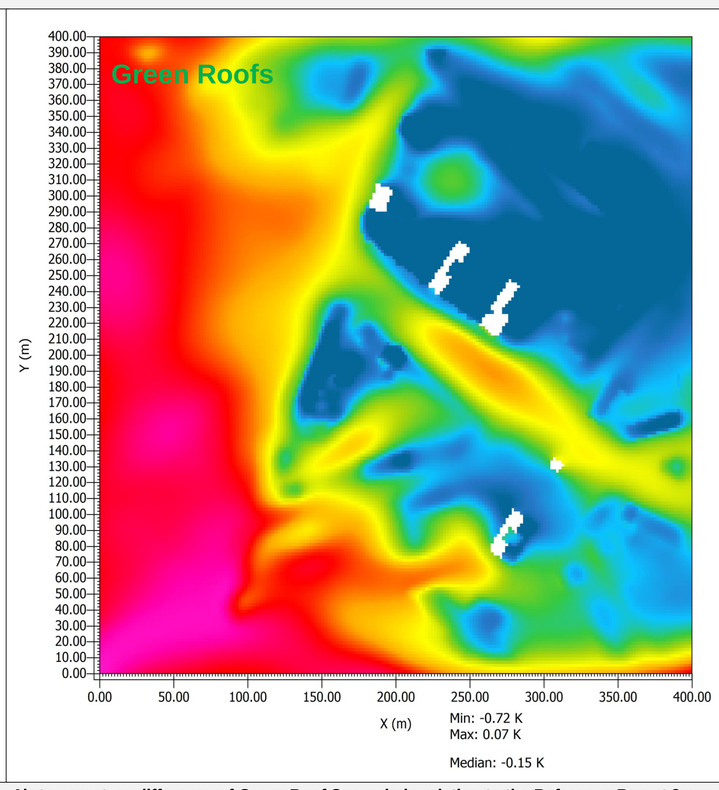


Szenario 2: **Blue Roofs** (water bodies) on all building roof terraces

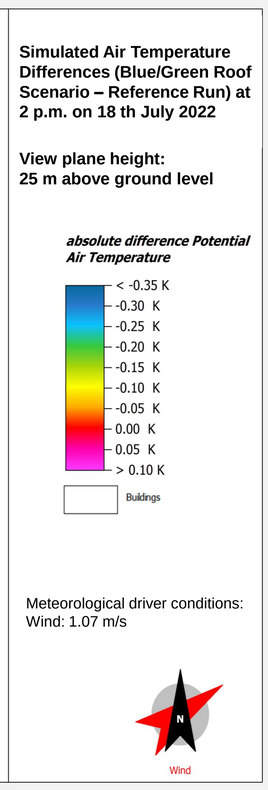
Modelling Results:

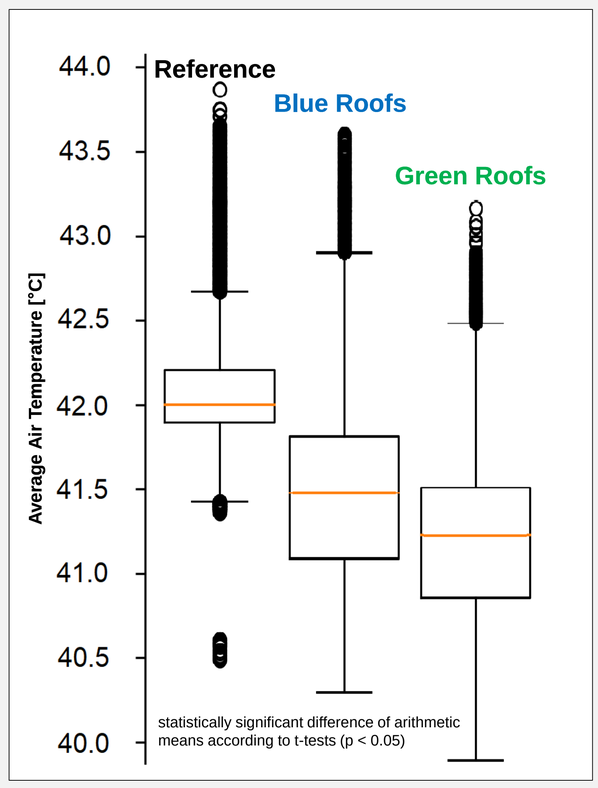


Air temperature difference of Blue Roof Scenario in relation to the Reference Run at 2 p.m..

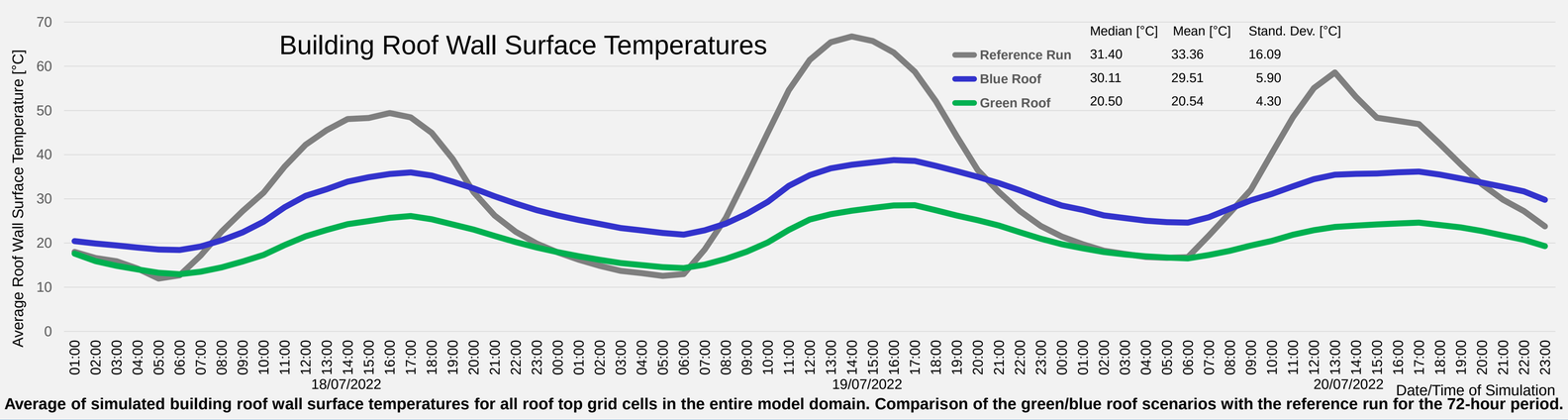


Air temperature difference of Green Roof Scenario in relation to the Reference Run at 2 p.m..





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**.

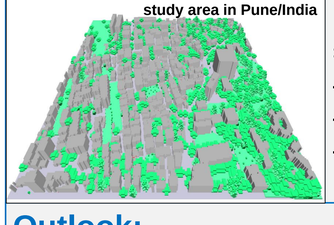
=> *Suitable climate adaptation and flood mitigation pathways.*

- 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.

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.

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



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