HSLU Lucerne University of Applied Sciences and Arts

“GreenPV” – The potential of the building envelope

“绿色光伏”--建筑围护结构的潜力

Solution approaches for optimal façade design with PV and greening in relation to climate change

光伏和绿化最佳幕墙设计的解决方法

Engineering and Architecture
July 27, 2023

FH Zentralschweiz

Agenda 目录，报告主题
→ Presentation topics

1. Climate change 气候变化
Observations and research *观测与研究*
New climate data sets *新的气候数据集*

2. The importance of areal observations 区域观测的重要性
Climate data and urban heat island effect 气候数据和城市热岛效应
Measures for the urban climate 城市气候措施

3. GreenPV – Project idea and goals GreenPV – 项目理念和目标
Participants, structure and project status 参与者、结构和项目现状标准
Criteria

4. GreenPV - Results 绿色光伏 – 成果
Main findings and challenges 主要发现和挑战
Planning with a district climate model 利用地区气候模型进行规划

5. Summary and outlook 总结与展望
Exchange of experiences 经验交流
Discussion about the applicability of the statements to China 讨论其对中国的适用性

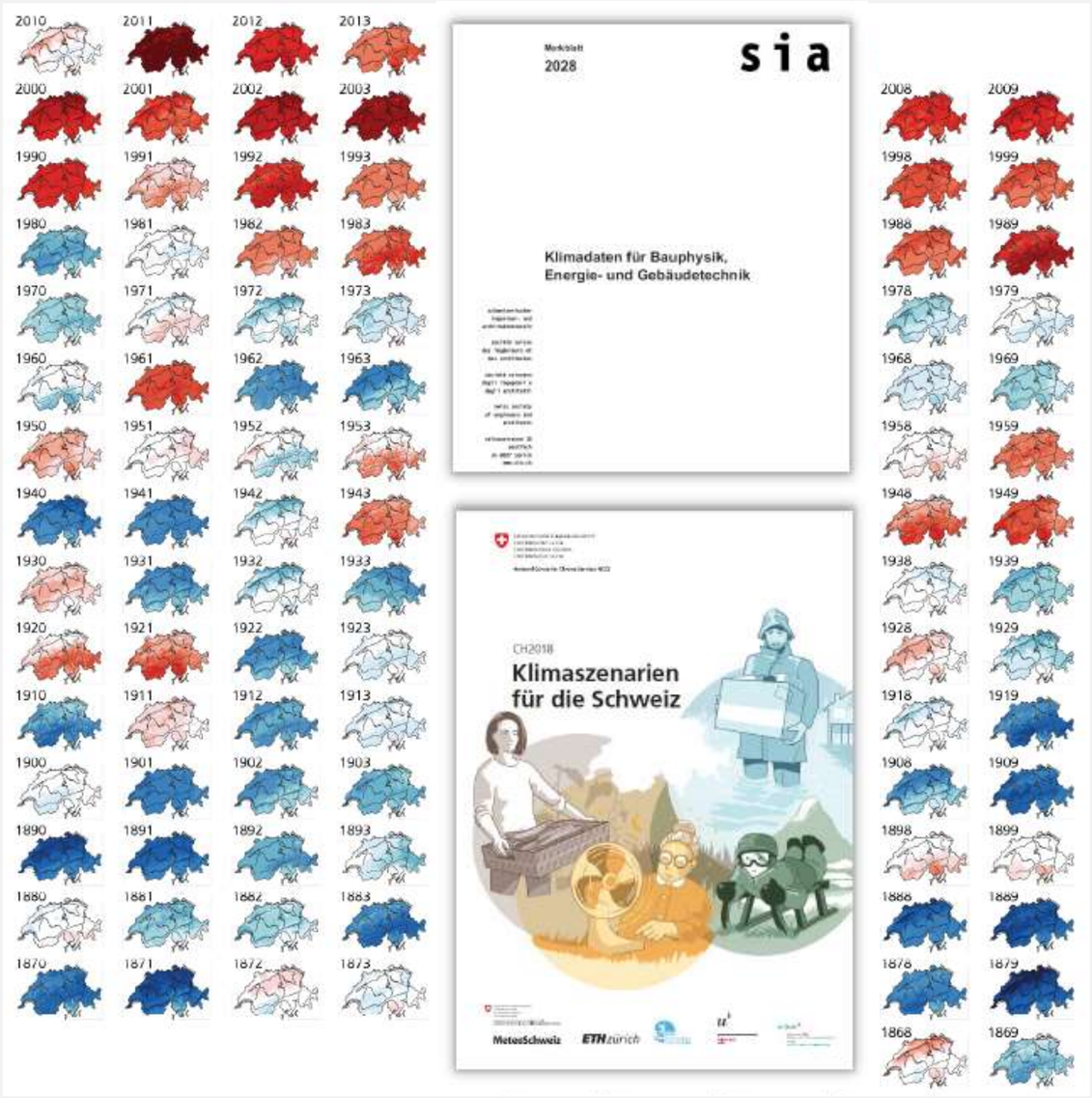
top: "Bosco Verticale", Milan, Boeri Studio, image © 2019 private
below: Residential building "Solaris", Zurich, Huggenbergerfries Architektur, image © 2018 Stephan Rappo for Solaris, Hochparterre magazine series

Climate Change…

气候变化

Contents:

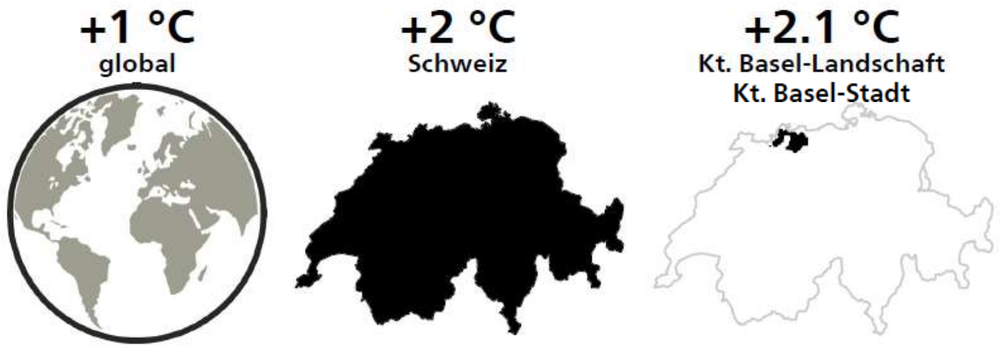
- Development and forecasts 发展与预测
- Key points for planning 规划要点
- SIA climate data for the future 未来的 SIA 气候数据
- *Supporting tools for planning* 规划的辅助工具
- Examples from simulations 模拟实例
- Impact in urban areas 对城市地区的影响



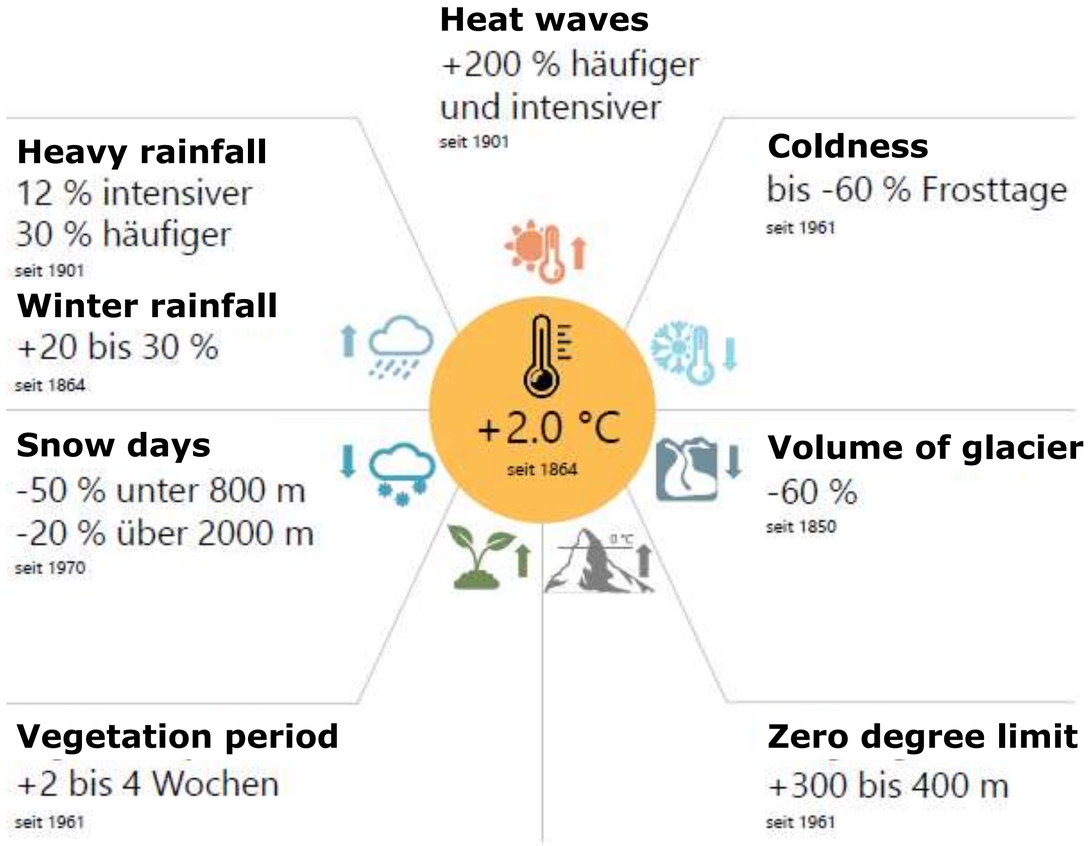
Climate Scenarios for Switzerland CH2018

瑞士气候情景 CH2018

Development so far



Since pre-industrial times



Sources: NCCS (ed.) 2021: Climate Change in the Canton of Basel-Landschaft - What has happened so far and what can we expect in the future? (Version 1.0) National Centre for Climate Services, Zurich, 15 p.

Climate Scenarios for Switzerland CH2018

瑞士气候情景 CH2018

Thaw in the Alps

Permafrost thaws - is the time of the great landslides approaching?

阿尔卑斯山解冻永冻土解冻--
滑坡时代即将来临？

New peak values

Permafrost continues to thaw

Friday 13.01.2023 19:53

峰值变化
永冻土继续融化

Sources: https://www.srf.ch/news/schweiz/tauwetter-in-den-alpen-permafrost-taut-naht-die-zeit-der-grossen-bergstuerze ; https://www.srf.ch/news/schweiz/neue-spitzenwerte-permafrost-taut-immer-weiter-auf

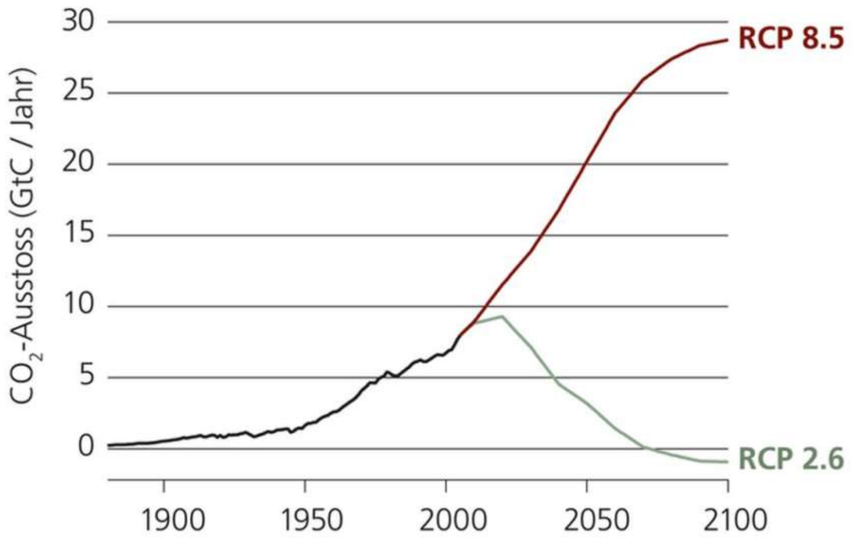
Climate Scenarios for Switzerland CH2018

