Weltkongress Gebäudegrün
World Green Infrastructure Congress WGIC 2023
Berlin
27 - 29 June 2023
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University of Ljubljana
Faculty of Mechanical Engineering

LOTZ
Laboratory for Sustainable Technologies in Buildings

# Characterization of the dynamic thermal response of green roofs under actual boundary conditions

## quantifying the benefits of green roofs with a proposed factor

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# About us



## Laboratory for Sustainable Technologies in Buildings

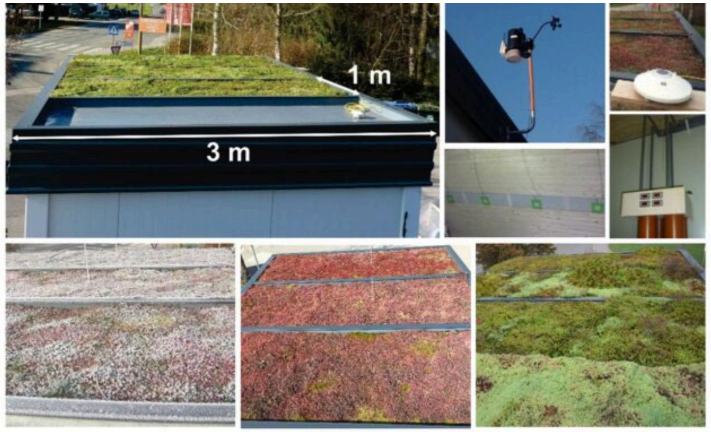
### Green roofs and facades

Thermal response

Hydrological response

Simulations

Project „self-sufficient living cell“.

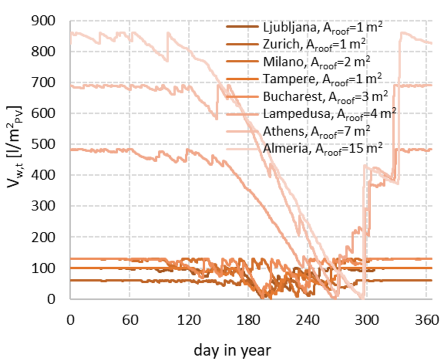



### Renewable technologies

Photovoltaics, BIPV

thermal technologies

### Sustanability

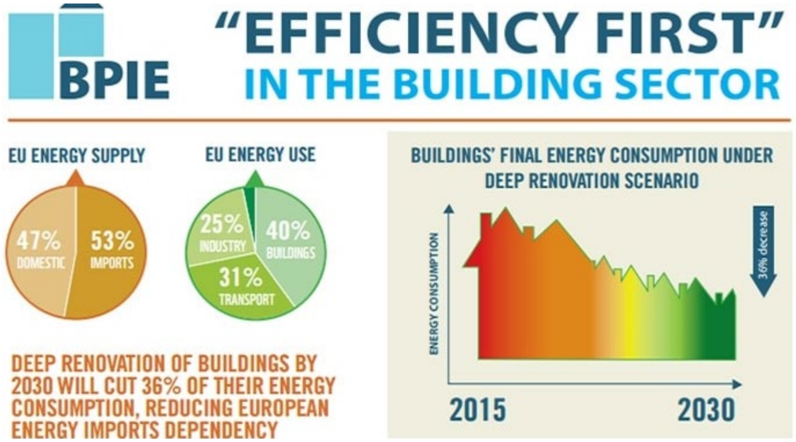



Žižak et al. Efficiency and sustainability assessment of evaporative cooling of photovoltaics, Energy, vol. 254.

# 1. Introduction – benefits of green roofs



Building sector represents 40% of EU energy use




Frances Bean, Mariangiola Fabbri, Buildings Performance Institute Europe (BPIE)

Green roofs have been shown to have a positive impact on thermal performance of buildings

Demonstrated by studies (with complex simulations):

- 4-11% annual energy savings rate

Zeng et al.: Optimal parameters of green roofs in representative cities of four climate zones in China: A simulation study, Energy Build., 150 (2017), pp. 118-131

- 30 % decrease in annual cooling energy demand of insulated roofs

Susca.: Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate, Building and Environment, 162 (2019), 106273

Results dependent on construction, vegetation, location etc.

