Semi-intensive green roofs – an innovative tool for climate change adaptation and environmental protection.

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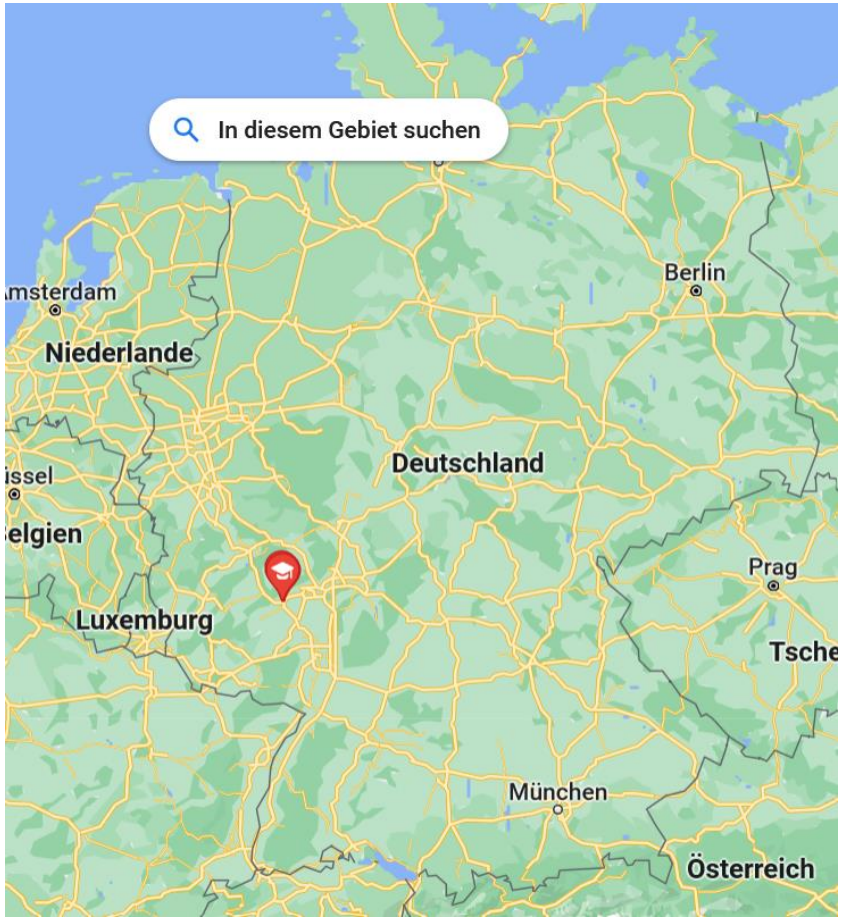
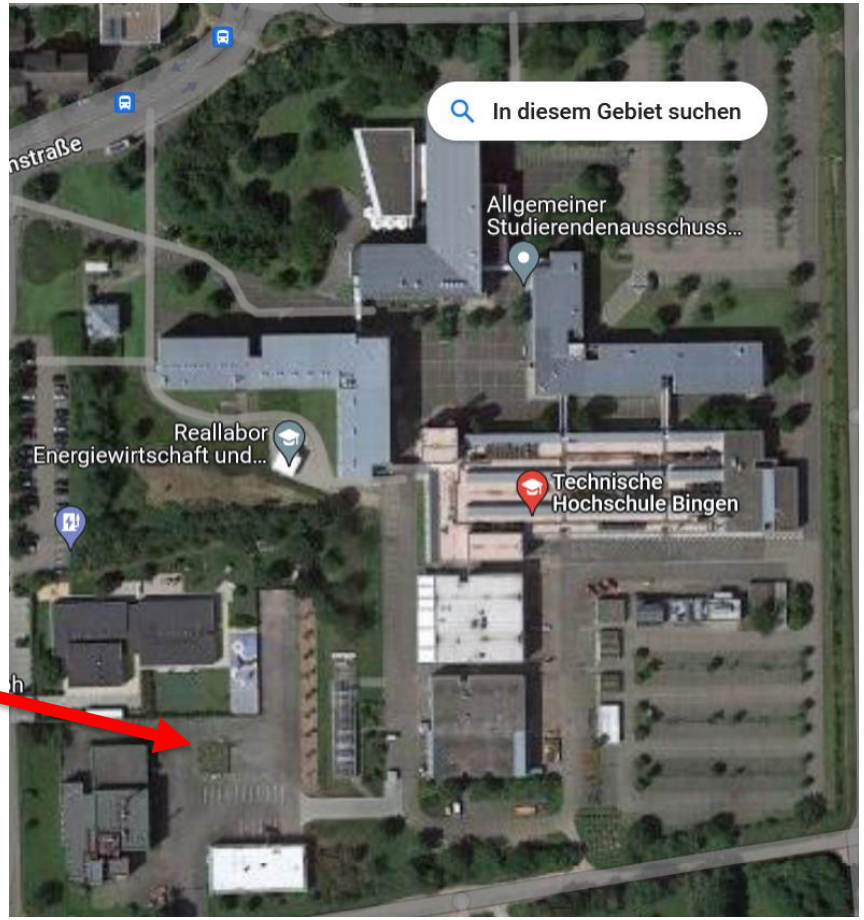


