Heating of Urban Environments by Photovoltaic Modules

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Motivation

- Photovoltaic (PV) modules play a major role in power supply.
- Building Integrated PV (BIPV) or Building Applied PV (BAPV) provide solutions for a decentralized power generation in urban areas.
- The energy balance of the urban environment may change due to introduction of PV modules.

Research Questions

- Is the **module design relevant for heat generation?**
- **What is the effective heat generation** of a PV module considering electrical power generation and module reflection as an energy sink?
- **Do solar modules have a positive or negative impact** on heat generation?

Approach

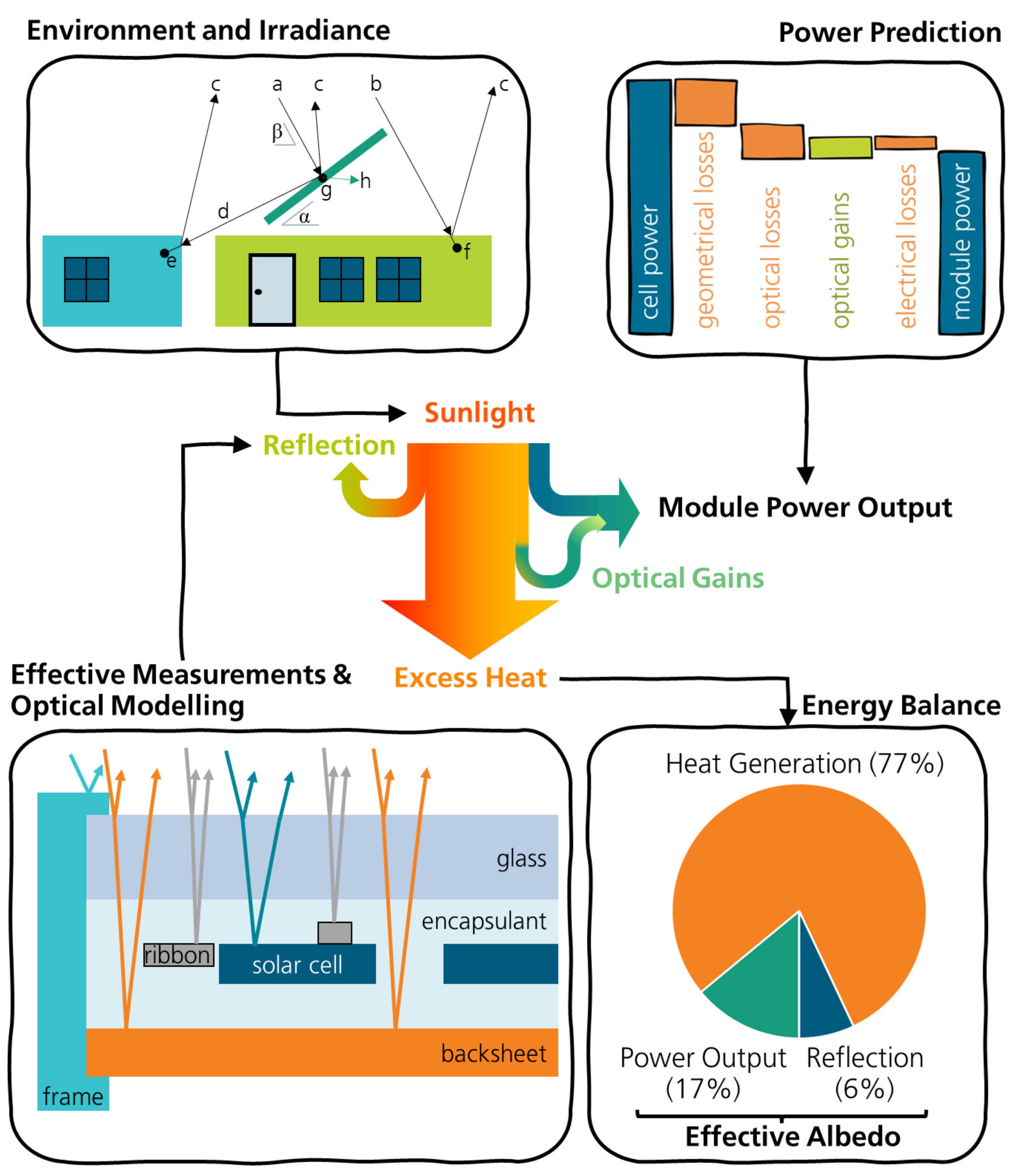

Fig. 1: Graphical description of the approach

- Calculating the resulting heat generation of a PV module under varying operation conditions considering:
  - Module orientation and Angle of incidence (AOI)
  - Mounting surface properties
  - Angular electrical performance of the solar module
  - Optical properties of the solar modules
- Determination of energy input on PV module and surrounding surfaces based on geometrical calculations
- Module power estimation based on bottom-up multi-physics loss channel analysis (Cell-To-Module simulations) using SmartCalc.Module considering module temperature and non-STC operation conditions [1-3]