瑞士气候情景 CH2018

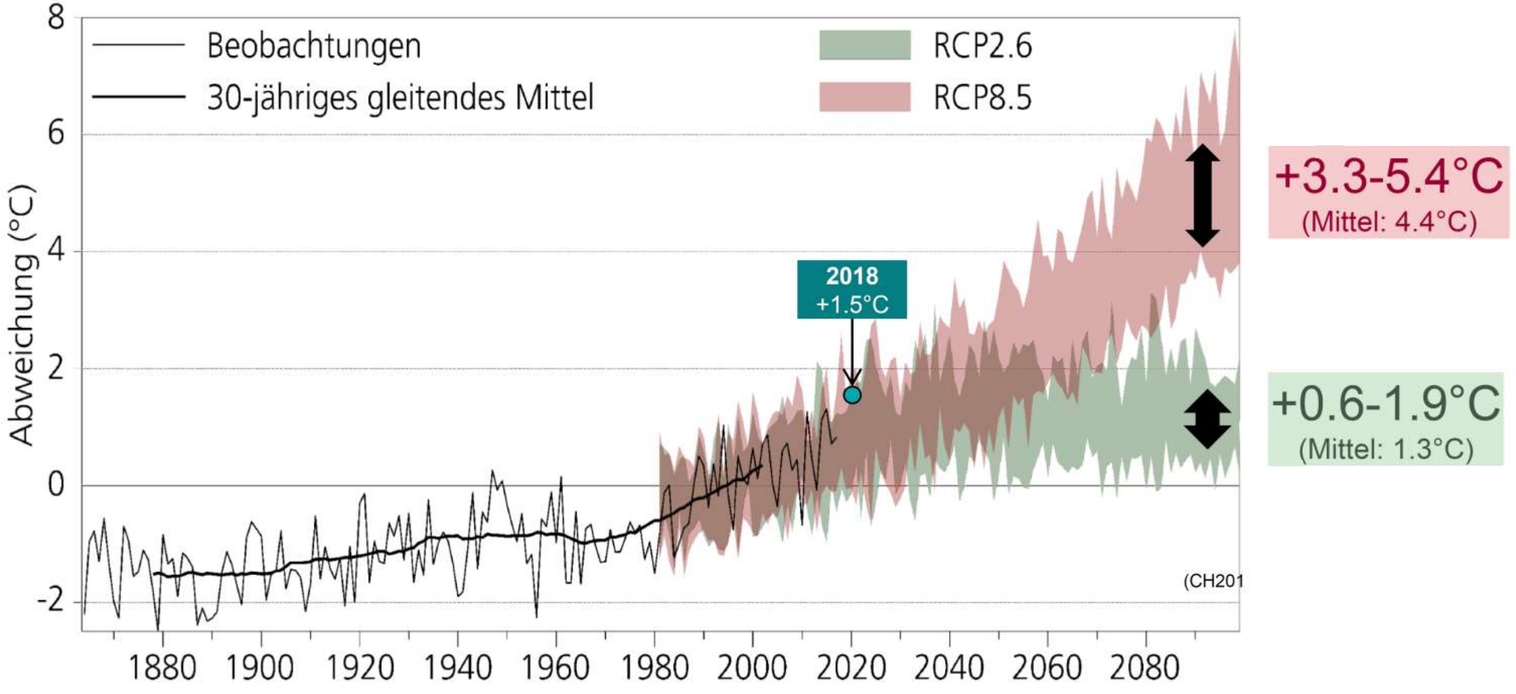
Global emissions scenarios

全球排放情景

No climate protection 无气候保护
Consequent climate protection 有相应的气候保护



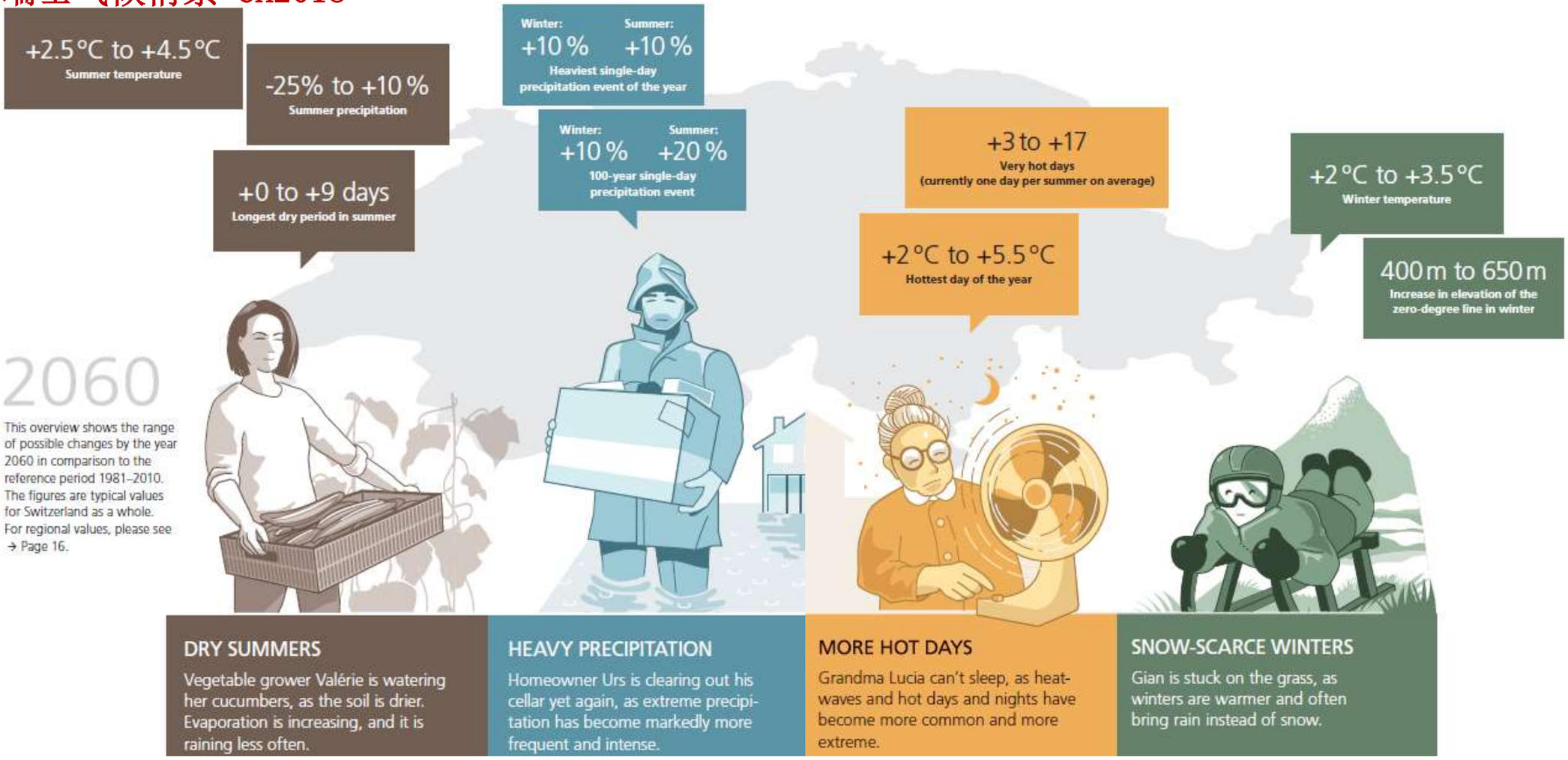
Swiss mean annual temperature 瑞士年平均气温（1981–2010年期间与标准值的偏差）
(deviation from the standard period 1981-2010)



Sources: NCCS (ed.) 2018. CH2018 - Climate scenarios for Switzerland. National Centre for Climate Services, Zurich. 24 S. ISBN number 978-3-9525031-0-2.

Climate Scenarios for Switzerland CH2018

瑞士气候情景 CH2018



Sources: NCCS (ed.) 2018. CH2018 - Climate scenarios for Switzerland. National Centre for Climate Services, Zurich. ISBN number 978-3-9525031-0-2.

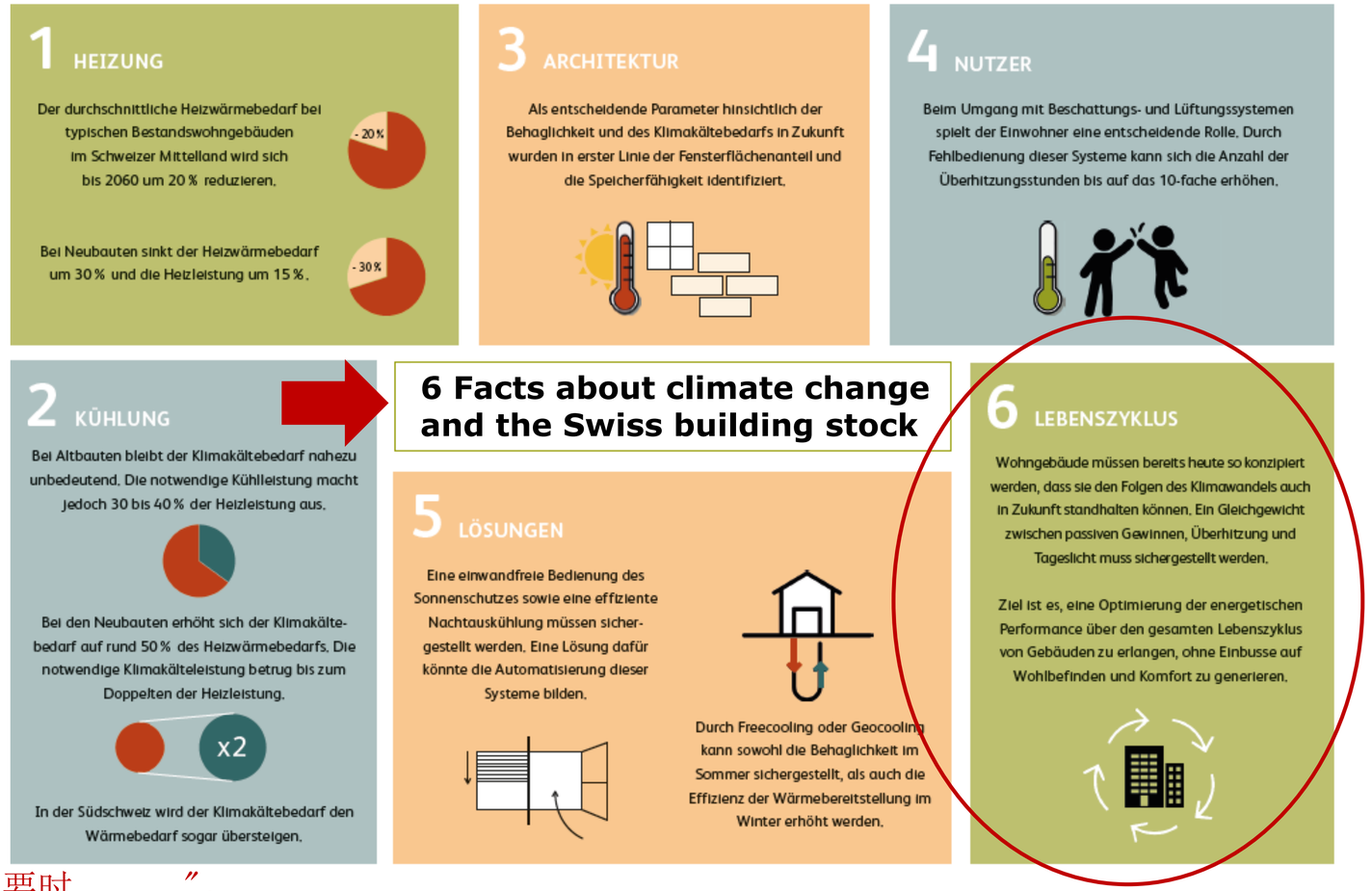
Project «ClimaBau» (2018) – Planning in the context of climate change

项目 “气候保护”（2018 年）--气候变化背景下的规划工作

Paradigm shift: 模式转变

- "Climate change - when cooling becomes more important than heating...".
- Focus: Planning that guarantees **well-being** and **health**

→ Consider the life cycle of the building



”气候变化--当制冷变得比供暖更重要时.....”。
重点：保证幸福和健康的规划
考虑建筑物的生命周期

New climate data sets for the future indoor climate

未来室内气候的新气候数据集

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz

MeteoSchweiz

sia
schweizerischer ingenieur- und architektenverein
société suisse des ingénieurs et des architectes
società svizzera degli ingegneri e degli architetti
swiss society of engineers and architects

HSLU Hochschule Luzern

Climate scenarios for the future indoor climate (SIA 2028)

未来室内气候情景（SIA 2028）

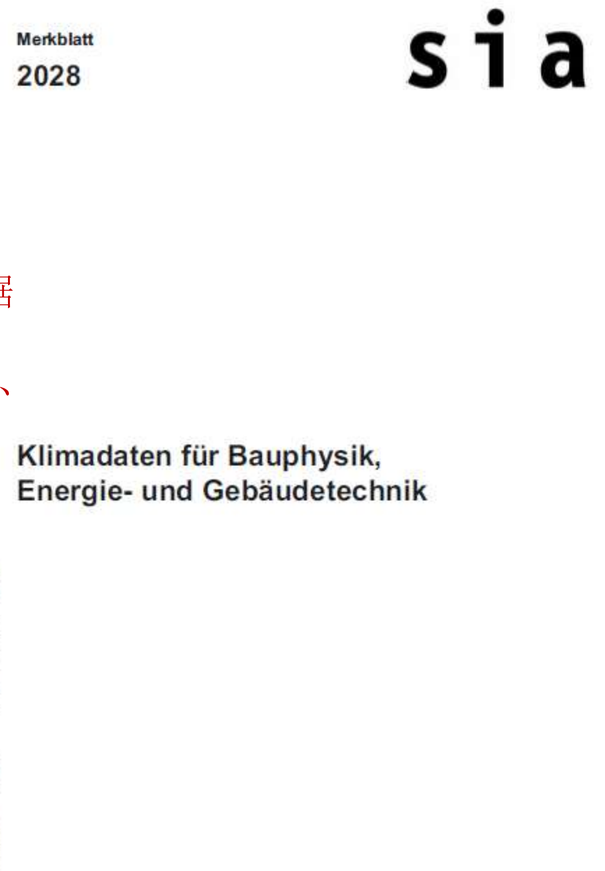
Final report

气候适应性建筑--未来的基础 "和 "A.15 建筑设计终端的实际气候数据 "项目的最终报告

of the projects "Climate-adapted building - bases for the future" and "A.15 Actual climate data for the building design end".

New climate data sets for the future indoor climate

未来室内气候的新气候数据集



Current instrument – SIA 2028 当前SIA 2028

«Design reference years» (DRY) for today's climate

- 1 year of hourly data (observations) representing the mean climate 1984-2003
- Physically consistent parameters (temperature, humidity, radiation, wind, cloudiness)
- **40 meteo stations in Switzerland**

当今气候的 "设计基准年"（DRY）代表 1984-2003 年平均气候的 1 年每小时数据

观测值物理参数一致（温度、湿度、辐射、风、云量）

瑞士40 个气象站

Objective in the new instrument – SIA 2028 新SIA 2028 目标

Addendum – DRY for the climate of the future (CH2018)

- Same criteria and additionally
  - **Focus on heat waves**
  - **Data for cities**

相同的标准，另外关注热浪和城市数据

New climate data sets for the future indoor climate

未来室内气候的新气候数据集

New instrument – SIA 2028

新工具 – SIA 2028

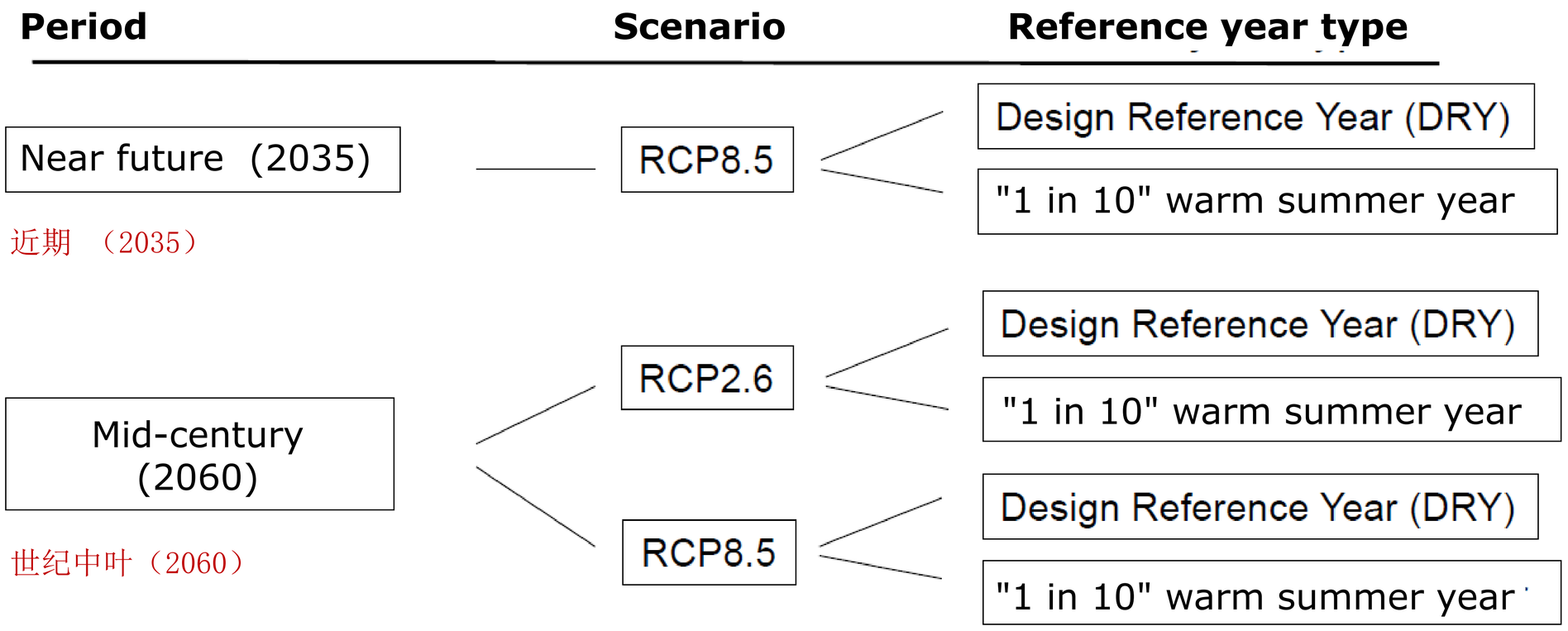
- **40 peripheral meteo stations**
- **4 urban meteo stations**

40 个外围气象站
4 个城市气象站

New climate data sets for the future indoor climate

未来室内气候的新气候数据集

Generated reference years 参考年份



Source: MeteoSwiss, SIA and Lucerne University of Applied Sciences and Arts, 2022: Klimaszenarien fürs zukünftige Innenraumklima (SIA 2028) - Schlussbericht der Projekte "Klimaangepasstes Bauen - Grundlagen für die Zukunft" und A.15 "Aktuelle Klimadaten für Bauplanende" Fachbericht MeteoSchweiz, 279, 124 pp.