Green Roof Model



Google Maps, 2023

Authors

Biodiversity

Prof. Dr. Elke Hietel

Water balance

Prof. Dr.-Ing. Ute Rößner

Particulate matter

Dr. Klemens Seelos

Microclimate

Prof. Dr. Oleg Panferov

Acknowledgements

Statistics

Prof. Dr. Cornelia Lorenz-Haas

Installation, Measurements

Dipl.-Biol. Ben Warnecke

Installation, Measurements

M.Sc. Jan Wustmann

M. Bernhard – *UAS Images*

Green Roofs in Germany

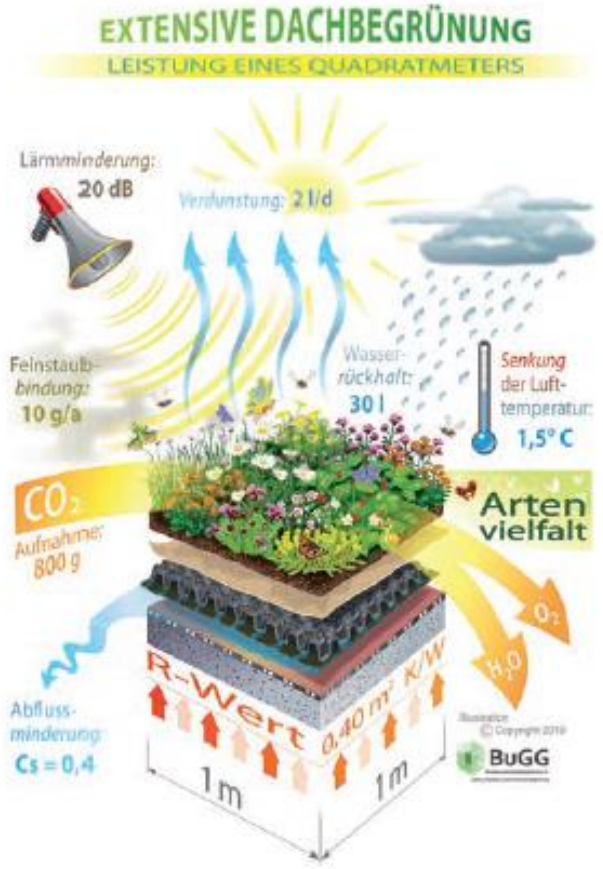
BUGG, 2022, Fig. 4

- Total Green Roof (GR) area, Germany: 120 – 150 mio m².
- New area in 2021: 8.681.416 m² with 82,5 % extensive
- Extensive GR: 8-15 cm substrate layer, 80-170 kg/m²
- Low maintenance, drought resistant

BUGG, 2022

Expected advantages

- Cooling effects
- CO_2-Sequestration
- Increase of biodiversity
- Storm water retention
- Deposition of pollutants
- Noise reduction



BUGG, 2022, Fig. 1

Quantification of Effects?

Our first results: extensive GR vs gravel

Extensiv GR: 9 cm, Sedum, 2011

Bitumen and 3 - 5 cm gravel

Hietel et al., 2016

Efficiency of GR

- Microclimate – low efficiency (not statistically significant): low ET (Sedum+Substrate), low albedo differencies. Higher temperature contrasts on GR.
- Higher biodiversity on GR.
- Better stormwater retention (>0.7 retention coefficient for dry substrate)

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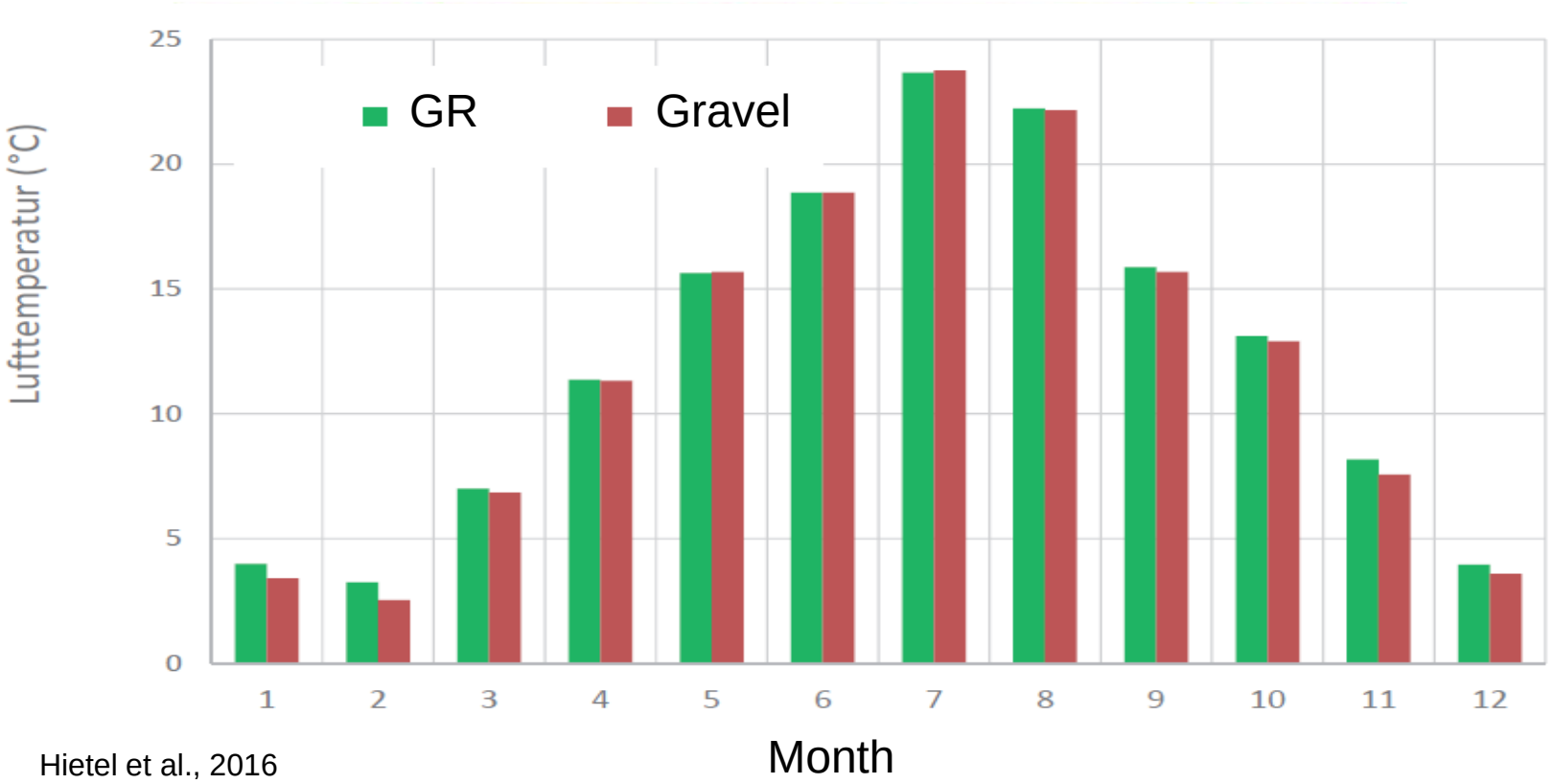