- Optical parameters of module materials based on measurement
- Module design variations performed
  - Black and white backsheet
  - Black and grey aluminum frame
- Heat generation is calculated using energy equilibrium.
  - Generated heat = irradiation – reflection – electrical power
- The effective albedo describes the energy share not converted into heat
  - Effective albedo = (irradiation – generated heat) / irradiation = (reflection + electrical power) / irradiation

Irradiance Calculation

- Calculation of irradiance on module, module mounting area and neighboring surfaces
- Variation in mounting angle and sun inclination performed
- Reflection properties of surfaces are considered.

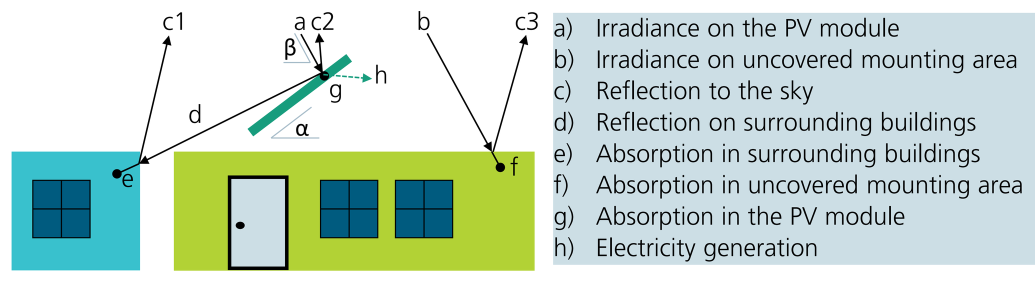

Fig. 2: Considered light paths in calculation of irradiant energy

Material Characterization and Calculation of Module Reflection

- Optical properties of module materials and module stacks measured (frames, backsheet area, ribbon area, cell area)
- Calculation of total module reflection using area shares.

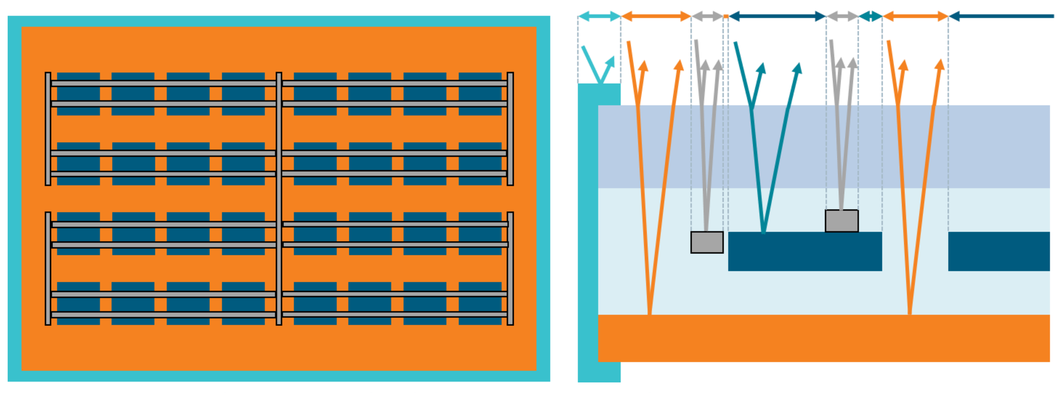

Fig. 3: Area shares with different optical properties in PV modules (light blue: frame, orange: backsheet, dark blue: solar cell, grey: interconnector ribbons)