New climate data sets for the future indoor climate

未来室内气候的新气候数据集

Test simulations – peripheral stations

Residential use - 3 different climate zones

测试模拟 – 外围站点住宅用途 – 3 个不同气候区）

Swiss Plateau (Kloten)

- Increasing importance of climate cooling

瑞士高原：气候制冷的重要性与日俱增

Alpine locations (Davos)

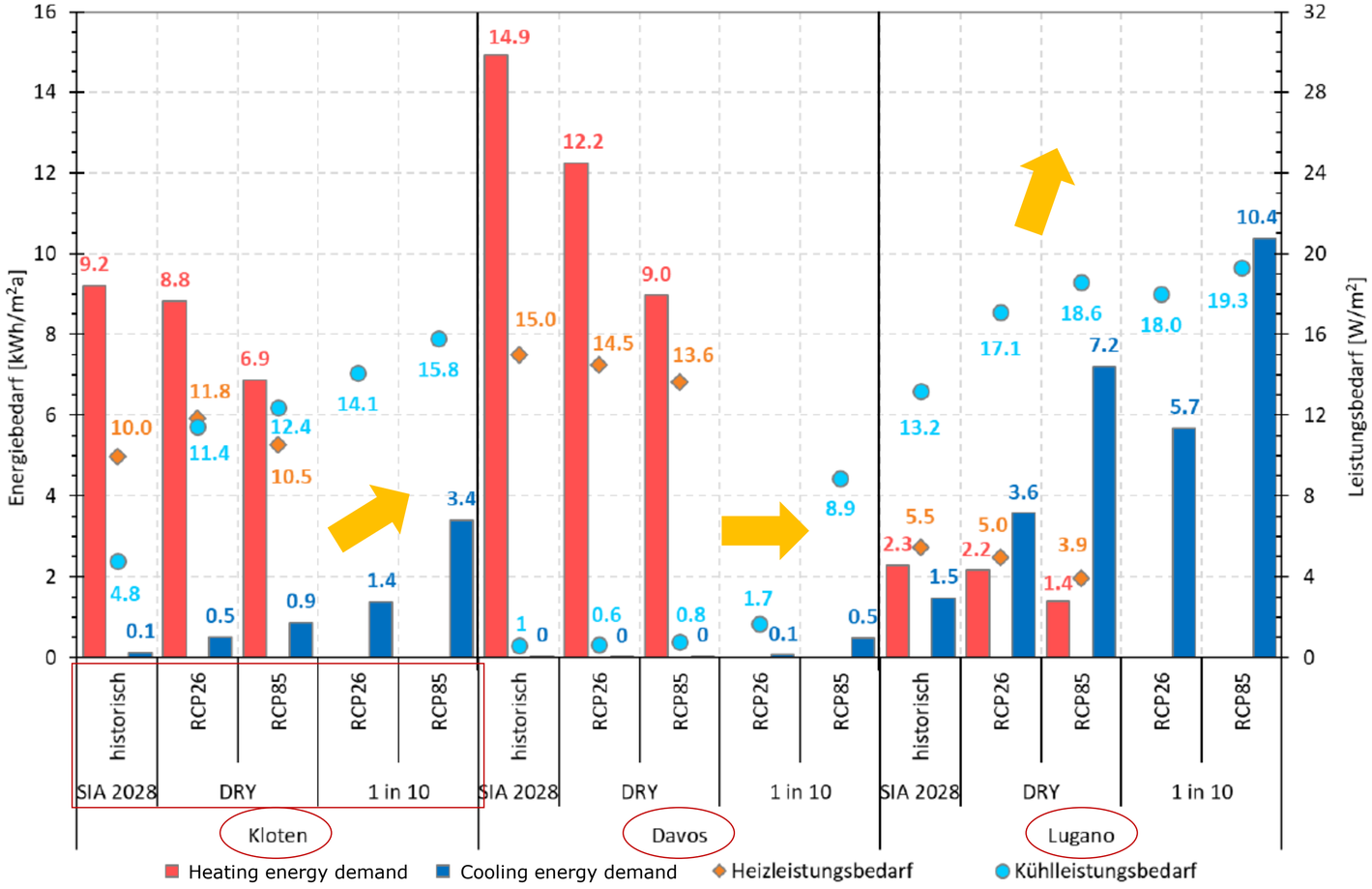
- Hardly any cooling

高山地区：几乎没有降温

Southern Alps (Lugano)

- Climate cooling demand higher than heating demand

高山地区：气候制冷需求高于供暖需求



Energy and power demand of residential buildings *(Periode: 1.1. – 31.12.)*

New climate data sets for the future indoor climate

未来室内气候的新气候数据集

Test simulations – urban station

Comparison to peripheral stations

测试模拟 – 城市站点与周边站点的比较

Urban area (Zürich)

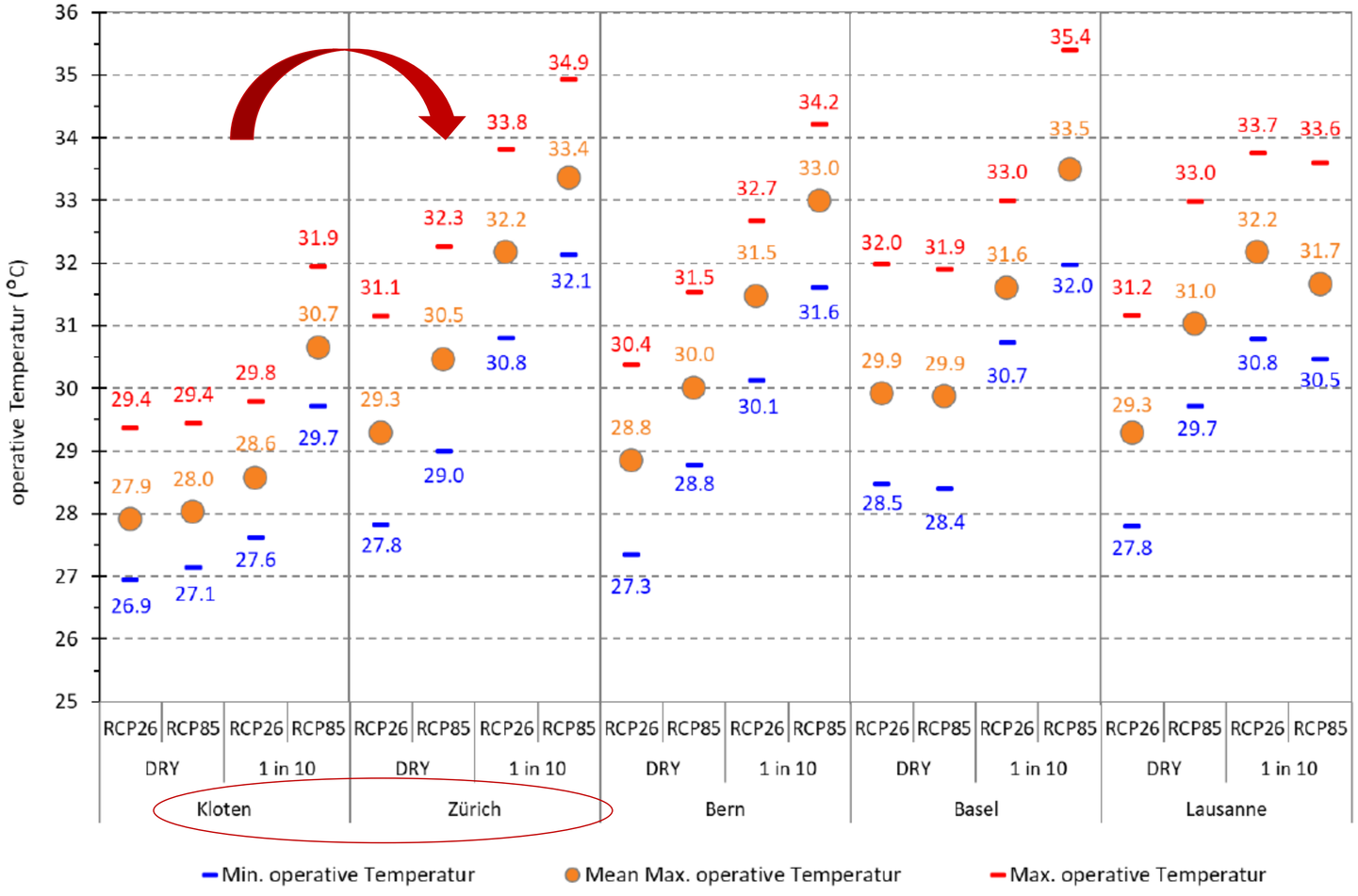
城市地区（苏黎世）

- measures are not sufficient (sun protection, night cooling)

措施不足（防晒、夜间降温）

- Buildings not planned for the climate of the future will require (active) cooling or will have to be refitted.

未根据未来气候进行规划的建筑需要（主动）降温，或必须进行改造



Temperatures in the residential building for Kloten and for urban stations during use *3110 h (Periode: 16.4. – 15.10.)*

Importance of the city/ area consideration...

城市/地区的重要性地区的重要性

Contents:

- Politics: Urban climate analysis

  政治 城市气候分析

- *New instruments*

  新工具

- *Example: City of Basel*

  实例： 巴塞尔市

- Strategies and catalogue of measures

  战略和措施目录

- Greening in areas

  地区绿化

Urban climate maps and planning principles for building in 2050

适应气候的建筑--规划基础2050 年城市气候图和建筑规划原则

Urban climate analysis 城市气候分析

Urban climate maps and planning principles for building in 2050

适应气候的建筑--规划基础2050 年城市气候图和建筑规划原则

Urban climate analysis – Basel-city Nocturnal temperature environment

城市气候分析 – 巴塞尔市夜间温度环境

2019

2030 RCP4.5

Source: Burmeister, C., et al., 2019: Stadtklimaanalyse Kanton Basel-Stadt 2019. Grundlagen, Methoden, Ergebnisse. Lufthygieneamt beider Basel, 52 pp.

Measures by the cities

城市适应气候的建筑措施

Urban climate analysis – Basel-city Catalogue of measures 城市气候分析 – 巴塞尔城市措施目录

Green measures

Grüne Massnahmen

M1	Diversify green spaces and design them in a climate-adapted way
M2	Create new green spaces and increase the proportion of greenery in open spaces and traffic areas.
M3	Shade squares, streets and paths as well as buildings with trees.
M4	Align vegetation to climate warming and site conditions

Blue measures

Blaue Massnahmen

M5	Promoting tangible water
M6	Unsealing paved surfacesr
M7	Closing the rainwater cycle in open spaces
M8	Establish irrigation of greenery with rainwater

Measures on buildings/ building positioning

Massnahmen an Gebäuden und Gebäudestellung

M9	Intensively green new flat roofs and store water on them
M10	Greening façades or designing them with climate-adapted materials
M11	Align building interventions with ventilation, cold air flow, irradiation and shadows cast

Further technical measures

Weitere technische Massnahmen

M12	Align materialisation in the outdoor space with low heat storage function
M13	Technical solutions for shading and cooling in open spaces

Source: Building and Transport Department of the Canton of Basel-Stadt. Städtebau & Architektur, 2023: Stadtklimakonzept zur klimaangepassten Siedlungsentwicklung im Kanton Basel-Stadt. Bau- und Verkehrsdepartement des Kantons Basel-Stadt, 132 pp.

Climate-adapted building

Measures by the cities

城市适应气候的建筑措施

City of Zürich – Grass instead of asphalt against heat

苏黎世 – 用草坪代替沥青防暑降温

Here Zurich is testing the car park of the future

In a unique experiment, the city wants to find out how pavements and parking spaces can be designed to have a cooling effect

苏黎世正在测试未来的停车场，希望了解如何将人行道和停车位设计得具有降温效果

66 verschiedene Beläge und Unterbauten: Die Testanlage vor dem Theater 11.

Das Prinzip ist einfach: Wo Wasser versickern und später wieder verdunsten kann, ist die Oberfläche kühler.

Foto: Jonathan Labusch

Kies statt Asphalt: Die umgestaltete Heinrichstrasse.

Foto: Liliane Minor

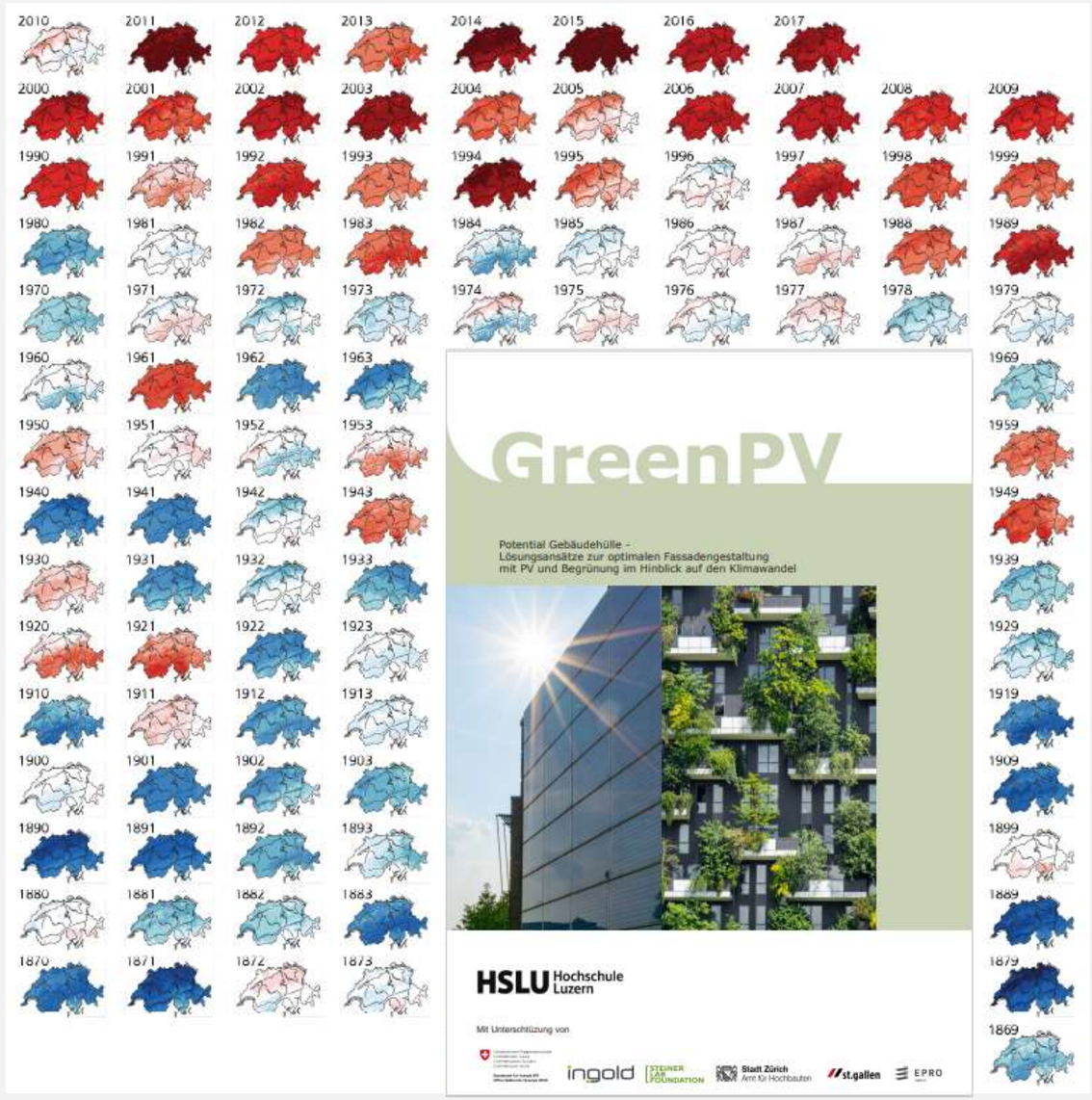
Source Tagesanzeiger, Published on 17.7.2023
https://www.tagesanzeiger.ch/hier-testet-zuerich-den-parkplatz-der-zukunft-747939712698