Hietel et al., 2016

Efficiency of GR

Similar results in other studies

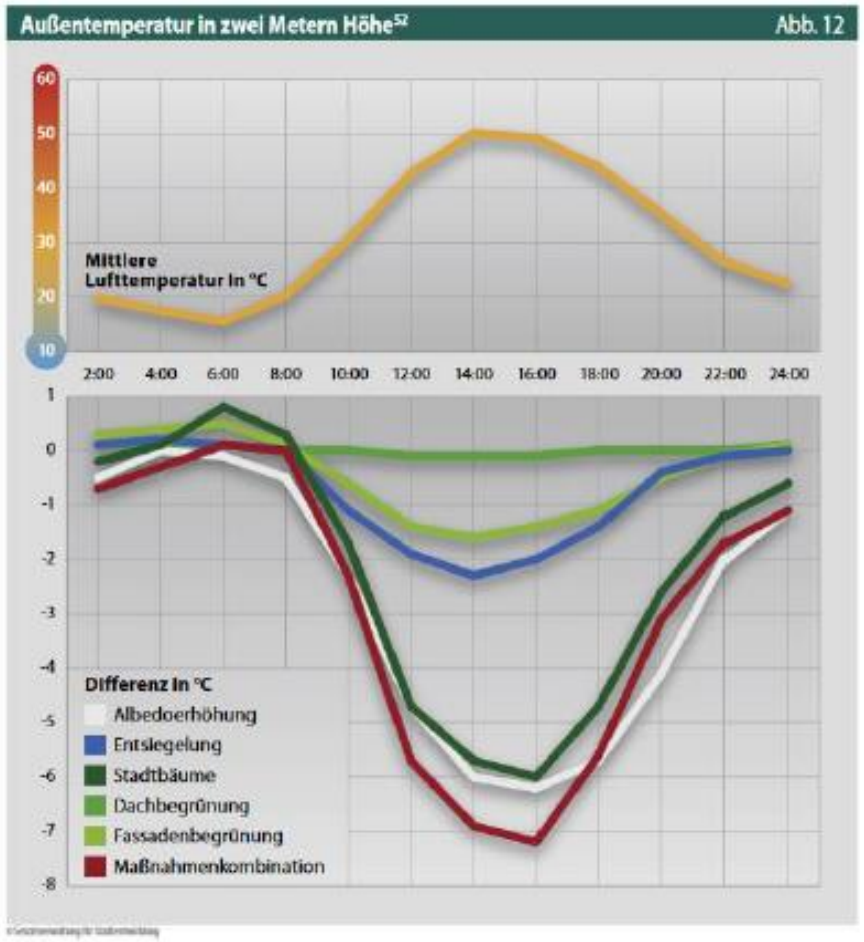
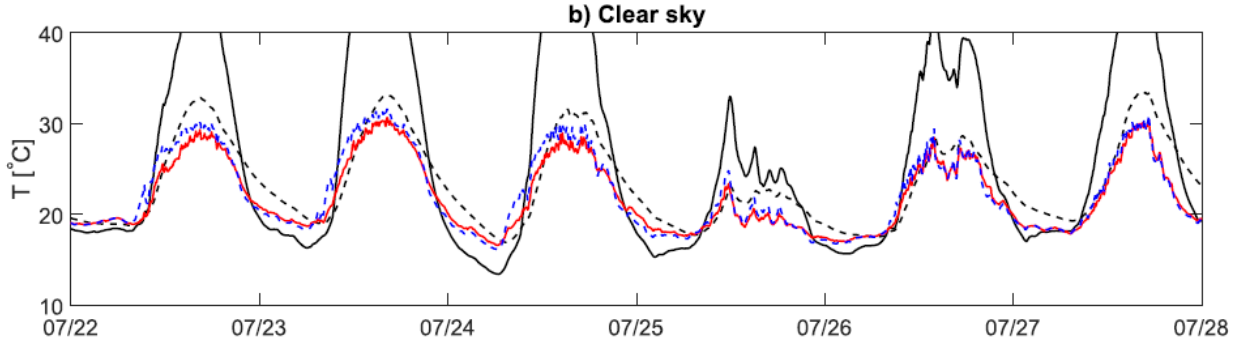
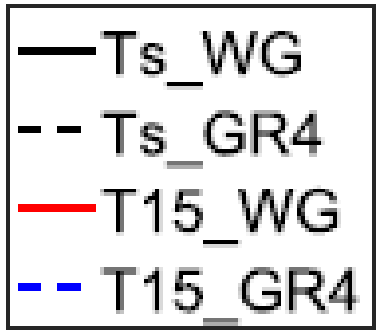


Abbildung 31 Einfluss verschiedener Klimaanpassungsmaßnahmen auf die lokale Außentemperatur (Quelle: Senatsverwaltung für Stadtentwicklung Berlin, 2014)

WOM Report, 2020



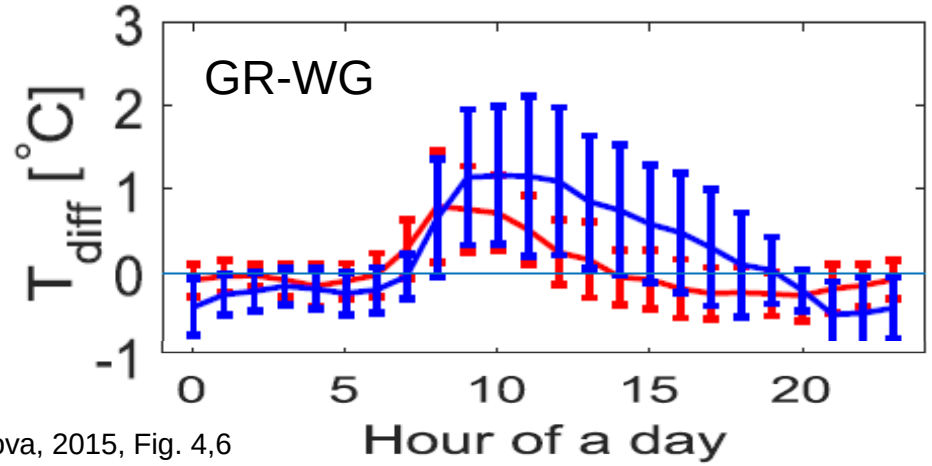


$T_{Surface}$ white gravel

$T_{Surface}$ green roof

$T_{15\ cm}$ white gravel

$T_{15\ cm}$ green roof



Solcerova, 2015, Fig. 4,6

Solution: semi-intensive greening, irrigation

2019 - 2022: **Efficient innovative greening** – semi-intensive system with rainwater irrigation (Effin-Grün)

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit

67DAS148

Goal:

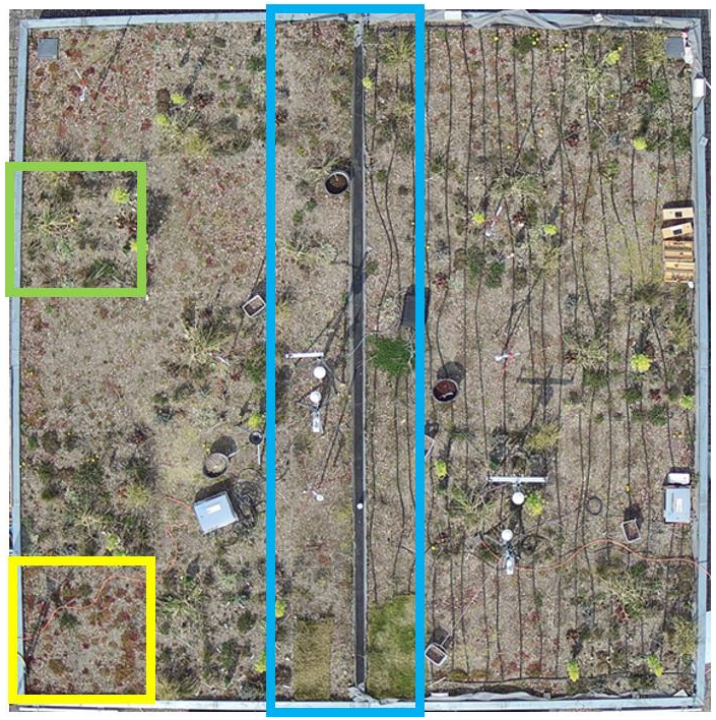
Climate change adaptation: development of cooling semi-intensive green roof with rainwater irrigation pumped with solar energy

TH BINGEN
University of Applied Sciences

Transformation Extensiv-Semi-intensive

ZinCo GmbH: Structure+Substrate

10 m



Implementation

Automatic drip/trickle rainwater irrigation (pumped with PV)
Irrigation avg: 2 mm per day
Planted: 26 species

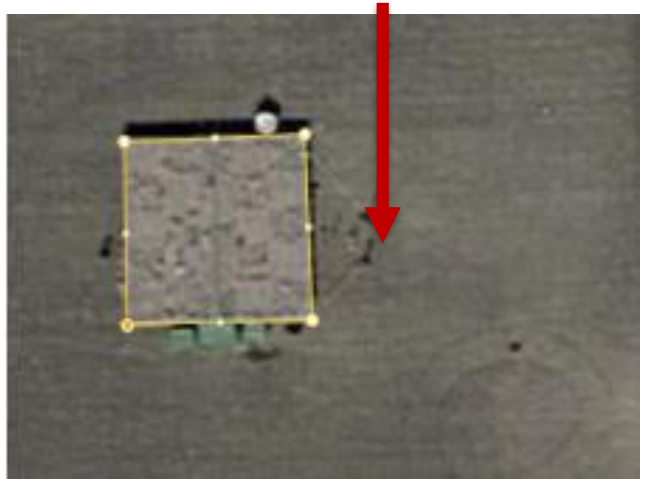
Measurements:

- Automatic weather stations ($t_{0.5}$, RH, GR, WD, WS, P)
  Measurement of GHG fluxes CO_2, H_2O, CH_4 (soil chambers method, LI-COR 6800, UGGA Los Gatos)
- UAS Images
  Simulation of heavy rainfall events
  Measurement of the quality of runoff water
  Simulation of the energy flows in the building
  Identification of arthropods as indicator species
  Plant assessments
  Measurement of particulate matter on plants
- (Particle detection software RADIUS)

Comparison

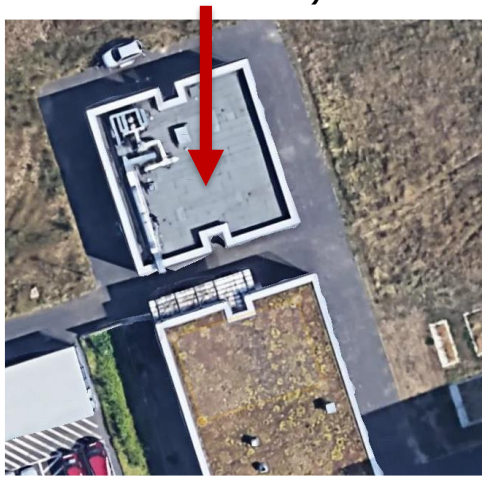
Semi-intensive Green roofs vs different reference surfaces:

Parking lot, Bingen



Cool roof, Mainz

Bitumen roof, Mainz



EFFin-Grün, Final Report, 2022

In this presentation the main focus is on comparison: Green roof vs parking lot

Results: Biodiversity

Conversion: Extensive to semi-intensive greening
Planting is more efficient than sowing: rapid and targeted greening

Spontaneous growth:
- 34 different plant species, 6 neophytes
- High levels of coverage and a high level of biodiversity.
- Quick gap-filling

Semi-intensive GR:
Species-rich and better reproductive habitat.
Significantly longer flowering comparing to extensive sedum roofs promotes pollinating insects.

May

October

EFFin-Grün, Final Report, 2022

Results: Water balance and quality

- ***Infiltration***: 1250mm h^{-1}.
- ***Total water retention***: 60L m^{-2}.
- ***Water retention*** semi-Intensive GR with irrigation: 30-35L m^{-2}.
- Runoff coefficient: 0.22 was achieved for an extensive green roof model with unplanted substrate.
- With plants: no increase in water holding capacity. But: precipitation interception and evaporation.
- ***Quality:*** Run off water meets the requirements of the Drinking Water Ordinance for: pH, el. conductivity, ammonium, nitrite and nitrate.
- El. conductivity: planted green roof higher than the unplanted.
- Nitrate: planted green roof is significantly lower than unplanted - increased denitrification process.

Results: Water balance and quality

For 100 m² semi-intensive roof

- With irrigation 2 L $m^{-2}d^{-1}$, required storage volume of 1.4 m³ per week
- P_{ann} = 400 mm and runoff coefficient of 0.3: up to 12 m³ of runoff water could be stored for a 100 m² roof per year.
- This results in an irrigation range of 60 days.

Irrigation problem in dry regions, like Bingen (P_{ann} = 488 mm a^{-1}).

Data: DLR RLP, 2023 https://www.wetter.rlp.de/Agrarmeteorologie/Wetterdaten/Alphabetisch/AM101

Results: Particulate matter

Conditions:

Wind speed, V = 0.8 m s^{-1},

Dust per plant: 6 * 100 mg / 10-min interval.