# 1. Introduction – presenting the benefits





A lack of straightforward properties that emphasize the benefits of green roofs

- Thermal transmittance *U* ?

conventional lightweight roof with 25 cm insulation

+

Lightweight extensive roof with 8 cm substrate and vegetation

⇨ *ISO 6946: water saturated layers not considered in calculation*

⇨ Theoretical calculation with saturated substrate thermal conductivity

$U=0.134\ W/m^2K \Rightarrow U=0.131\ W/m^2K$

# 1. Introduction – presenting the benefits

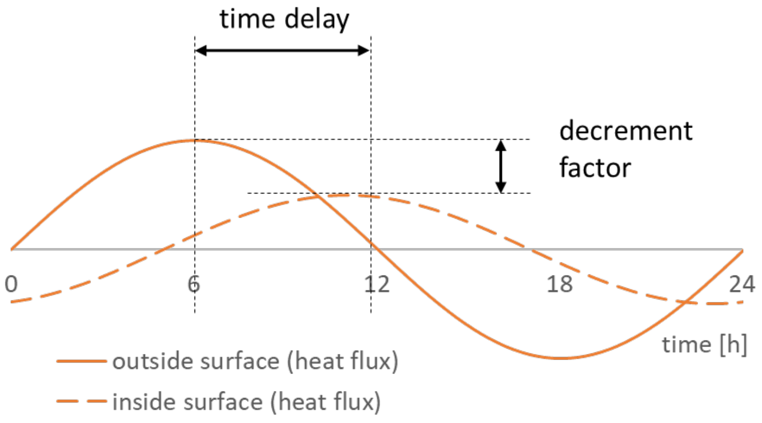




## A lack of straightforward properties that emphasize the benefits of green roofs

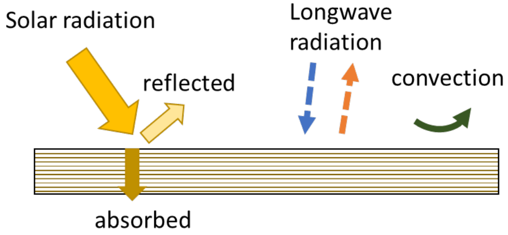
Dynamic thermal properties

- Time delay dt ?
- Decrement factor f ?




Calculated according to standard EN ISO 13786

Outside air temperature is the only boundary condition




Solar radiation and other boundary conditions not taken into account

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# 1. Introduction – presenting the benefits



## A lack of straightforward properties that emphasize the benefits of green roofs

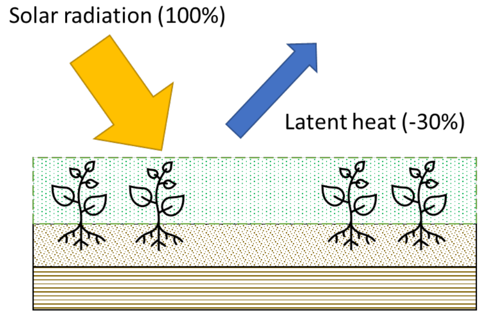
- Solar absorptivity?

„cool roof“ – real operating conditions (aged and washed) ⇨ $\alpha_s$ = 0,3

Akbari et al., ‘Aging and Weathering of Cool Roofing Membranes’. Lawrence Berkeley national laboratory. 2005.