GreenPV – Project idea and goals

绿色光伏—项目理念和目标

Contents:

- Background 项目背景
- Project partners 项目合作伙伴
- State of research 研究现状
- *Methodological approach and products* 方法和产品
- Evaluation criteria 评估标准



Background
→ Energy strategy for Switzerland

背景→瑞士能源战略

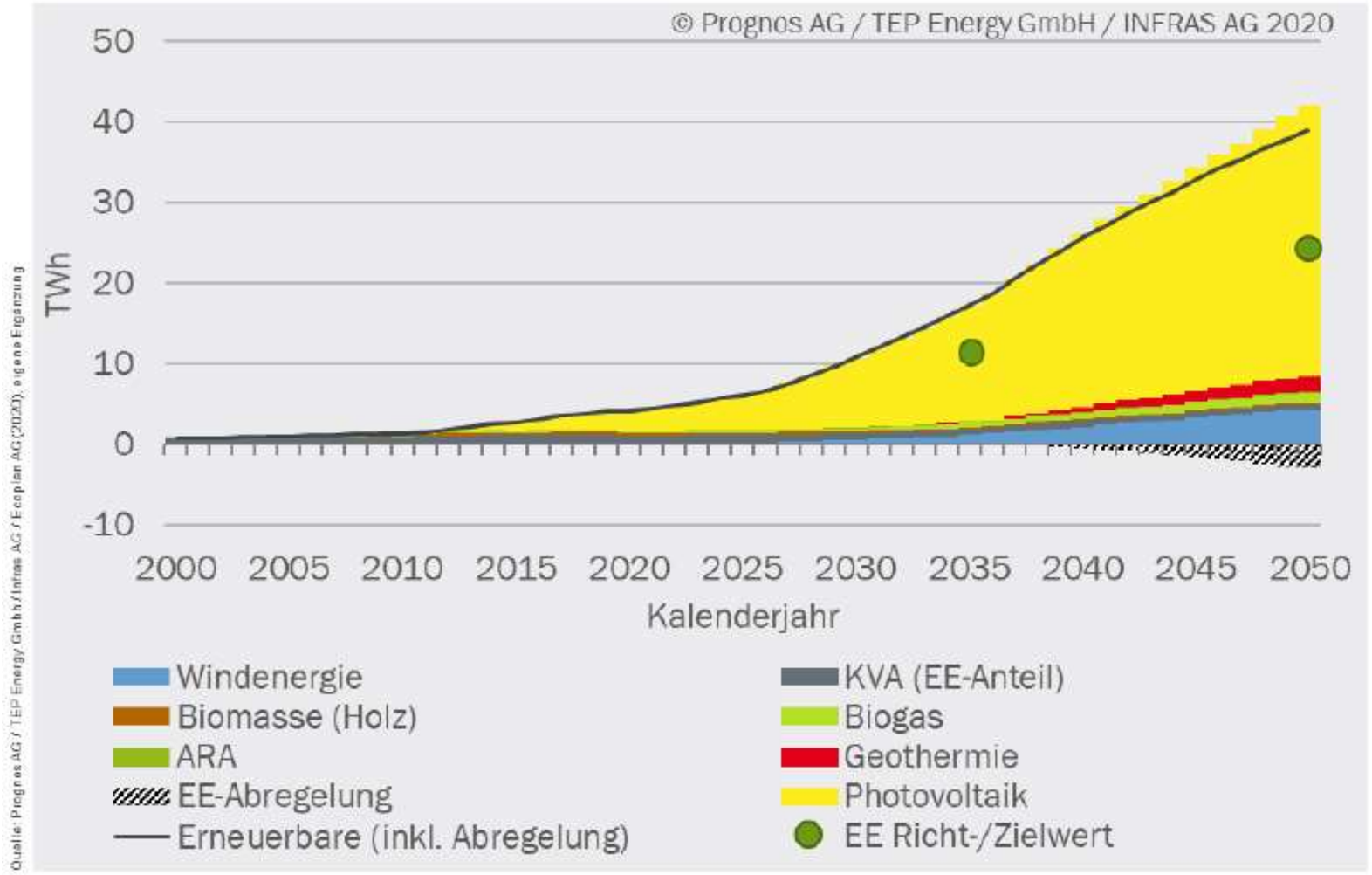
Energy perspectives 2050+

Annual electricity generation new renewables

→ Today 4 TWh

→ **Target 39 TWh!**

可再生能源年发电量
→目前 4太瓦时
→目标 39太瓦时



Background
→ Energy strategy for Switzerland

背景→瑞士能源战略

PV potential according to the Swiss Federal Office of Energy

瑞士联邦能源办公室提供的光伏发电潜力数据

www.sonnendach.ch
50 TWh

www.sonnenfassade.ch
17 TWh

Energy strategy for Switzerland
→ Winter electricity!

瑞士能源战略→冬季电力

Annual production: 年发电量

- Roof 屋顶 950 kWh/kWp
- South façade 南立面 700 kWh/kWp

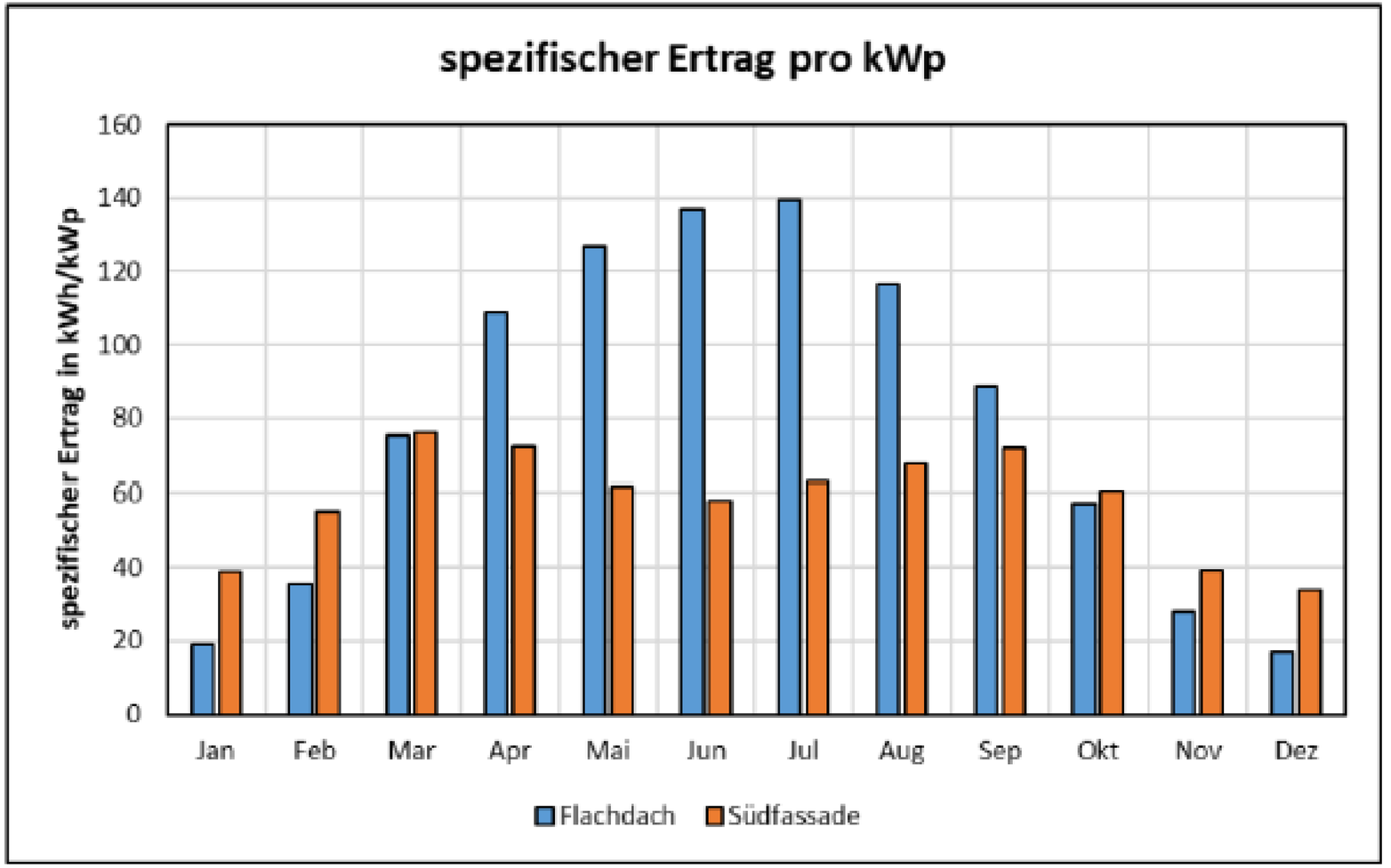
Winter production:冬季发电量

- Roof 屋顶 230 kWh/kWp
- South façade 南立面 310 kWh/kWp

Share in the winter half-year :

冬季半年所占份额

- Roof 屋顶 25%
- South façade南立面 45%



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Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN

"GreenPV" – The potential of the building envelope

"绿色光伏"--建筑围护结构的潜力

Solution approaches for optimal façade design with PV and greening in relation to climate change

光伏和绿化最佳幕墙设计的解决方法

FH Zentralschweiz

Approach

Both systems offer **advantages...**

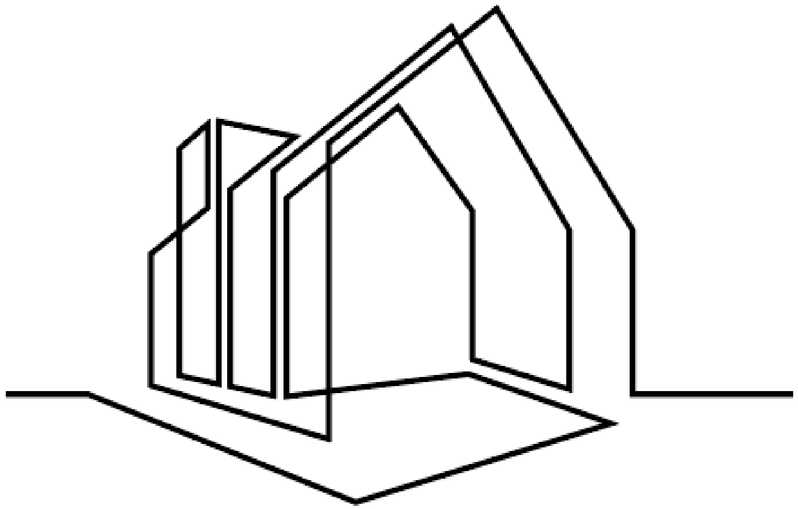
这两种系统都具有优势

Greenery can help to cool the outside air (**evaporative cooling, heat reduction**)

绿色植物可以帮助冷却外部空气（蒸发冷却、减少热量）

Electricity production through **PV** will become increasingly important in the future...

光伏发电在未来将变得越来越重要...



...however, there has **not yet** been **a widespread application** of PV and greening on the façade.

然而，光伏发电和外墙绿化尚未得到广泛应用

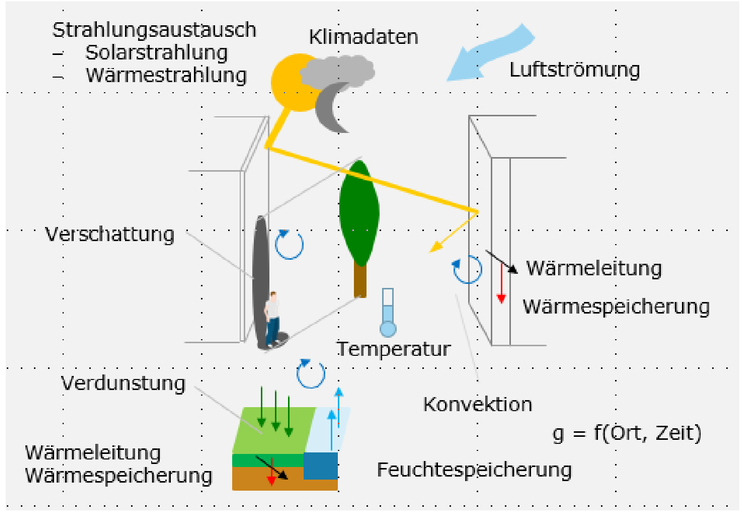
Climate-adapted building - various approaches and research projects

适应气候的建筑—不同方法和研究项目

Exterior
外墙

Building interface
建筑面

Interior
内部



ITC „**Greening and Urban Climate**“
Measurements with drone flights;
Focus: Quantification of the importance of facade and roof greening
绿化与城市气候：利用无人机飞行进行测量，量化外墙和屋顶绿化的重要性

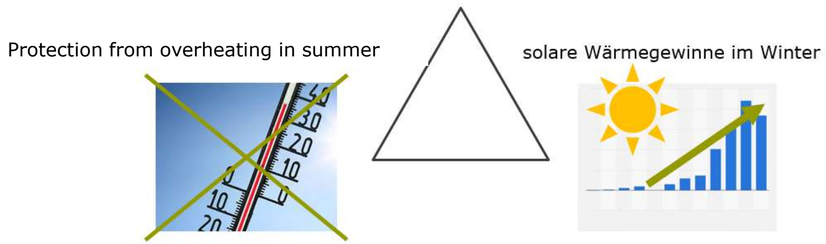
ITC "**Neighbourhood Climate**"
Overall Healing Sustainability; Focus: Analysis of the social value and economic feasibility of climate-relevant measures

“邻里气候”：总体愈合可持续性， 分析气候相关措施的社会价值和经济可行性

„**Neighbourhood climate modelling**“Tool
Physical effects of environmental design and elements (greenery, water, materialisation, etc.)
Focus: Planning tool for interactive neighbourhood climate modelling in the early project planning phase
“邻里气候”模型：环境设计和要素（绿化、水、物化等）的物理效应，在项目规划早期阶段进行互动式街区气候建模的规划工具

Results flow in

„**GreenPV – Potential of building envelope**“
Energy balance and ambient cooling of building envelopes (PV / green / openings). Focus: Analysis for optimal design of roof and façade surfaces. Effect on interior and immediate exterior spaces. (Energy, costs and comfort at the house).



„**ClimaBau**“ Planning for Climate Change
Analysis of today's residential buildings with current and future outdoor temperatures Focus: Quantification of energy demand and comfort over the building's lifetime
气候变化规划：分析当前和未来室外温度下的住宅建筑，量化建筑寿命期内的能源需求和舒适度

“绿色光伏--建筑围护结构的潜力：建筑围护结构的能量平衡和环境制冷。分析屋顶和外墙表面的最佳设计，对室内和室外空间的影响（能源、成本和室内舒适度）

Results flow in

„**Air conditioning** in the context of climate change “
Consequences of the inevitable increase in cooling demand in residential buildings; Focus: Energy-efficient use of air conditioning units
住宅楼制冷需求增加的后果，空调设备的节能使用

„Ready for climate change? **Recommendations** for building owners and planners “
Importance of window proportion and distribution for energy demand, thermal and visual comfort Focus: practical recommendations for the planning of buildings suitable for climate change
窗户的比例和分布对能源需求、热舒适度和视觉舒适度的重要性，为适应气候变化的建筑规划提供实用建议

Aims of the project 项目目标

- Investigate ***barriers / acceptance*** of the use of greening and PV.
  调查使用绿化和光伏的接受程度
- Provide information on the influence of different façade systems on the ***heat island effect***. 提供不同外墙系统对热岛效应影响的信息
- Contrast the reduction of the heat island effect through greening with the ***potential of energy production*** by PV and demonstrate synergies.