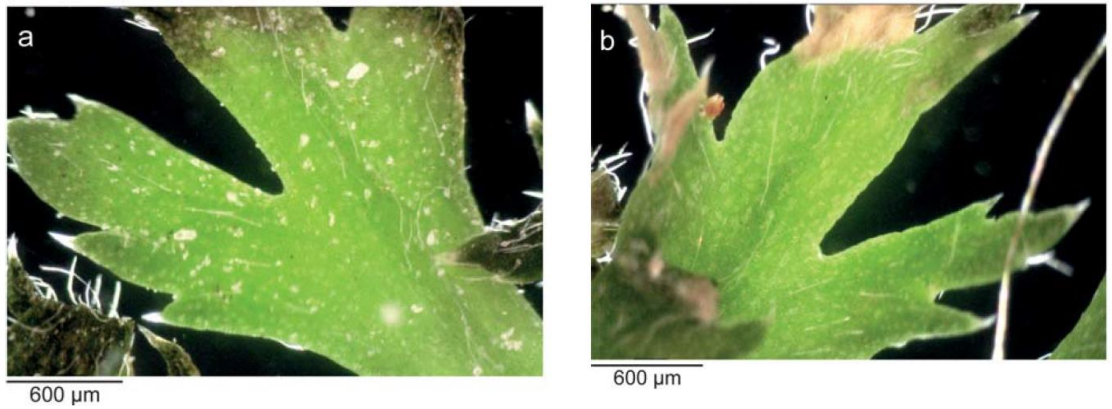
Main factors:

Leaves surface structure: smooth (highest particle density), rough, folded;

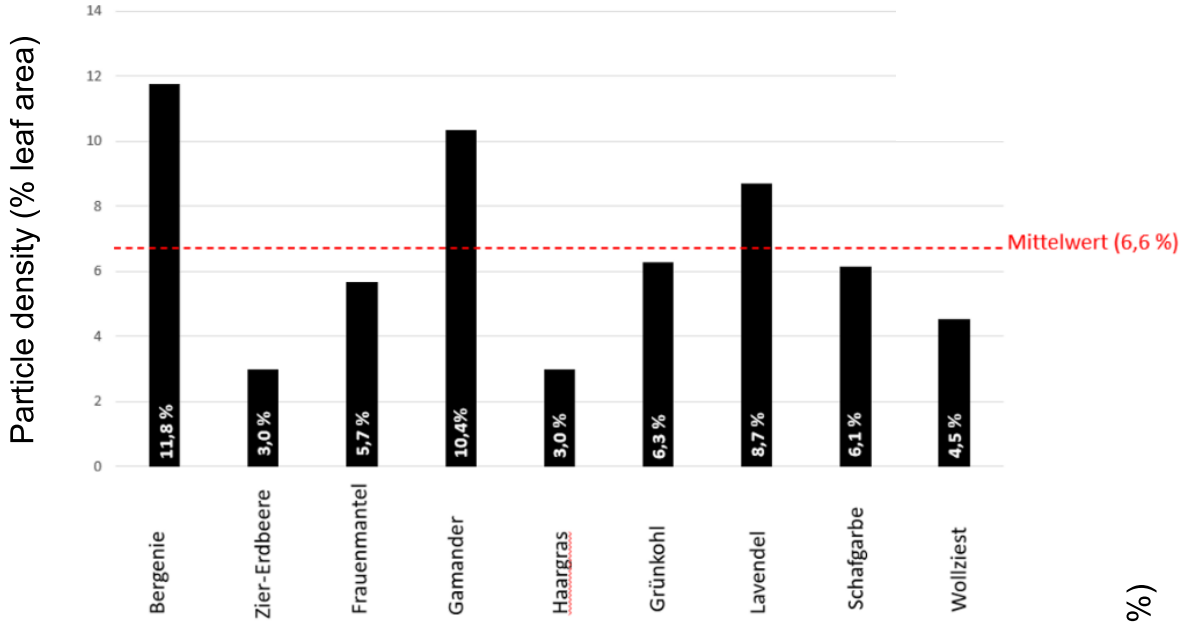
Number and shape of the plant hairs: haired – less PD

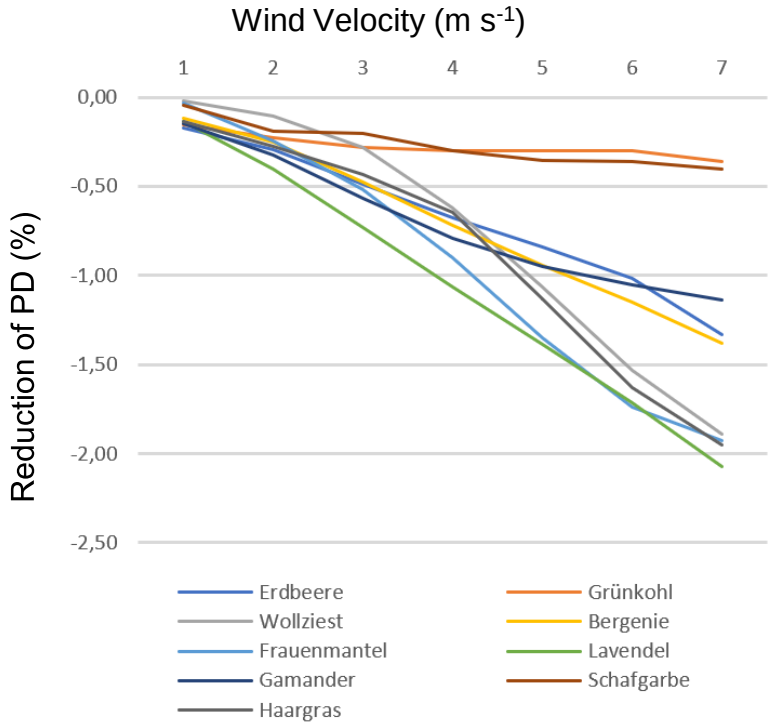
Holding capacity at higher V: folded structure

None of the plants tested in this study meet all the requirements optimally.