Extensive green rof covered with sedum plants ⇨ $\alpha_s$ = 0,78

Latent heat of evapotranspiration not taken into account



# 1. Introduction – presenting the benefits





A lack of straightforward properties that emphasize the benefits of green roofs

| | Conventional roofs | Adaptive building envelopes | |
|---|---|---|---|
| | | „Cool“ roofs | Green roofs |
| Thermal transmittance *U* | ✓ | | |
| Time lag *dt*<br>Decrement factor *f* | ✓ | | |
| Solar absorptivity $\alpha_s$ | | ✓ | |
| | | | ? |

# 2. Green roof thermal response



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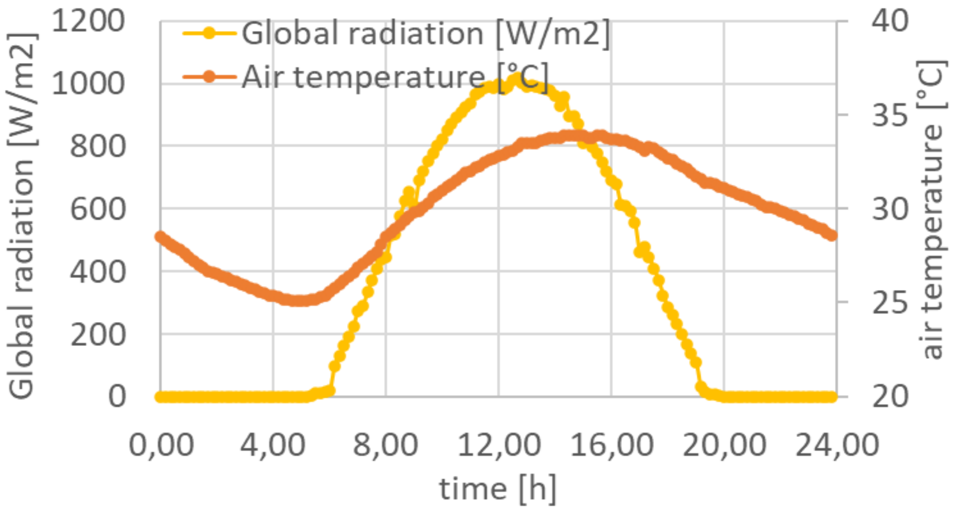
## Case study

### Reference summer day

Boundary conditions:
Temperature, solar radiation, wind and humidity

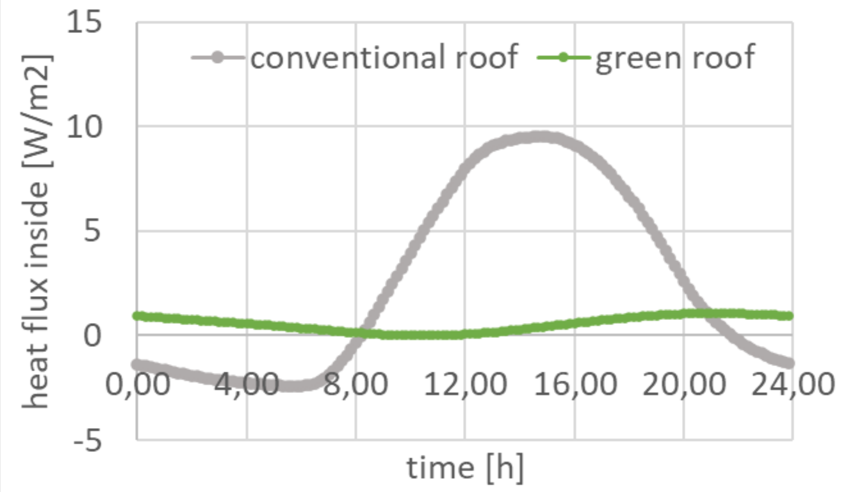



### Dynamic thermal response (inside surface heat flux)

Validated unsteady heat transfer numerical model

Arkar et al. Heat transfer in a lightweight extensive green roof under water-freezing conditions. Energy and Buildings 2018;167:187–99.