  将通过绿化减少热岛效应与光伏发电的潜力进行对比，展示协同效应

Research questions 研究问题

- Which are the ***decisive factors*** in the overall optimisation of the building façade considering climate change?
  在考虑气候变化的情况下，哪些是全面优化建筑立面的决定性因素？
- How can an ***optimal façade design*** with PV, green, opaque and transparent surfaces be achieved, taking into account various qualitative and quantitative factors? 如何在考虑各种定性和定量因素的情况下，实现光伏、绿色、不透明和透明表面的最佳幕墙设计？
- How can the identified approach be integrated into the building and how can its ***application*** be promoted ***in the building stock***?
  如何将已确定的方法融入建筑，如何在建筑群中推广应用？

top: "Bosco Verticale", Milan, Boeri Studio, image © 2019 private
below: Residential building "Solaris", Zurich, Huggenbergerfries Architektur, image © 2018 Stephan Rappo for Solaris, Hochparterre magazine series

Method

→ Comparison of 4 façade systems with a reference façade (fibre cement board)

4 种外墙系统与参照外墙（纤维水泥板）的比较

Façade greening

外墙绿化

ground-based system 地面系统

wall-mounted system 墙面安装系统

PV- Façade

光伏外墙

opaque PV modules 不透明光伏组件

transparent PV modules 透明光伏组件

Method

→ Evaluation criteria

评估标准

Qualitative aspects (literature)

定性方面（文献）

- Noise in urban areas
  城市地区的噪音
- Air quality
  空气质量
- Biodiversity
  生物多样性
- Rainwater retention
  雨水收集
- Attractiveness of outdoor spaces
  户外空间的吸引力

Quantitative aspects (simulations, measurements, calculations)

定量方面（模拟、测量、计算）

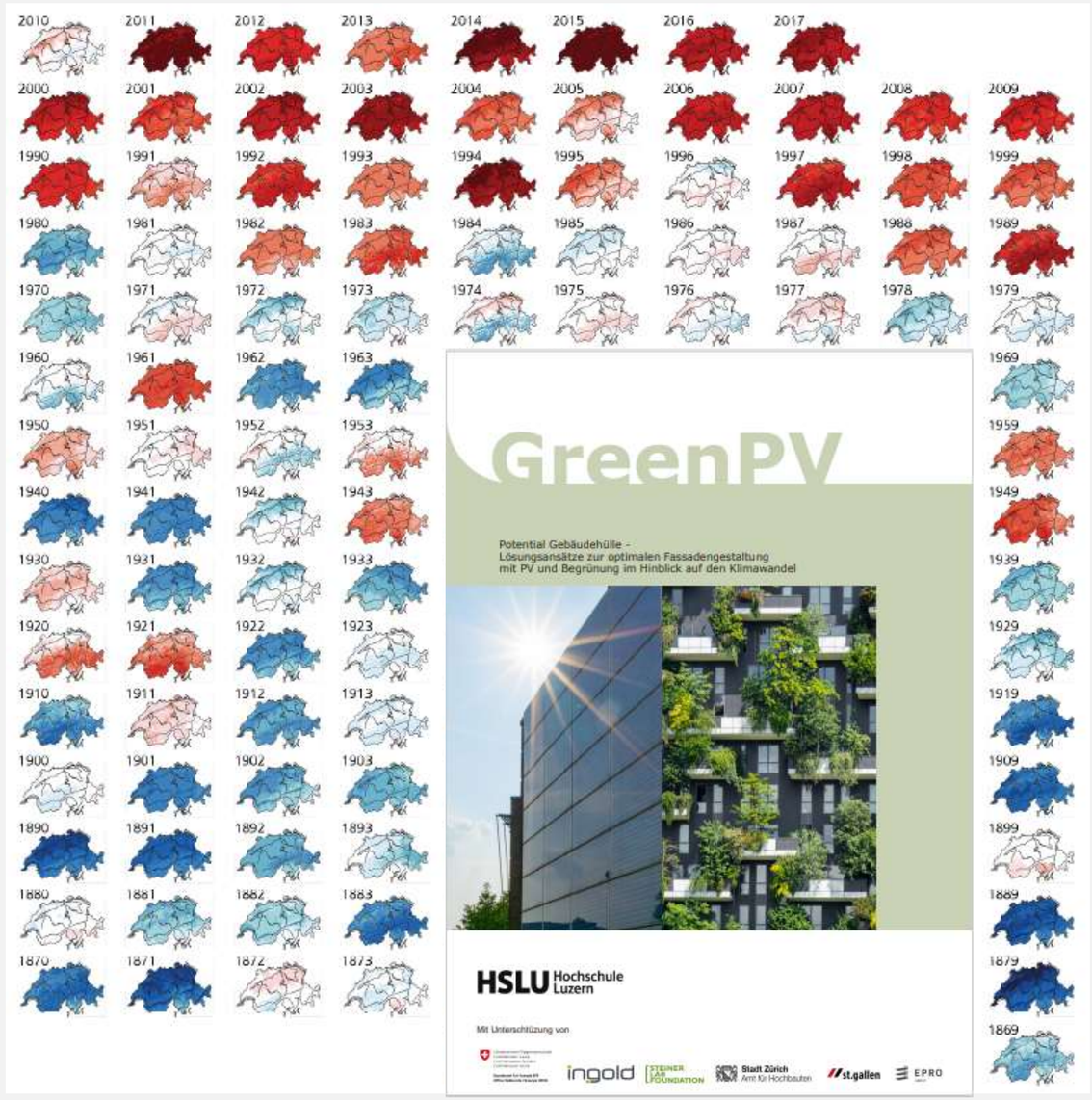
- Thermal well-being
  热利用
- Operational phase: heating and cooling demand, electricity (general consumption)
  运行阶段：供暖和制冷需求、电力（一般消耗量）
- Electricity generation (quantity, seasonal consideration, etc.)
  发电量（数量、季节性因素等）
- Microclimate: temperature around the building
  微气候：建筑周围的温度
- Life cycle assessment of the systems (LCA)
  系统的生命周期评估（LCA）
- Cost analysis of the systems (LCC)
  系统成本分析（LCC）

GreenPV – Results…

绿色光伏
结果

Contents:

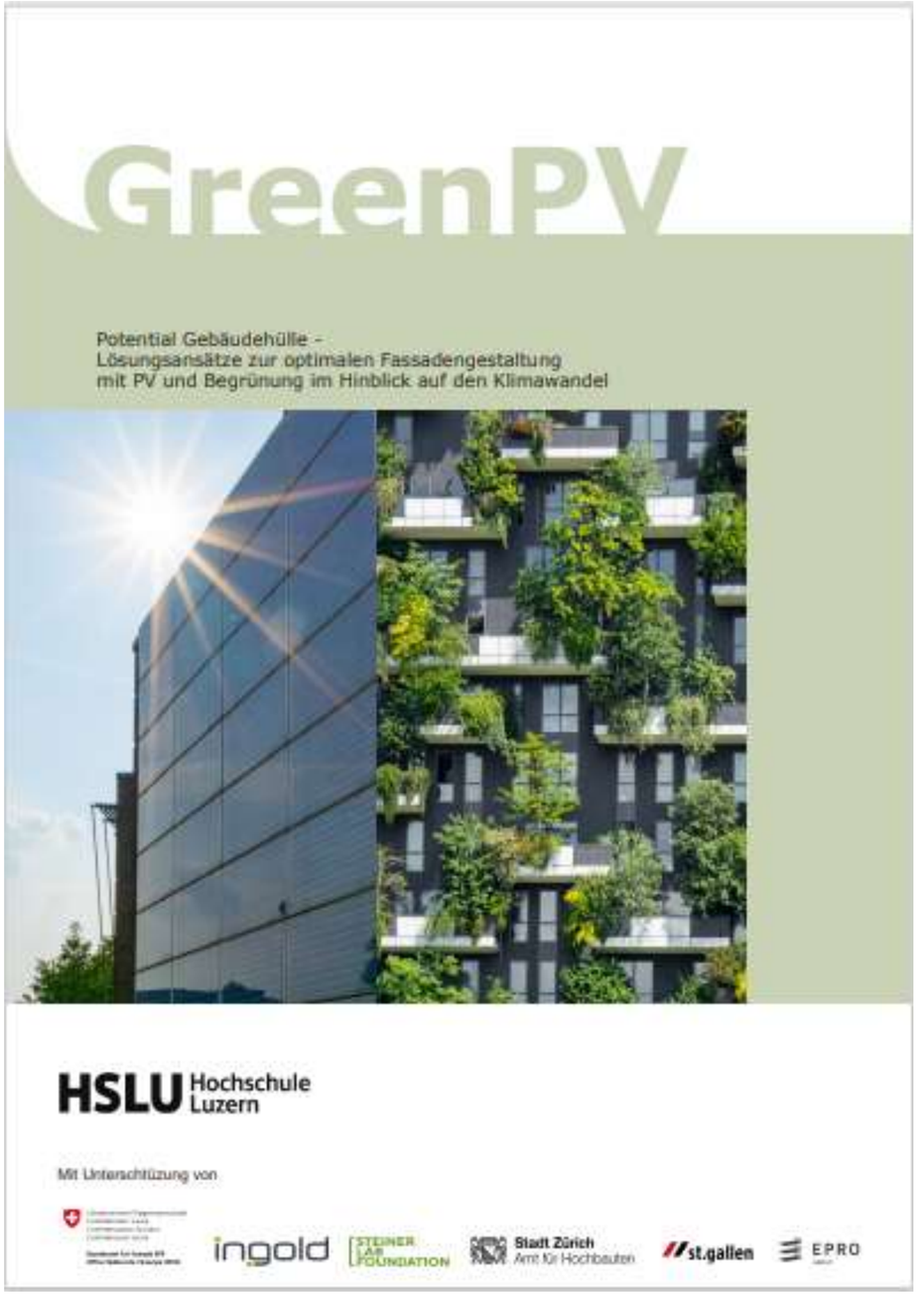
- Brochure 宣传册
- Examples: Qualitative aspects 实例：质量方面
- Examples: Quantitative aspects 实例： 定量方面
- Challenges 挑战
- *Measurements* 测量
- District climate modelling 地区气候建模



Recommendations for planners and investors
→ GreenPV Brochure 对规划者和投资者的建议 → GreenPV 手册

Contents

- ***Advantages*** of the respective façade systems 各种外墙系统的优势
- ***Checklists*** for planning 规划清单
- ***SWOT analyses*** of façade & roof systems 幕墙和屋顶系统的 SWOT 分析
- ***Notes and recommendations*** on the layout of the systems ("decision-taking aid") 系统布局的说明和建议（“决策辅助工具”）
- ***Overview tables and graphics*** on the influence of the systems on *qualitative and quantitative criteria*, taking *orientation and floors* into account 系统对定性和定量标准的影响概览表和图表，同时考虑到朝向和楼层
- Selected ***details and important basic principles*** 选定的细节和重要的基本原则
- ***Good practice*** on relevant topics such as fire protection, care and maintenance & design, important hints for planning & case studies 防火、保养、维护和设计等相关主题的正确做法，规划和案例
- ***Most important findings of the study***
  Summary and conclusion 最重要的研究结果，总结和结论



Examples
→ Brochure
手册举例

ADVANTAGES THE SYSTEMS

PHOTOVOLTAIC FAÇADE

WINTERSTROM

The advantage of PV façades over roof systems is **primarily in winter**. On south-facing façades, electricity can be produced **more efficiently in** these months by a **vertical system** than by a flat elevated system on the roof. In addition, the **yield from** a south-facing façade is **much more balanced throughout** the **day and year**.

LONG-TERM ECONOMIC ADVANTAGES

A PV façade is a sustainable investment that has the **chance to pay for itself**. Savings from the use of solar power in operation (**own consumption**) and **remuneration** for feeding into the grid mean that a PV system pays for **itself** quickly. **Energy costs are reduced immediately** and the initial investment costs are usually amortised over the life of the system.

AUE Basel © Daisuke Hirabayashi / jessenvollenweider

MFH Basel © Roman Weyeneth / Solathé Architekten

ARCHITECTURAL DESIGN ELEMENT

PV modules are now available in a wide **variety of designs** (colours, textures, patterns, trans- parency levels...). This means that they can be used as an **architectural design element**.

Façades play an important role in the **cityscape** and **the design of outdoor spaces**. Thus, PV façades have a high potential to create attractive outdoor spaces with a **high quality of stay**.

Another advantage of using photovoltaics on the façade is that **no additional usable space** is required. This means that roof areas of buildings or other open spaces (undeveloped land) can be used for other purposes.

RESOURCES & RECYCLABILITY

Our **resources** are becoming **scarcer and scarcer**, which is why we should take care to keep our consumption as low as possible. PV modules transform the **façade** from a purely weatherproof function into an **active element**. On the one hand, this saves the material for the alternative façade surface, and on the other hand, PV modules use **high-quality and durable materials**.

In addition, PV modules have a high **recycling potential**, as more than **75 %**[1] can be **reused**. In Switzerland, the return and reprocessing of raw materials is secured by an advance recycling fee (ARF).

1 SENS eRecycling, www.erecycling.ch/wiederverwertbarkeit/

POSITIVE ECO-BALANCE

The construction of the PV modules generates **grey energy**, which cannot be neglected. Over the entire life cycle, however, **sensibly installed PV modules** usually pay for themselves quickly (on average after 2.5 - 3.5 years for south, east and west façades).

SECURITY OF SUPPLY

Solar energy can be produced and used **directly on site**. This makes the consumer **less dependent on price fluctuations**. Well-planned, self-consumption-optimised systems accordingly offer a high level of supply security. By producing electricity via façades, more autonomy can be achieved, especially in months with low hydropower production.

International School © Adam Mørk / C.F. Møller Architects

NEW Blauhaus © Robert Mehl / kadawittfeldarchitektur

SUSTAINABLE ELECTRICITY PRODUCTION

PV façades can be used to promote the production of electricity from **renewable energy sources**. **In** this way, the **existing solar energy on site is** used to generate electricity, thus making a positive contribution to the reduction of environmentally harmful emissions.

Energy Perspectives 2050+ has analysed the development of Switzerland's energy system to ensure net-zero greenhouse gas emissions and a secure energy supply in 2050 and proposes a **rapid and massive expansion of renewable energies** in Switzerland. **PV façades** should **make** an **important contribution in** this regard: the goal is to increase the installed capacity of photovoltaics by a **factor of 13** over the next 30 years.

MAINTENANCE

Vertical systems have the advantage over roof systems that they remain **snow-free in** the winter months. Likewise, the vertical orientation of the systems means less soiling, as less dust and dirt (fallen leaves, animal excrement, etc.) accumulates. Accordingly, the maintenance costs can be classified as low. The surface treatment of the glass is decisive here: the development is moving towards self-cleaning surfaces.

Examples

→ Brochure

手册举例

ADVANTAGES OF THE

FACADE GREENING

PROMOTION OF BIODIVERSITY

Green facades create **new habitats** and make a positive contribution to **biodiversity**. Green facades can have a special added value if they serve as **connecting elements of green spaces** in cities (e.g. as green belts, green corridors) and different plant species are used.

NOISE REDUCTION

Due to their structured design, façade greening has a surface has a **high sound absorption coefficient (α = 0.50 to 0.65)2**. This means that only a certain part of the incoming sound is reflected and the **noise pollution** in urban areas can be **reduced.**

SkyFrame © Claudia Luperto / Strut Architects

Bosco Verticale © Claudia Luperto / Strut Architekten

LONG-TERM ECONOMIC ADVANTAGE

Facade greening can not only make a significant **contribution to sustainability in** times of climate change, but also significantly increase the **attractiveness of a property.**

A green place to work and live attracts the interest of workers and tenants. The results are **good rentability** and **long-term tenancies**. This leads to economic advantages in the long term.