Results: Particulate matter





EFFin-Grün, Final Report, 2022

Results: Microclimate

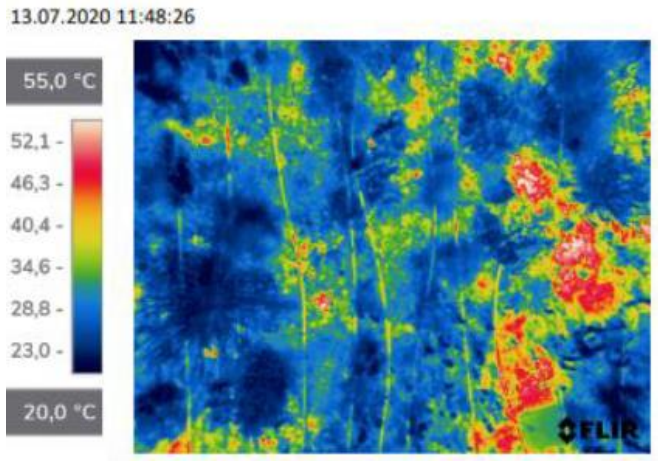
Albedo (spring - summer)

Green roof	0.15 – 0.174 (Sedum 0,16 – 0,172)
Parking lot	0.139 – 0.145

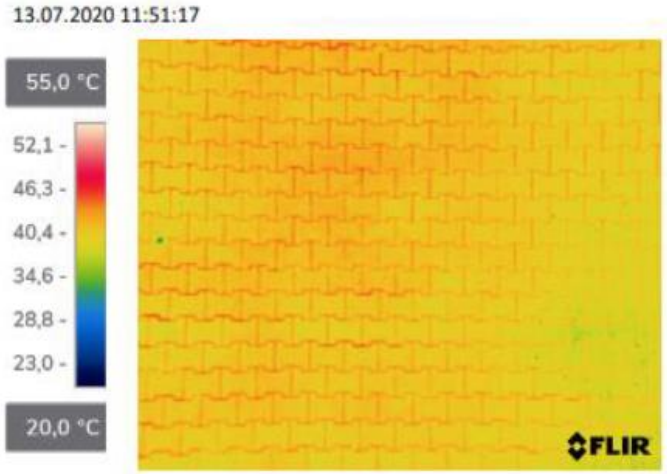
NR01 Hukseflux

Surface temperature

Green roof



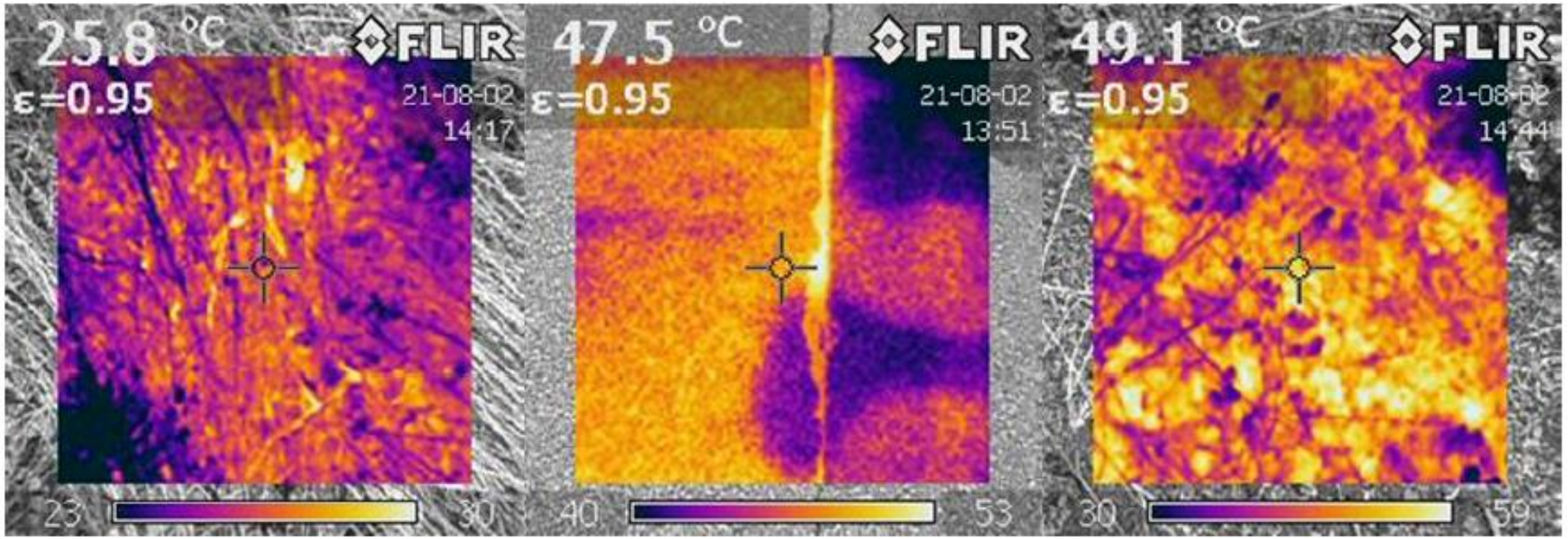
Parking lot



EFFin-Grün, Final Report, 2022

Results: Microclimate, effect of irrigation

Irrigated semi-intensive GR ***Bitumen roof*** ***Extensive GR***



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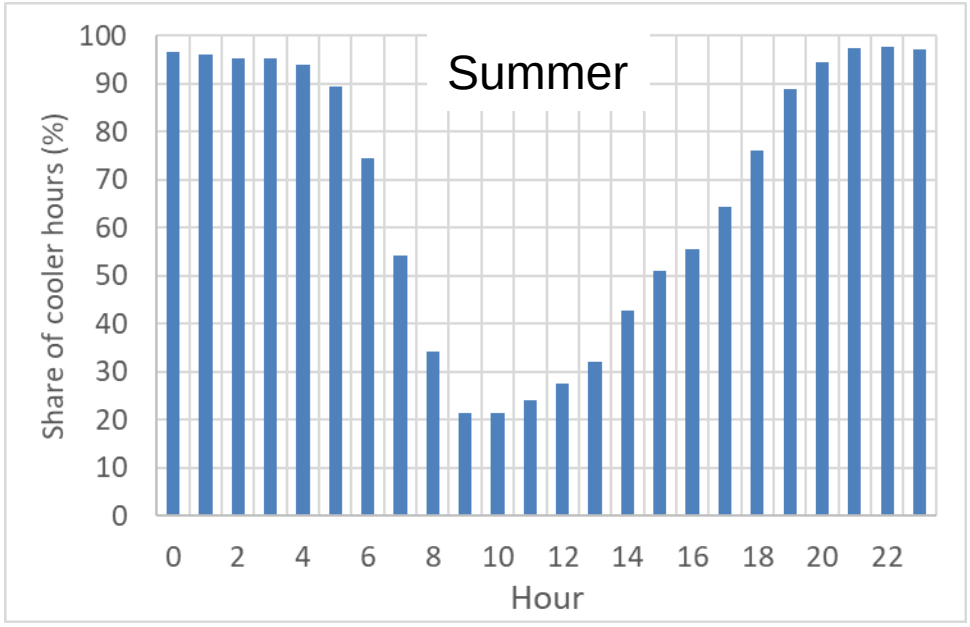
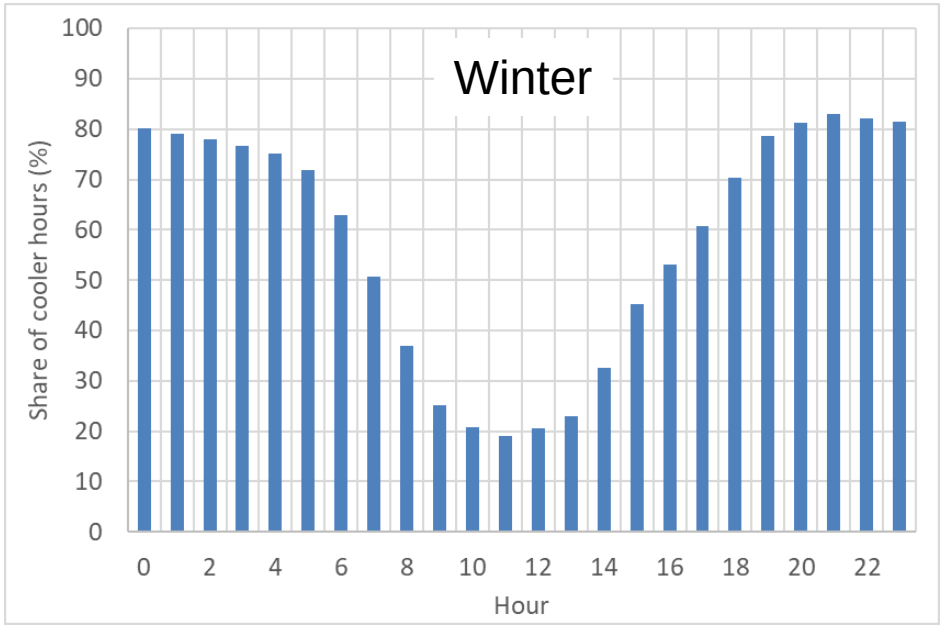
Results: Air temperature