Same core construction



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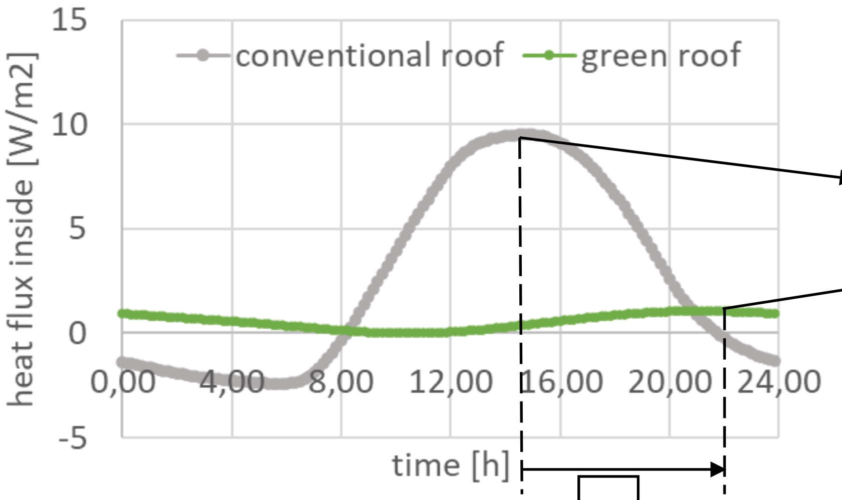
# 2. Green roof thermal response



## Case study: definition of the green roof characteristics (properties)

Solar absorptivity of conventional roof $\alpha_s = 0{,}7$




Time lag = 6 h 10 min

Demonstrates the ability of green roof to shift the maximum cooling load to (favourable) night hours

Same core construction

| Conventional roof | Green roof |
|---|---|
| Max heat flux = 9.5 W/m$^2$ | Max heat flux = 1.1 W/m$^2$ |

**Heat flux reduction factor**

$$= \frac{max\ heat\ flux\ (conv)}{max\ heat\ flux\ (green)} = 9$$

(„9-times better“)

Demonstrates the ability of green roof to reduce peak summer cooling loads compared to conventional roof with same core structure

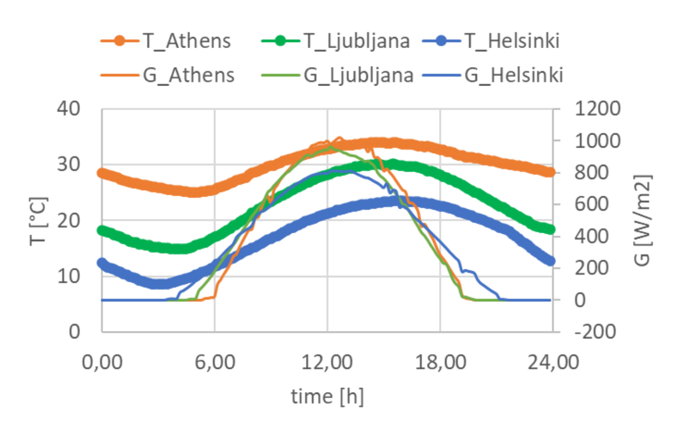
# 3. Heat flux reduction factor and time lag





## Scope of the analysis

Locations: Athens, Ljubljana, Helsinki
-Reference summer day
-Inside temperature is daily average outside




Lightweight flat roof

Varying parameters:
-Thermal transmittance $U$
-Solar absorptivity $\alpha_s$

+

Extensive green roof
- 5 cm mineral substrate
- 3 cm organic substrate
- Sedum plant vegetation (*LAI=3*)

Fully saturated (irrigated)
48 $l/m^2$ water

Dynamic thermal response → Dynamic thermal response

*Improvement of upgrade?*

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# 3. Heat flux reduction factor and time lag