THERMAL INSULATION AND ENERGY BALANCE

Summer thermal protection is becoming increasingly important, especially in times of **climate change**. Greenery can be used as natural sun protection (**shading effect of the plants**). **Summer-green plants** also lose their leaves in winter, which means that solar heat gains are not restricted during this time of year. Furthermore, façade greening can improve the **thermal insulation properties of the exterior wall** (lower U-value, especially in old buildings).

RAINWATER MANAGEMENT

Green facades can help to **absorb rainwater**. This is then gradually released back into the atmosphere through **evaporation**. This not only has a **cooling effect** (evaporative cooling) on the environment, but also contributes to **relieving** the drainage **network.**

COOLING THROUGH EVAPORATION

Plants have a **cooling effect**, as they release the absorbed water back into the environment through evaporation. In addition, greenery can shade the façade, which leads to lower surface temperatures. These aspects not only improve the **microclimate** but also have a positive effect on **reducing the urban heat island effect**. A good ambient climate supports **efficient night-time cooling of** the interior spaces.

Musée du quai Branly © Patrick Blanc

Villa M © +IMG / Tryptique Architecture

QUALITY OF STAY IMPROVEMENT

Green spaces are indispensable for the **quality of stay** in cities. The **positive effects** can be both physical and psychological. Among other things, green spaces can **reduce stress**, **promote health** and **increase productivity** and **creativity**. They also serve as **social meeting places** and promote **sporting activities** and **exercise**.

Green facades can also be used as an **architectural element**. The design of the façade can be varied and have an effect on buildings and the urban space.

OF AIR QUALITY

Green facades can make a positive contribution to **improving air quality**. This is especially true in urban areas, where various emission sources (construction sites, traffic, etc.) can lead to higher air pollution.

Greening can demonstrably help to reduce fine dust, nitrogen dioxide, sulphur dioxide, bind CO2 and ozone and produce oxygen.

The filtering capacity of green facades increases depending on the **pollutant concentration** and the **proximity to the emission source**. In street canyons, the greatest effect can be achieved up to a **height of 4.5** m3.

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Examples
→ Brochure
手册举例

SWOT ANALYSIS

FACADE GREENING SOIL-BOUND

STRENGTH

+ **Higher air quality:** Plants bind air pollutants such as CO2, ozone and fine dust and thus contribute to an increase in air quality. Facade greening can be used where greening measures (trees, shrubs, meadow...) on the ground are not possible due to space constraints (e.g. in narrow street canyons).

+ **Noise reduction:** Due to their structured surface, green facades generally have a higher sound absorption coefficient than conventional facades, which is why they have a noise-reducing effect.

+ Rainwater **retention:** Rainwater can be absorbed via the substrate layer (infiltration) and then gradually released back into the environment via the plants (evaporation). This can promote natural water cycles and relieve the sewer system.

+ **Promoting biodiversity:** Greening facades creates habitats for animals and promotes biodiversity. Ground-based greening can connect green spaces in urban areas ("green belt").

+ **Improvement of** the **microclimate:** The cooling effect of greenery (evaporative cooling) as well as the shading of the facade by the plants can contribute to lowering the temperatures on the facade. This also has a positive effect on the surrounding climate (heat reduction in the summer months).

+ **Low maintenance:** Both water and nutrient requirements are lower for ground-based greenery than for wall-based systems.

+ **Low cost:** Floor-bound systems are easier to implement than wall-bound systems, which is also associated with lower investment costs.

WEAKNESSES

- **Space conditions:** or soil-bound greening, there must be sufficient available space (substrate layer) with appropriate soil conditions. This is not always the case, especially in street areas.

- **Management:** Green facades must be regularly maintained for visual and fire protection reasons. The higher the greenery (growth height), the more complex the management can become. The maintenance of the greenery should be carried out by qualified personnel.

- **Growth period:** Depending on the plant species, it can take several years (average growth height of approx. 1.5 - 2 m per year, on sunny facades up to 4 -6 m per year)4 until the desired facade appearance or the desired microclimatic relevance is achieved.

- **Design flexibility:** In the case of ground-based greenery, the design flexibility is somewhat less than in the case of wall-based systems (the direction of growth is usually predetermined). However, the direction of growth can be influenced by scaffold climbers and the use of climbing aids (rods, tubes, ropes, grids, nets).

- **Fire protection regulations:** There is still no superordinate fire protection ordinance for facade greening (for building heights from 11 m, no special requirements below this). This requires an individual concept for each object. Experts can provide support here and should be involved at an early stage.

RISKS

- **Life cycle assessment:** The climbing structure and the irrigation system incur different expenditures and associated CO2 emissions. However, this impact can be reduced by using recyclable or renewable mat- erials (e.g. steel or wood) and by dispensing with or using simplified irrigation systems.

- **Damage to the facade:** If a system with climbing aids is not used (direct growth) and the greenery is not regularly maintained or checked, shoots of certain plant species (self-climbers, climbers) can penetrate into joints and gaps. This can damage the facade.

OPPORTUNITIES

+ **Design options:** Greening holds potential to visually enhance the façade. New archi- tectonic and aesthetic possibilities are created.

+ **Attractiveness of outdoor spaces:** Green spaces in cities promote the quality of life and stay and have a positive influence on human visual well-being. They serve as social meeting places and have a positive impact on health and productivity.

+ **Promotion of urban climatic focal points:** Through targeted application, greening serves as an instrument for creating sustainable settlement areas (lower heat island effect, more biodiversity, better air quality...).

+ **Increased property value:** Green surroundings increase the value and attractiveness of the property. Long-term leases and fewer vacancies can lead to economic benefits.

+ **Exploit synergies:** By combining greening and PV, the potential of the facade area can be well utilized (sunny areas for PV, areas close to the city for vegetation). At the same time, synergies between the two systems can be exploited: The cooling effect of greening can increase the performance of PV modules.

12 4 Pfoser "Facade and Plant. Potentials of a new facade design", 2016

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Examples
→ Brochure
手册举例

LOCATION AS A CENTRAL FACTOR

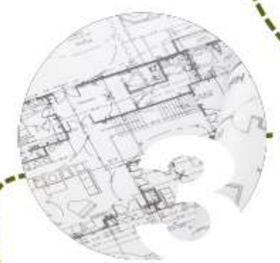
The location is usually a component that **cannot be directly influenced**. The façade **design** must therefore be adapted to the **existing context**, as this **is** essential for the **efficiency of the systems**. The **potential of the façade areas** must be evaluated during the **site analysis**. Various aspects must b e taken into account, including shading, noise situation, climate, existing green spaces, etc.).

In new construction projects, an **object-specific and optimal façade design** consisting of opaque, transparent, greened and PV surfaces can be achieved. For refurbishments, the focus should be on the existing surface potential.

INVOLVE EXPERTS AT AN EARLY STAGE

Experts for façade greening and PV façades should be consulted in the **early planning phases** and included in the **decision-making process. In** this way, **important information** on efficiency, statics, fire protection, maintenance and care, space requirements and accessibility, etc. can be obtained and the **possibility of implementing** the systems can be clarified. Experts can also assist in the **selection of a suitable façade system**, taking into account the previously defined project goals, and point out typical "stumbling blocks".

The early involvement of experts is also **an** essential factor for **cost planning** and **economic efficiency** (e.g. use standard sizes for PV panels, as this has a strong influence on the price, or the right choice of plants for façade greening). Furthermore, possible interfaces with other trades must be considered and coordinated from the beginning, e.g. sanitary installations must be able to provide sufficient water for greenery.



CLEARLY DEFINE PROJECT OBJECTIVES

At the beginning of a project, **the goals** should be **clearly defined** together with the client.
First, the advantages of the different façade systems should be shown to the building owners (**sensitisation**). The added values of greening and PV with regard to **society, economy and the environment** should be discussed and a joint **decision made on the choice of system**.

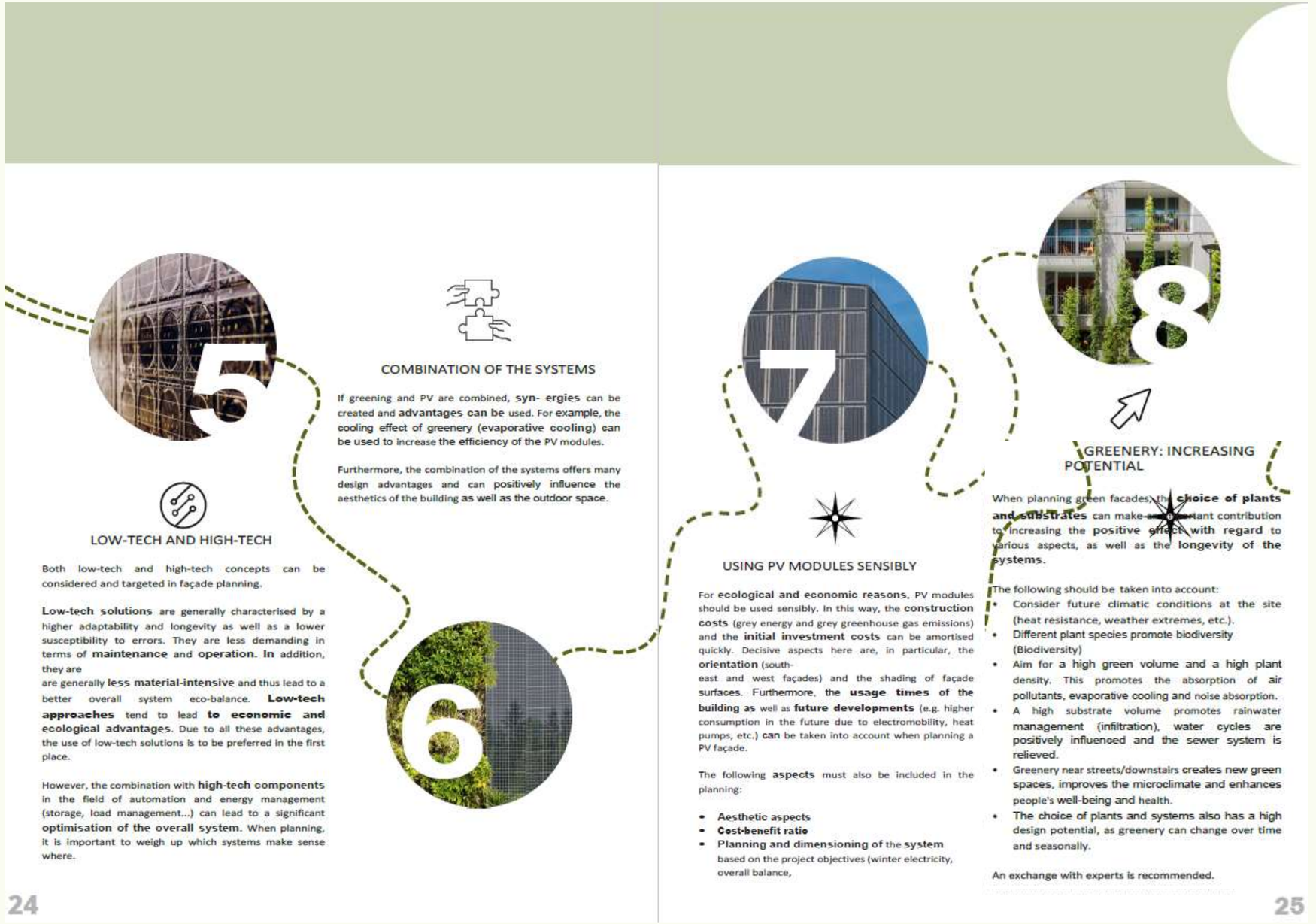
It is also essential to consider the use of greenery and PV on the **roof** and in the **surrounding area** (what makes sense on the façade/roof/in the surrounding area?). Here, too, it is important to consider the advantages and disadvantages and to define a **sustainable overall concept** (ecological, economic and social).

FLOOR AND FAÇADE SPECIFIC PLANNING

Each **context** has different requirements.
Surrounding elements (e.g. neighbouring buildings, mountains, trees, etc.) are crucial for the use of PV **elements**, as they can lead to **shading of the modules** and thus negatively influence their efficiency. PV modules should therefore primarily be used on **façade surfaces where** there **is no shading**.
But even for **façade greening**, where shading hardly plays a role, **planning by storey and façade is** indispensable to achieve the highest added value:

- *Reduction of noise:* proximity to the noise source is decisive, especially relevant in urban areas (traffic noise, construction noise, etc.).
- *Improvement of air quality:* proximity to the emission source is decisive, highest potential on the lower floors (≤ height of 4.5 m).
- *Heat reduction: The* cooling effect (evaporative cooling) of greenery can be enhanced by a high green volume.
- *Rainwater retention:* Consideration of the weather side, highest potential in Switzerland generally in the west.
- *Promotion of biodiversity:* Green spaces are often partially arranged, especially in urban areas; green facades can serve as a connecting element ("green belt, green corridor"); highest potential in this respect is usually on the lower floors.
- Increasing *the quality of stay:* highest potential in urban areas where there is increasing density and little green space. Greatest added value on the lower floors, since
the proximity to the human being is given.

Examples
→ Brochure
手册举例



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LOW-TECH AND HIGH-TECH

Both low-tech and high-tech concepts can be considered and targeted in façade planning.

Low-tech solutions are generally characterised by a higher adaptability and longevity as well as a lower susceptibility to errors. They are less demanding in terms of **maintenance** and **operation. In** addition, they are
are generally **less material-intensive** and thus lead to a better overall system eco-balance. **Low-tech approaches** tend to lead **to economic and ecological advantages**. Due to all these advantages, the use of low-tech solutions is to be preferred in the first place.

However, the combination with **high-tech components** in the field of automation and energy management (storage, load management...) can lead to a significant **optimisation of the overall system**. When planning, it is important to weigh up which systems make sense where.

COMBINATION OF THE SYSTEMS

If greening and PV are combined, **syn- ergies** can be created and **advantages can be** used. For example, the **cooling effect of greenery (evaporative cooling)** can be used to increase the efficiency of the PV modules.

Furthermore, the combination of the systems offers many design advantages and can positively influence the aesthetics of the building as well as the outdoor space.

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USING PV MODULES SENSIBLY

For **ecological and economic reasons**, PV modules should be used sensibly. In this way, the **construction costs** (grey energy and grey greenhouse gas emissions) and the **initial investment costs** can be amortised quickly. Decisive aspects here are, in particular, the **orientation** (south-
east and west façades) and the shading of façade surfaces. Furthermore, the **usage times of the building as** well as **future developments** (e.g. higher consumption in the future due to electromobility, heat pumps, etc.) can be taken into account when planning a PV façade.

The following **aspects** must also be included in the planning:

- **Aesthetic aspects**
- **Cost-benefit ratio**
- **Planning and dimensioning of** the **system** based on the project objectives (winter electricity, overall balance,

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GREENERY: INCREASING POTENTIAL

When planning green facades, the **choice of plants and substrates** can make an important contribution to increasing the **positive effect with regard** to various aspects, as well as the **longevity of the systems**.

The following should be taken into account:

- Consider future climatic conditions at the site (heat resistance, weather extremes, etc.).
- Different plant species promote biodiversity (Biodiversity)
- Aim for a high green volume and a high plant density. This promotes the absorption of air pollutants, evaporative cooling and noise absorption.
- A high substrate volume promotes rainwater management (infiltration), water cycles are positively influenced and the sewer system is relieved.
- Greenery near streets/downstairs creates new green spaces, improves the microclimate and enhances people's well-being and health.
- The choice of plants and systems also has a high design potential, as greenery can change over time and seasonally.