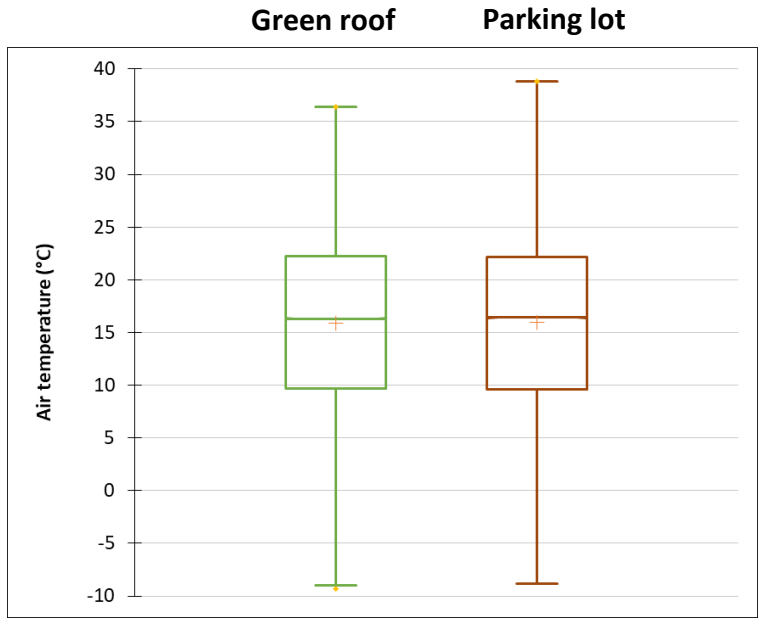
Green roof vs Parking lot

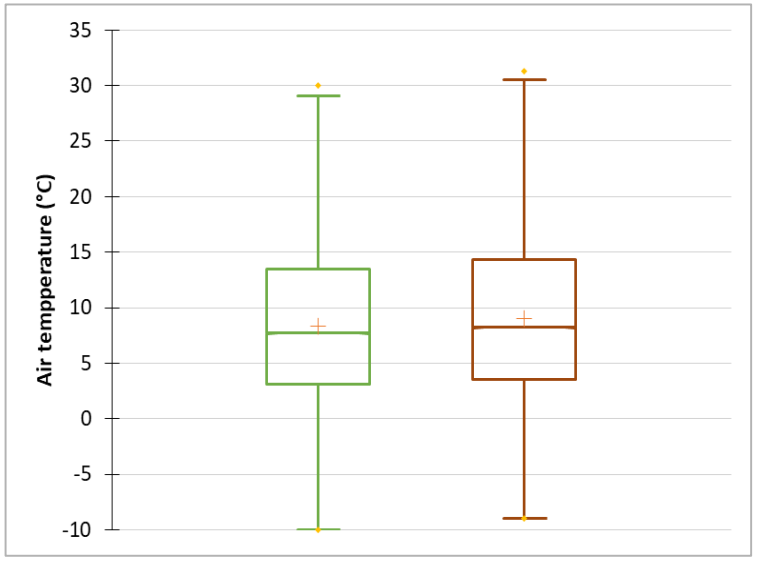




Results: Air temperature

	Green roof:	Parking lot:
	Day, GR > 5 W m^{-2}	
$T_{day, mean}$	15.85 ± 8.1°C	15.95 ± 8.2°C
$T_{day, max}$	36.4°C	38.8°C
$T_{day, min}$	-9,3°C	-8,8°C
	Night, GR < 5 W m^{-2}	
$T_{night, mean}$	8.4 ± 6.5°C	9.01 ± 6.8°C
$T_{night, max}$	30.0°C	31.3°C
$T_{night, min}$	-10.0°C	-9,1°C





Results: Air temperature

Calm Day (GR > 5 W m^{-2}, V < 0,2 m s^{-1})

	n	T_{min}	T_{max}	T_{mean}	StDev
Green roof:	6197	-8,2	29,9	10,5	6,7
Parking lot:		-7,625	32,77	10,952	6,878

Calm Night (GR > 5 W m^{-2}, V < 0,2 m s^{-1})

	32015	-10,0	27,8	8,13	6,4
		-8,71	31,11	8,95	6,697

$p < 0.001$

Theis, 2022

Results: Air temperature

Summer Day ($t_{max} \geq 25^{o}C$)

	n	T_{min}	T_{max}	T_{mean}	StDev
Green roof:	36559	25,0	36,4	28,16	2,23
	36559	25,00	38,81	29,02	2,609
Parking lot:	36559	25,00	38,21	28,49	2,618

$p < 0.001$

Hot Day ($t_{max} \geq 30^{o}C$)