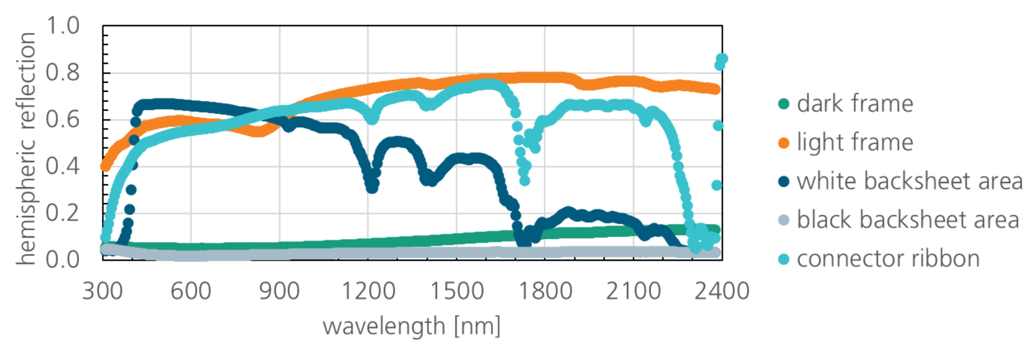

Fig. 4: Reflection of different module areas

Module Design Variation

- Module design variations performed regarding frame (black, grey) and backsheet (black, white) color.
- 240x M10 half cells, round wire interconnection and 2278 x 1134 mm² module dimensions.

Module Power Calculation

- Module power (acting as a heat sink) is calculated using Cell-To-Module (CTM) analysis considering AOI, module mounting angle and heat exchange with the environment.
- Results from optical characterization and module geometry used as input in analysis, additional inputs taken from commercially available module materials.

Energy Balance Calculation

- Dissipated heat is calculated as the difference between irradiance, power output, reflection to the sky and absorption in other areas
  - Module mounting area and other building areas considered in heat generation
- Mounting area with albedo of 0.2 (i.e. green roof or roofing shingles), other building areas using 0.65 (light paint)

Results on Module Reflection

Area	solar cell	backsheet	frame	ribbons	total	
Absolute	2.352	0.102	0.088	0.042	2.583	m²
Area share	91.0	3.9	3.4	1.6	100.0	%

White backsheet, grey frame

Reflection	solar cell	Backsheet	frame	ribbons	total	
Per module	113.4	56.8	53.6	21.7	246.0	W
Per m² module area	43.9	22.0	20.7	8.4	**95.2**	W/m²
Irradiance					1000	W

Black backsheet, black frame

Reflection	solar cell	backsheet	frame	ribbons	total	
Per module	113.4	24.1	5.2	21.7	164.4	W
Per m² module area	43.9	9.3	2.0	8.4	**63.6**	W/m²
Irradiance					1000	W

- 9.5% solar spectrum weighted PV module reflection for white backsheet and grey frame, 6.4% for black backsheet and black frame
- Module reflection is a heat sink [2].

→ **Module design is relevant and impacts module reflection and power generation.** ✓

Results on Heat Generation

- Generated heat depends on module power generation and irradiance on module and other surfaces.
- For larger angles of incidence, light irradiant on mounting area becomes relevant.