An exchange with experts is recommended.

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Examples
→ Brochure
手册举例

REASON PV

CATALOG THE ASPECTS

Positive factors for the effect of greened and PV façades

Noise in cities

+ High plant density
+ High green volume
+ Small leaf structures
+ Loosely stored substrates
+ Proximity to the emission source (usually on the lower floors)

+ Distance to the emission source (usually in the upper floors)
+ Combination with greening

Biodiversity

+ Various plant species
+ Give preference to native plant species, but in sun-exposed locations use plant species that are suitable for warm climates.
+ Use as a connecting element of green spaces ("green belt")

+ Combination with transparent PV elements (shading -> different microclimate)

Rainwater retention

+ high substrate layer (infiltration)
+ High green volume (evaporation capacity)
+ Weather Pages North/North-West

Attractiveness of the outdoor spaces

+ Various plant species
+ Flowering times and colours
+ Proximity to people or areas where people are staying (usually on the lower floors)

+ Design possibilities: Patterns, colours, degrees of transparency...
+ Combination with greening

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Air quality

+ High leaf density
+ high opacity
+ Sufficient water supply
+ Proximity to the emission source (usually on the lower floors)

Construction and operation Cumulative energy expenditure (incl. electricity production)

+ Less material-intensive systems, conscious choice of materials
+ High green volume

+ Rapid amortisation due to high efficiency
+ Avoid shading
+ Architecture with efficient layout, little Shading
+ Orientation: South, then East and West
+ Combination with mobility & heat generation, possibly storage

Energy demand for operation (**heating and cooling demand,** excl. electricity production)

+ High green volume / substrate volume
+ high opacity
+ Avoid shading the windows in winter
+ greatest effect in unrefurbished old buildings (high U-values)

Life cycle costs (LCC)

+ Systems with low care and maintenance effort
+ Robust plants and systems (long life span, reduce susceptibility)
+ Clarify possible funding

+ Use standard modules
+ Simplicity of the system
+ Yield optimisation
+ Robust systems with low vulnerability

Power production all year round

+ Combination of greening + PV (Verduns-cooling -> efficiency increase)

+ High efficiency
+ Avoid shading
+ Orientation: South, then East and West
+ Aim for durability and efficient systems (Maintenance and upkeep)

Power production winter

+ High efficiency
+ Steep to vertical arrangement
+ Avoid shading
+ Orientation: South, then East and West
+ Aim for durability and efficient systems (Maintenance and upkeep)

Microclimate (summer temperature on the façade)

+ High green volume / substrate volume
+ Sufficient water supply
+ Orientation: east, then south and west

+ good air circulation
+ Combination with greening

Creation (grey greenhouse gas emissions)

+ Use reusable and renewable materials (e.g. steel, wood...) for the substructure.
+ Reduce construction effort, consider additional effort Statics
+ Technical elements only where necessary
+ Prefer local companies

+ Use reusable and renewable materials (e.g. steel, wood...) for the substructure.
+ Compare product declarations / prefer local products
+ Durable and robust systems (guarantee dismantlability and plan for replacement modules)

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Examples
→ Brochure
手册举例

BIODIVERSITY

Focus of the study

Biodiversity is the prerequisite for the healthy and natural development of all living organisms and ecosystems. Biodiversity is usually considered on three levels: Habitats, species and genetic diversity. Green facades and the combination with PV can make a positive contribution to increasing biodiversity.**14**

Situation in Switzerland

Switzerland is home to a great deal of biodiversity, which is due, among other things, to the varied topography, the great differences in altitude with their corresponding climatic contrasts, and also the extensive use of cultivated land until the middle of the last century. Nevertheless, the Federal Office for the Environment considers the current state to be unsatisfactory. In cities in particular, biodiversity is limited due to the high degree of building, the extensive infrastructure and the high proportion of sealed areas.**14**

Potential of façade greening

- Green facades create additional habitats and make a positive contribution to local biodiversity
- The use of different plant species increases the positive effect.
- Green facades can expand green spaces and connect habitats ("green belt", "green corridor").
- Green facades can take on different functions, for example as feeding, nesting or catching places.

The combination of PV and greening creates additional potential: the shading of the panels can create different habitats with different microclimates.**15**

Fig. 6 Different functions of façade greening for wildlife (© Nicole Pfoser)

Fig. 7 Façade greening as a nesting site (© Roger Ingold)

14 Federal Office for the Environment (FOEN)

15 Jörg Schlegel, energies plus, magazine of the Swiss Federal Office of Energy

Evaluation of the façade systems

The following graph shows the influence of the different façade systems on the aspect of "biodiversity".

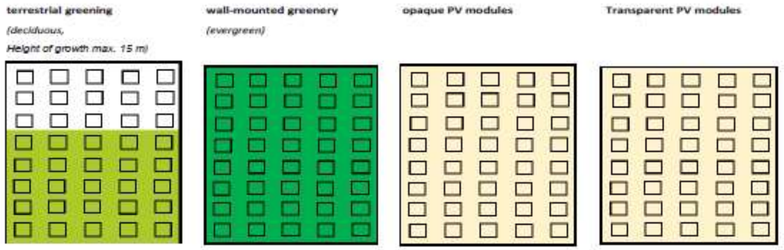


Fig. 8 Influence of greened and PV façades on the aspect of biodiversity

Summary

1. Green facades can make a positive contribution to the promotion of biodiversity, especially in urban areas where there is a high potential.
2. PV façades bear the risk of glare, which can be negative for birds, for example.
3. In combination with greening, however, PV modules can help to create habitats with different microclimates.
4. Deciduous plants only have a seasonal effect, while evergreen plant species (usually in wall-mounted systems) have a year-round effect.
5. Ground-based systems are limited in their growth height, while wall-based systems can usually be used at various heights.

Qualitative aspects - approach, presentation and findings

定性方面--方法、表述和结果

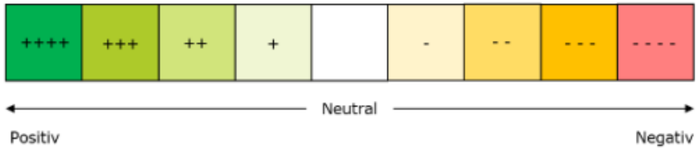
1. *literature research* on the most important fundamental principles with relation to

关于以下方面最重要基本原则的文献研究

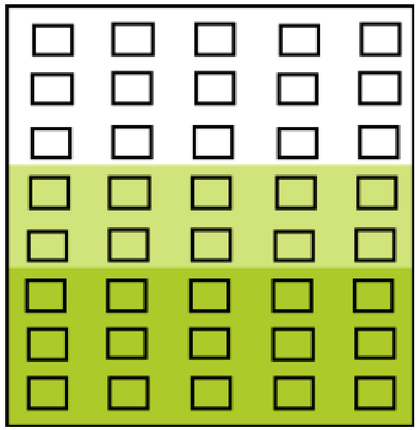
- Noise in urban areas 城市噪音
- Air quality 空气质量
- Biodiversity 生物多样性
- Rainwater retention 雨水收集
- Attractiveness of outdoor spaces 室外空间的吸引力

2. *evaluation of the potential of the different façade systems* on the basis of an 8-storey reference building (reference: fibre cement board)

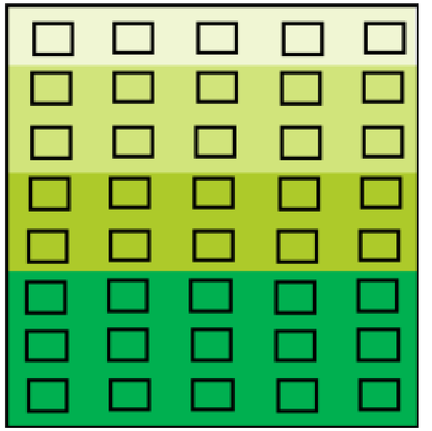
以一座8层参考建筑（参考建筑：纤维水泥板）为基础，评估不同外墙系统的潜力



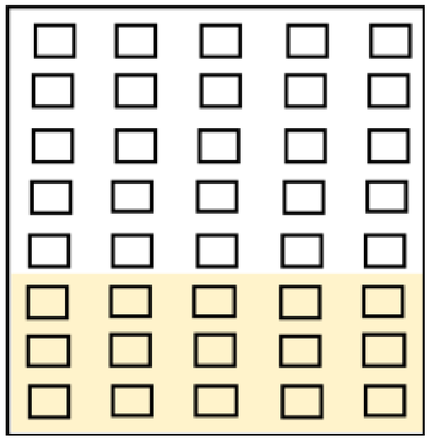
Ground-based façade greening (Summer green, height of growth 15m)



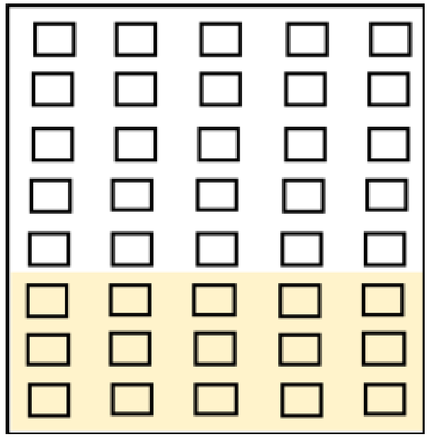
Wall-mounted façade greening (always green)



PV façade opaque modules



PV façade transparent modules



Qualitative aspects

Noise in urban areas

质量方面：城市地区的噪音

Ground-based façade greening (Summer green, height of growth 15m**)**

Wall-mounted façade greening (always green)

PV façade opaque modules

PV façade transparent modules

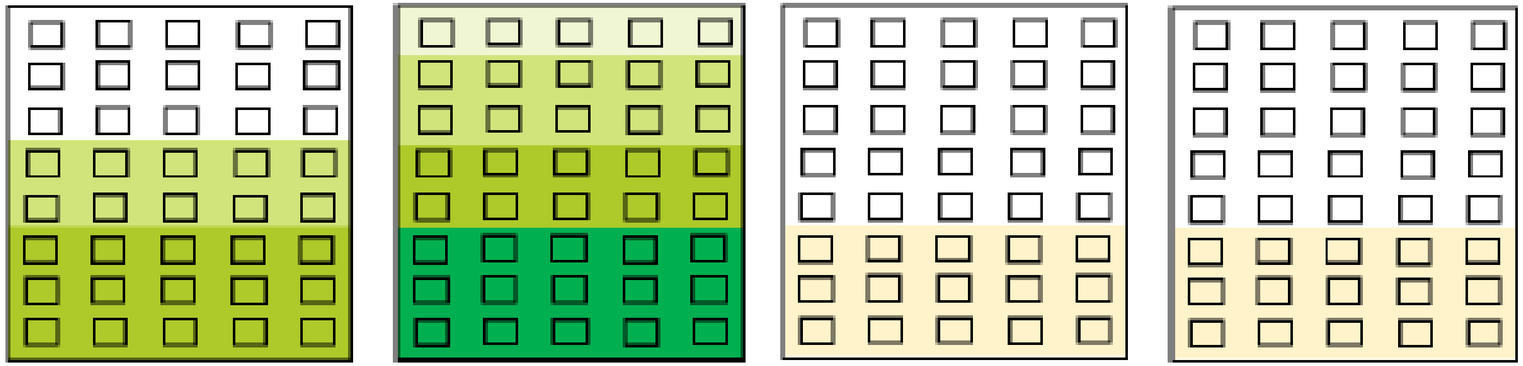


Abb. 3 Einfluss von begrünten und PV-Fassaden auf den Aspekt Lärm in Städten.

Zusammenfassung

1. Fassadenbegrünungen können einen positiven Beitrag zur Reduktion von Lärm in Städten leisten.
2. PV-Module haben eine akustisch harte, glatte Oberfläche, weshalb Schallwellen zu einem grossen Teil reflektiert werden.
3. Die Nähe zur Emissionsquelle ist entscheidend: Die positive Wirkung von Begrünungen ist grösser unmittelbar an der Emissionsquelle (i.d.R. in den unteren Geschossen), während der negative Reflektionseffekt von PV-Module kleiner ist in höher Entfernung vom Lärm (i.d.R. in den oberen Geschossen)
4. Pflanzenarten, welche für bodengebundene Systeme eingesetzt werden, sind i.d.R. sommergrün, weshalb der positive Effekt in den Wintermonaten geringer ist.
5. Werden für Fassadenbegrünung immergrüne Pflanzenarten gewählt (i.d.R. bei wandgebunden Systemen), so besteht der positive Effekt ganzjährig.

Qualitative aspects

Air quality

质量方面：空气质量

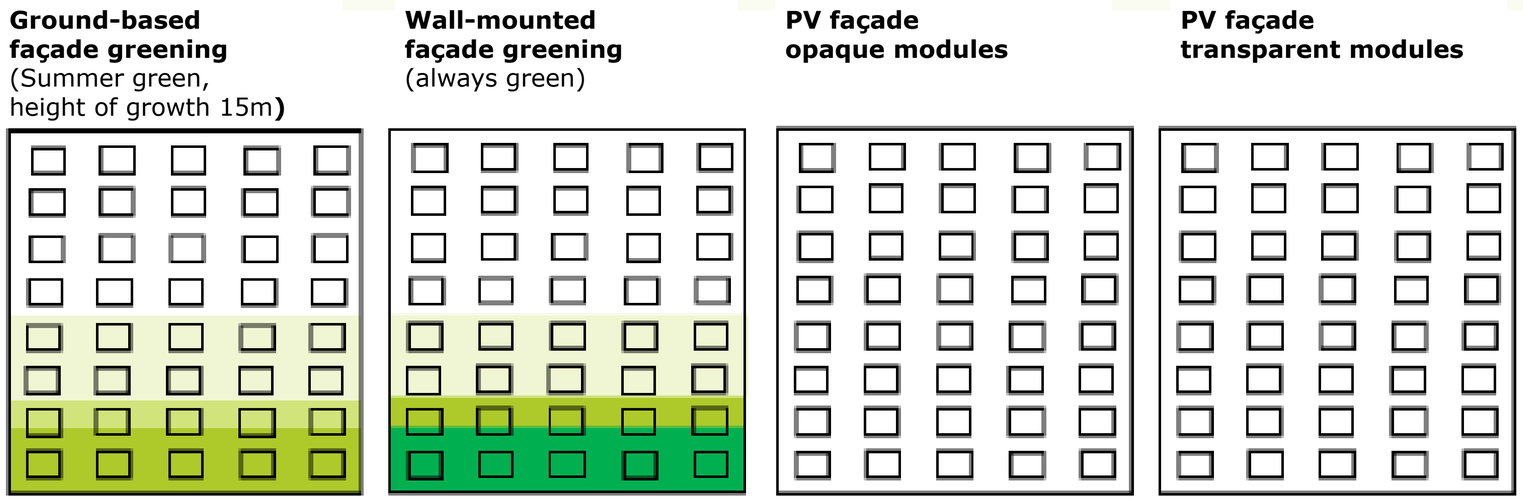


Abb. 5 Einfluss von begrünten und PV-Fassaden auf den Aspekt Luftqualität

Zusammenfassung

1. Fassadenbegrünungen können einen positiven Beitrag zur Verbesserung der Luftqualität leisten
2. PV-Module können keinen direkten Beitrag zur Verbesserung der Luftqualität beitragen. Durch die Nutzung von Solarenergie können jedoch CO_2-Emissionen vermieden werden (indirekt positiver Einfluss).
3. Die Nähe zur Emissionsquelle ist entscheidend: Der positive Einfluss von Begrünungen kann in Strassenschluchten vor allem bis zu einer Höhe von ≤ 4.5 m erfolgen.
4. In engen Strassenquerschnitten kann es durch dichte Baumstrukturen dazu kommen, dass es zu einem Stau von Luftschadstoffen unterhalb der Baumkrone kommen kann (Luftzirkulation wird eingeschränkt). Fassadenbegrünungen können in einem solchen Kontext zielführender sein.
5. Sommergrüne Pflanzen wirken nur saisonal, während immergrüne Pflanzenarten (i.d.R. bei wandgebunden Systemen) ganzjährig einen Effekt haben.