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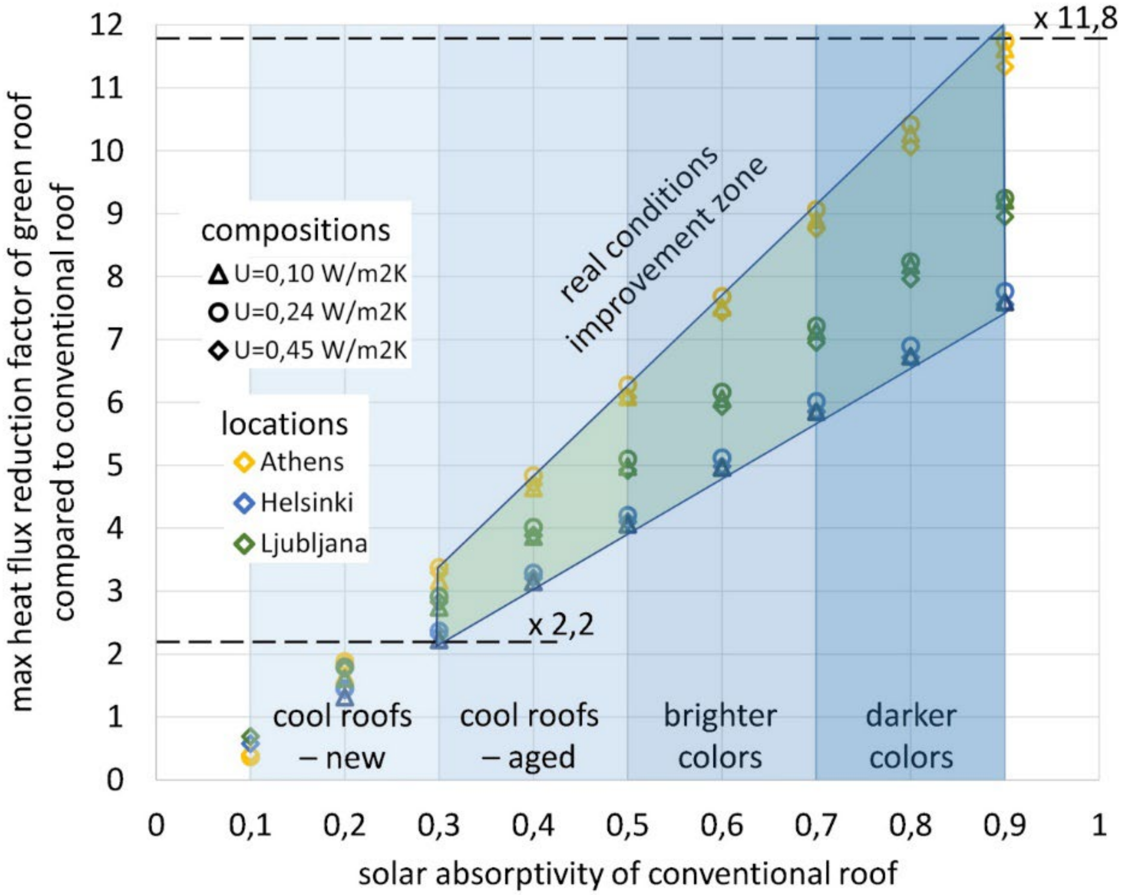
## Results: green vs. Conventional roof heat flux reduction factor