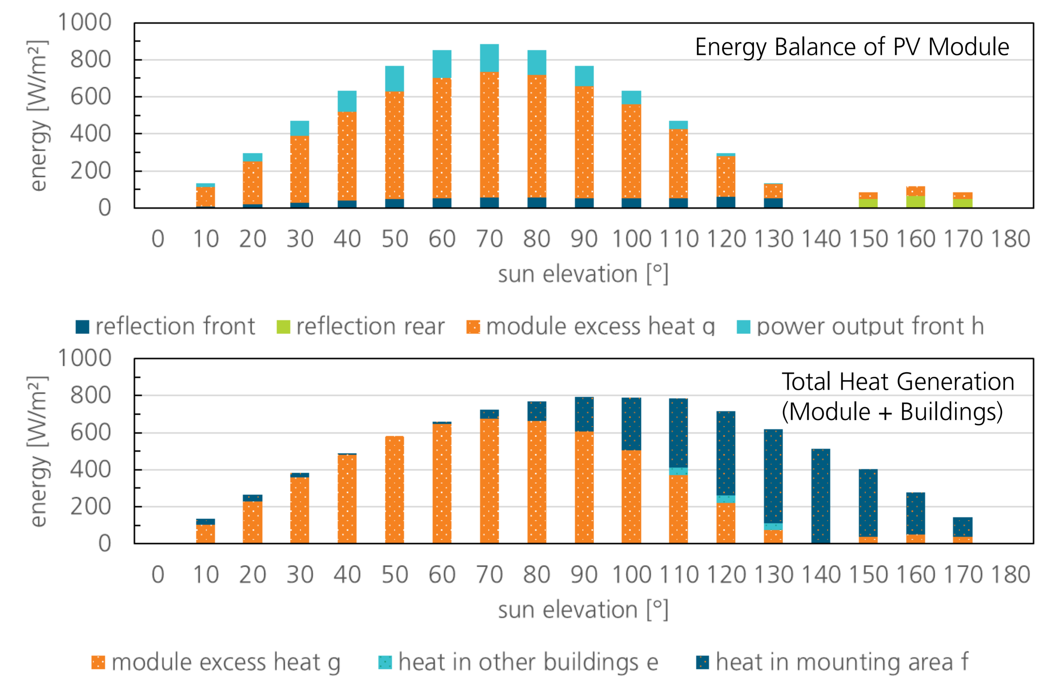

Fig. 5: Energy balance of the module (top) and heat generation of the PV system of module and additional areas (bottom), 1000 W/m² irradiance on horizontal plane, 40° mounting angle

- The effective albedo is found to be 0.2 which is a significant increase compared to the optical reflection.

→ **Module power production reduces heat generation.** ✓

Comparison to "no PV" scenario

- In a scenario without an installed PV module all energy is reflected or absorbed by the mounting area.
- Mounting area albedo and ground area coverage of the module define absorbed energy in the mounting area.

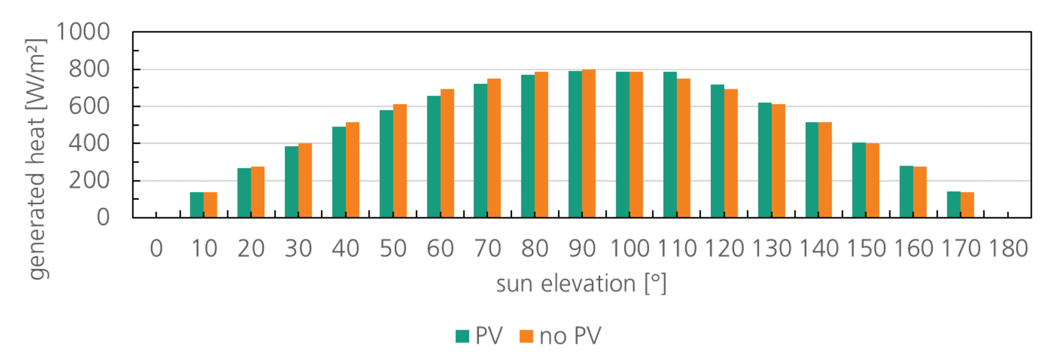

Fig. 6: Heat generation from PV module and surrounding areas compared to a „no PV" scenario 1000 W/m² irradiance on horizontal plane, 40° module mounting angle, mounting area albedo = 0.2

→ **No significant difference in total heat generation between a scenario with PV modules compared to a "no PV" scenario.** ✓

(1) www.cell-to-module.com; Model based on Hädrich, I. et al., „Unified methodology for determining CTM ratios", Solar Energy Materials and Solar Cells, 2014
(2) Mittag, M. et al. „Thermal Modelling of Photovoltaic Modules in Operation and Production", 36th EU PVSEC, 2019, Marseille, France
(3) Pfreundt, A. et al „Cell-To-Module Analysis Beyond Standard Test Conditions", IEEE 47th Photovoltaic Specialists Conference (PVSC), 2020

link to Fraunhofer ISE contributions of the 40th EU PVSEC

https://ise.link/eupvsec2023

Presented at 40th EU PVSEC, 2023, Lisbon, Portugal