6397	30,0	36,4	31,87	1,403
6397	30,03	38,81	33,43	1,824
6397	30,0	38,21	32,89	1,796

Theis, 2022

Results: Air temperature and RH

Calm Summer Day ($t_{max} \geq 25^{o}C$, $V < 0{,}2\ m\ s^{-1}$)

	n	T_{min}	T_{max}	T_{mean}	StDev
Green roof:	87	25,00	29,00	26,77	1,34
Parking lot:	87	25,54	32,77	29,34	1,67

	n	RH_{min}	RH_{max}	RH_{mean}	StDev
Green roof:	87	37,30	81,60	54,55	10,13
Parking lot:	87	31,05	64,73	42,67	7,20

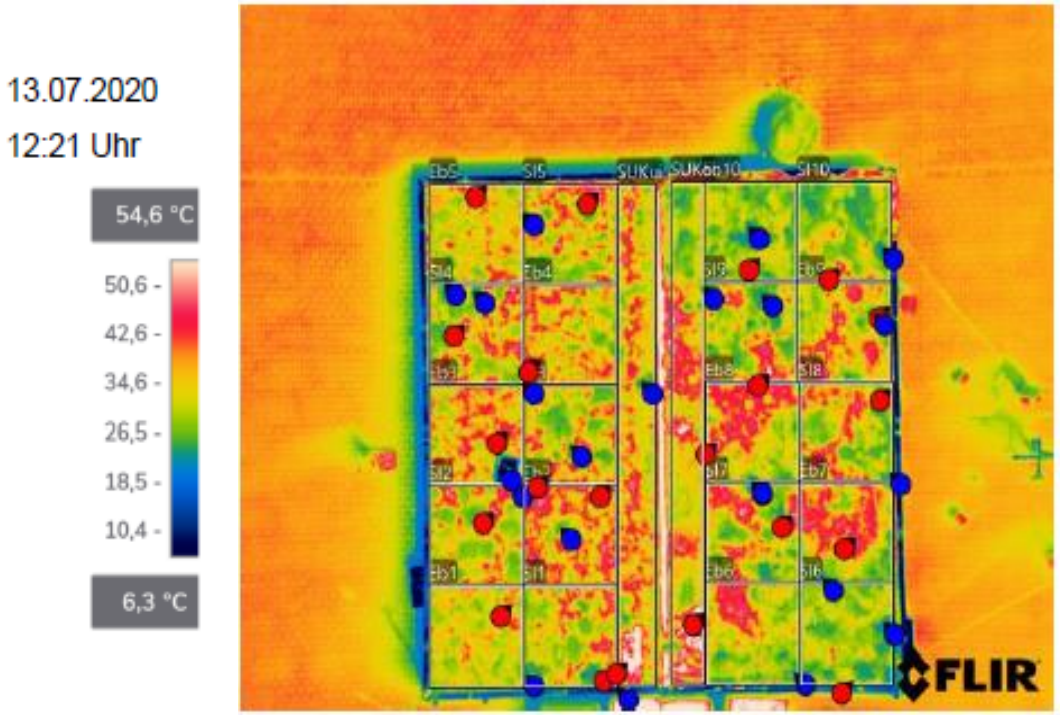
$p < 0.001$

Theis, 2022

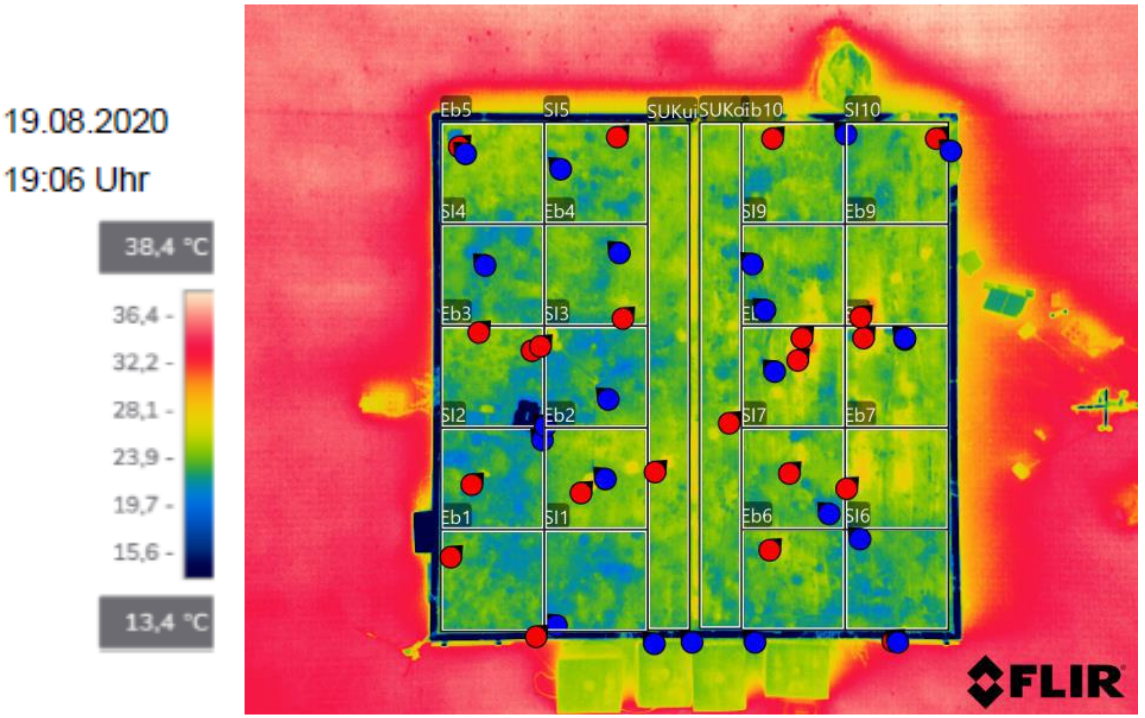
Results: Cooling plants

UAS IR-Images

13.07.2020
12:21 Uhr



19.08.2020
19:06 Uhr



Cool plants: Pampas grass, common yarrow, hyssop, quaking grass, true lavender and common alchemilla

Ritter, 2022

Summary

Semi-intensive green roofs – numerous advantages and higher efficiency comparing to extensive GR

- Automated rainwater irrigation ist relatively easy to install.
- Cooling effects, especially by hot days and summer nights
- Higher biodiversity
- Deposition of air pollutants
- Retention of storm water

Main problem in dry regions: availibility of rain water

Possible solutions: usage of water from neighbour roofs, alternative irrigation water sources e.g. groundwater, graywater

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