Thermal transmittance *U*
⇨ very low influence

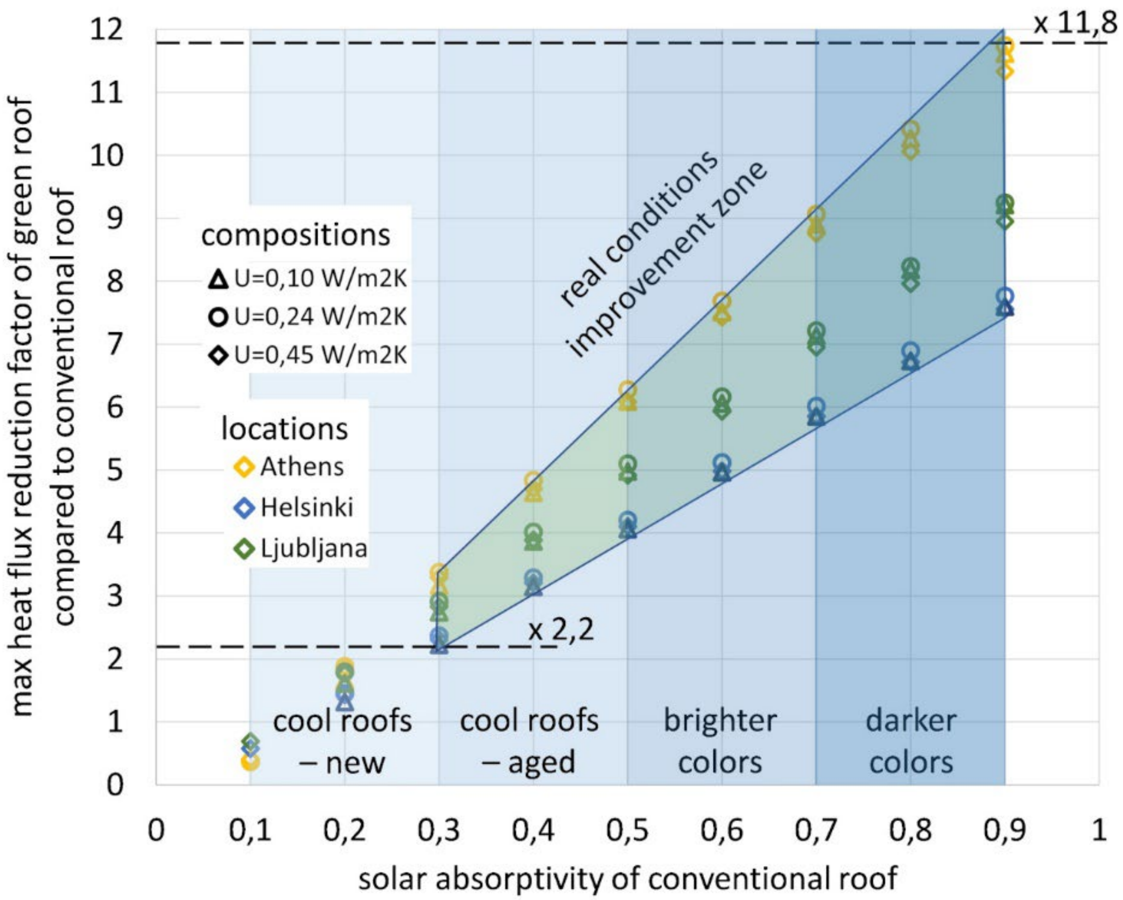
Location characteristics
⇨ noticeable influence
⇨ hotter climates have higher reduction factor

Solar absorptivity of conventional roof
⇨ large influence on the results
⇨ cool roofs upgrade has the lowest heat flux reduction factor

# 3. Heat flux reduction factor and time lag



## Results: green vs. Conventional roof heat flux reduction factor




„Cool" roof solar absorptivity in real conditions defined as 0.3 (minimum):

⇨ heat flux reduction factor from 2.2 for Helsinki up to 3.4 in Athens

Upgrade of conventional (dark) roof with solar absorptivity 0.9:

⇨ heat flux reduction factor from 7.8 for Helsinki up to 11.8 in Athens

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# 3. Heat flux reduction factor and time lag

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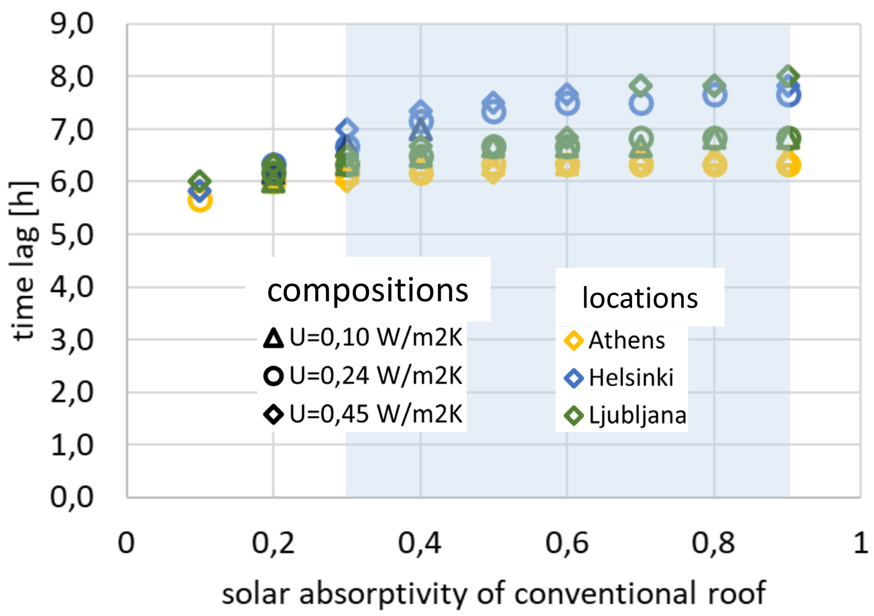
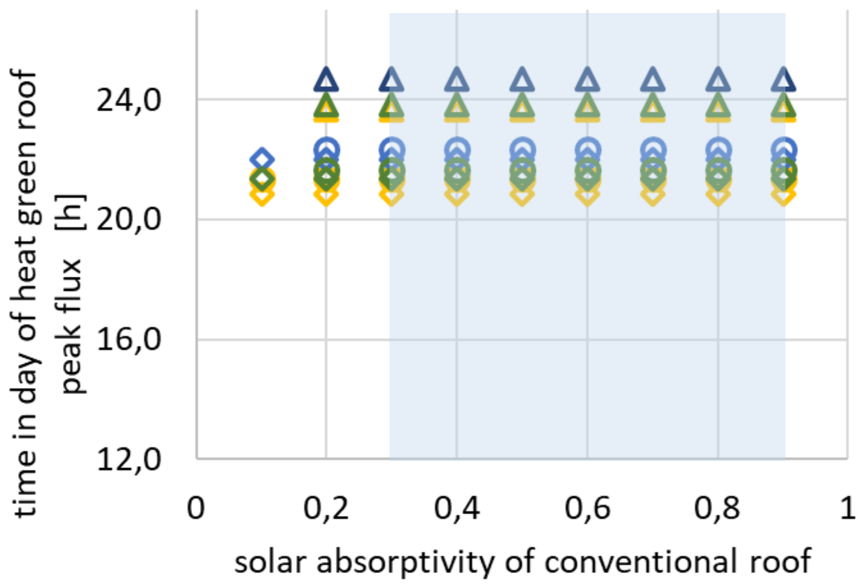
## Results: green vs. Conventional roof time lag




⇨Time lag from 6.1 to 8 hours compared to conventional

⇨ Peak heat flux consistently in night-time hours

⇨ Optimal for night-time passive cooling

# 4. Conclusion



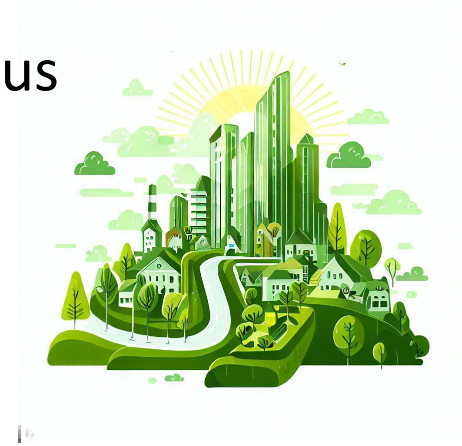
The lack of **green roof properties** to emphasize its **benefits**

easier for the project decision makers to **justify the implementation**

„A vision of Berlin with green roofs“ – made by DALL-E Ai image creator

More green roofs implemented

Better future for all of us



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# 4. Conclusion

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## Proposed characteristics:

### Heat flux reduction factor (for reference summer day)

*Relative factor showing the improvement of adding green roof to conventional lightweight roof*

**2.2 times** (Helsinki) up to **3.4 times** (Athens) heat flux reducement for upgrade of „cool“ roofs ($\alpha_s$ = 0,3)

**7.8 times** (Helsinki) up to **11.8 times** (Athens) heat flux reducement for upgrade of „dark“ roofs ($\alpha_s$ = 0,9)

### Time lag

*Absolute factor showing the improvement of peak heat flux shift to night hours*

Consistent peak heat flux shift 6.1 - 8 h (to night-time)

# Thank you for your attention

LOTZ team wishes you all the best

Q&A

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„A vision of Berlin with green roofs“ – made by DALL-E Ai image creator