Qualitative aspects

Biodiversity

质量方面：生物多样性

Ground-based façade greening (Summer green, height of growth 15m**)**

Wall-mounted façade greening (always green)

PV façade opaque modules

PV façade transparent modules

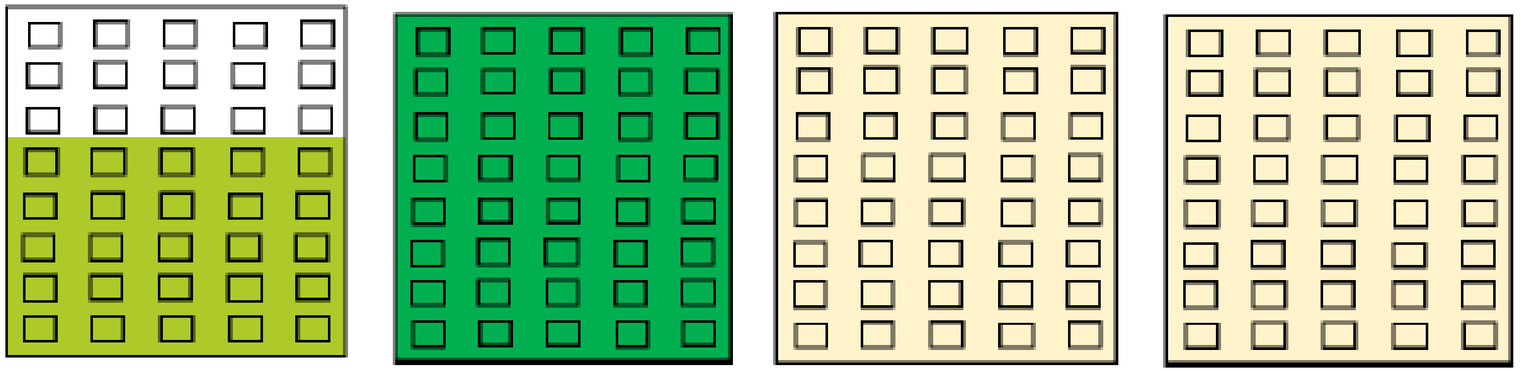


Fig. 8 Influence of greened and PV façades on the aspect of biodiversity

Summary

1. Green facades can make a positive contribution to the promotion of biodiversity, especially in urban areas where there is a high potential.
2. PV façades bear the risk of glare, which can be negative for birds, for example.
3. In combination with greening, however, PV modules can help to create habitats with different microclimates.
4. Deciduous plants only have a seasonal effect, while evergreen plant species (usually in wall-mounted systems) have a year-round effect.
5. Ground-based systems are limited in their growth height, while wall-based systems can usually be used at various heights.

Qualitative aspects

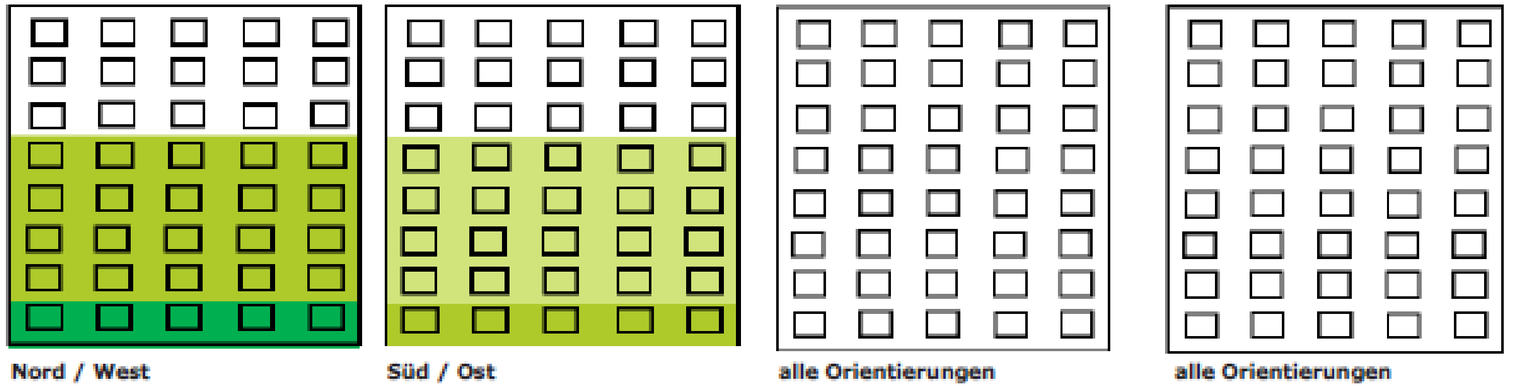
Rainwater retention

质量方面：雨水收集

Ground-based façade greening (Summer green, height of growth 15m)

PV façade opaque modules

PV façade transparent modules



Wall-mounted façade greening (always green)

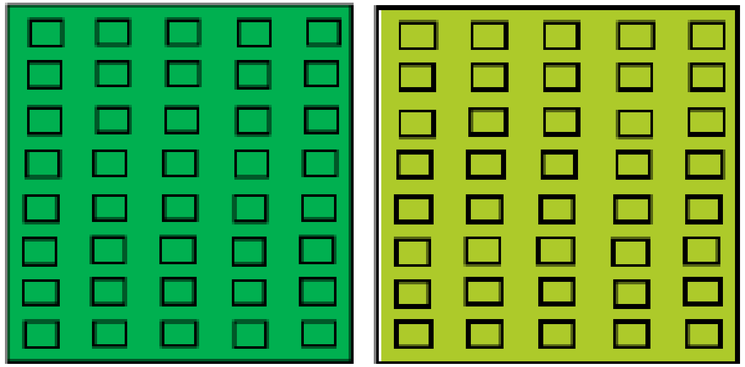


Abb. 11 Einfluss von begrünten und PV-Fassaden auf den Aspekt Regenwasserrückhalt

Summary

1. Green facades can make a positive contribution to the infiltration of rainwater. The greatest potential arises on the weather sides (Switzerland: north/north-west).
2. PV façades cannot add any value in this respect.
3. Deciduous plants only have a seasonal effect, whereas evergreen plant species have a year-round effect.
4. While wall-bound systems can achieve the same effect on the entire façade, the greatest potential for infiltration with board-bound systems lies close to the ground (sub-layer is decisive for infiltration).

Qualitative aspects

Attractiveness of outdoor spaces

质量方面：室外空间吸引力

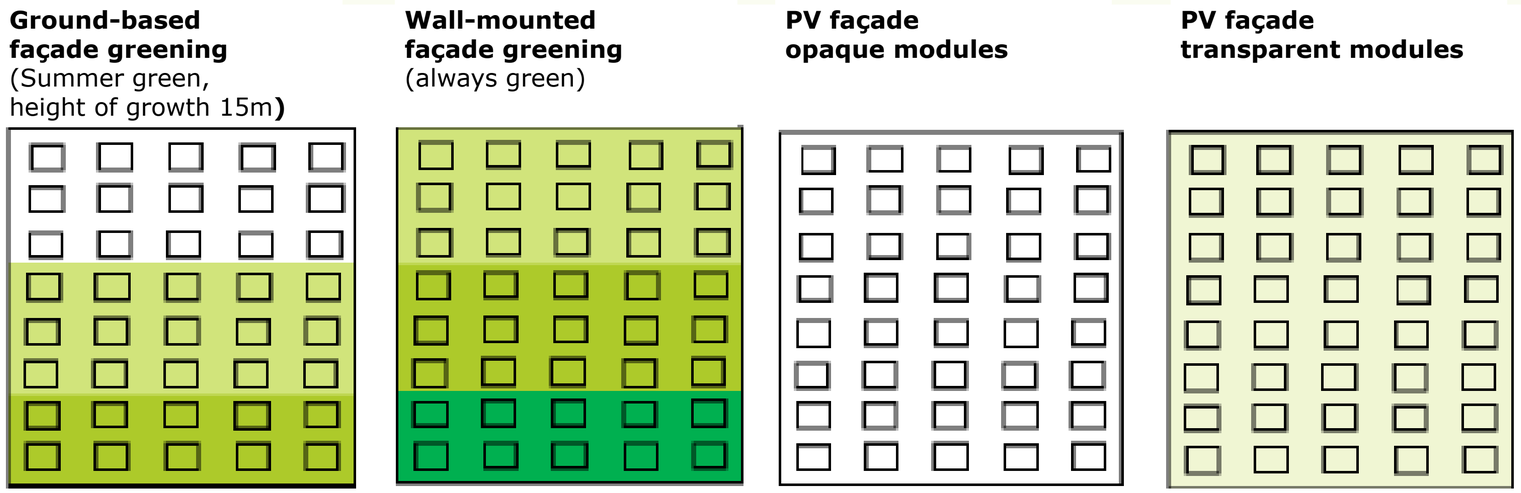


Fig. 13 Influence of green and PV façades on the aspect of attractiveness of outdoor spaces

Summary

1. Green facades have a high potential for creating attractive and liveable outdoor spaces.
me.

2. Greenery has the greatest potential in areas that are close to people (usually on the lower floors). On the façade, green areas can be used in a targeted manner and provide added design value on various levels (urban space, building structure, changing façade appearance),
etc.).

3. PV modules can be used in particular as an architectural design element. There are different colours and patterns for opaque modules
. Compared to the reference (fibre cement board), similar possibilities are available here. Transparent modules have an additional design advantage here.
aspect (degree of transparency).

4. Deciduous plants change strongly with the season and lose their leaves in the winter months. Evergreen plants retain their foliage throughout the year (façade appearance remains largely unchanged). Ground-based systems
are also limited in their height of growth.

Qualitative aspects - approach, presentation and findings

定性方面--方法、表述和结果

Qualitative aspects *Evaluation in comparison to the reference façade (fibre cement board back-ventilated)*	Facade greening		PV facade	
	ground-hugging *(deciduous, height of growth approx. 15 m)*	Wall-mounted *(evergreen, modular system)*	opaque	transparent
Noise in cities - *potential in a narrow street canyon with heavy road traffic (~ 80 dB, very loud)*				
EC	+ +++	+ ++++	-	-
1ST FLOOR	+ +++	+ ++++	-	-
2ND FLOOR	+ +++	+ ++++	-	-
3RD FLOOR	+ +	+ +++	*neutral*	*neutral*
4TH FLOOR	+ +	+ +++	*neutral*	*neutral*
≥ 5.OG	*neutral*	+ +	*neutral*	*neutral*
Air quality - *potential in a narrow street canyon with heavy road traffic*				
EC	+ +++	+ ++++	*neutral*	*neutral*
1ST FLOOR	+ +	+ +++	*neutral*	*neutral*
2ND FLOOR	+	+	*neutral*	*neutral*
3RD FLOOR	+	+	*neutral*	*neutral*
4TH FLOOR	*neutral*	*neutral*	*neutral*	*neutral*
≥ 5.OG	*neutral*	*neutral*	*neutral*	*neutral*
Biodiversity - *potential to promote new habitats and biodiversity, danger from reflections, etc.*				
EC	+ +++	+ ++++	-	-
1ST FLOOR	+ +++	+ ++++	-	-
2ND FLOOR	+ +++	+ ++++	-	-
3RD FLOOR	+ +++	+ ++++	-	-
4TH FLOOR	+ +++	+ ++++	-	-
≥ 5.OG	*neutral*	+ ++++	-	-

- In the considered qualitative aspects, ***greening*** in particular can make a positive contribution.

  在质量方面，绿化尤其可以做出积极贡献

- The influence of the systems on the aspects examined is less dependent on orientation, but rather on the ***surrounding context*** and the ***storey*** (proximity to ***humans*** or emission sources, etc.).

  在系统对所研究方面的影响与朝向关系不大，而是取决于周围环境和楼层（是否靠近人类或排放源等）

定性方面--方法、表述和结果
Quantitative aspects - approach, presentation and findings

Quantitative aspects *Evaluation in comparison to the reference façade (fibre cement board back-ventilated)*	Facade greening				PV facade			
	ground-based		wall-mounted		opaque modules		Transparent modules	
	shaded	not shaded	shaded	not shaded	shaded	not shaded	shaded	not shaded
Energy demand for operation (heating and cooling demand) - *maximum potential on the east > south > west > north façade.*								
North	+	+	+ +	+ +	neutral	neutral	neutral	neutral
East	+	+ +	+ +	+ + +	neutral	neutral	neutral	neutral
South	+	+ +	+ +	+ + +	neutral	neutral	neutral	neutral
West	+	+	+ +	+ +	neutral	neutral	neutral	neutral
Electricity generation all year round - *electricity generation potential (maximum potential on the roof > on the south > east > west > north façade).*								
North	neutral	neutral	neutral	neutral	+	+	-	-
East	neutral	neutral	neutral	neutral	+	+ +	-	+ -
South	neutral	neutral	neutral	neutral	+	+ + +	-	+ + -
West	neutral	neutral	neutral	neutral	+	+ +	-	+ -
Winter electricity generation - *electricity generation potential (maximum potential on the south façade > on the roof > on the east > west > north façade).*								
North	neutral	neutral	neutral	neutral	+	+	+	-
East	neutral	neutral	neutral	neutral	+	+ + +	+	+ +
South	neutral	neutral	neutral	neutral	+	+ + + +	+	+ + +
West	neutral	neutral	neutral	neutral	+	+ + +	-	+ +
Microclimate (summer temperature on the façade) - *maximum potential on the east > south > west > north façade.*								
North	+	+	+ +	+ +	neutral	neutral	neutral	neutral
East	+	+ + +	+ +	+ + + +	neutral	--	neutral	--
South	+	+ + +	+ +	+ + + +	neutral	--	neutral	--
West	+	+ +	+ +	+ + +	neutral	-	neutral	-

For the quantitative aspects, the ***orientation*** and possible ***shading of the façade*** by buildings, topography or other elements is particularly decisive.

就数量而言，建筑物、地形或其他因素对建筑立面的影响尤其重要

→ Graphical representation of the quantitative results analogous to the qualitative aspects

定量结果的图表表示与定性结果类似

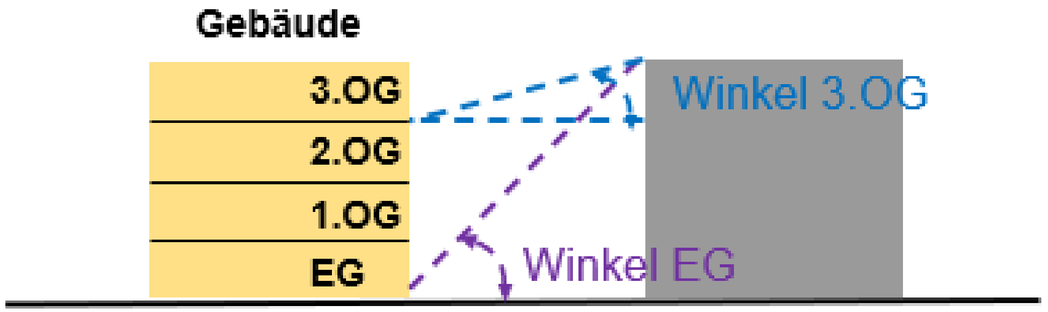
Quantitative aspects –

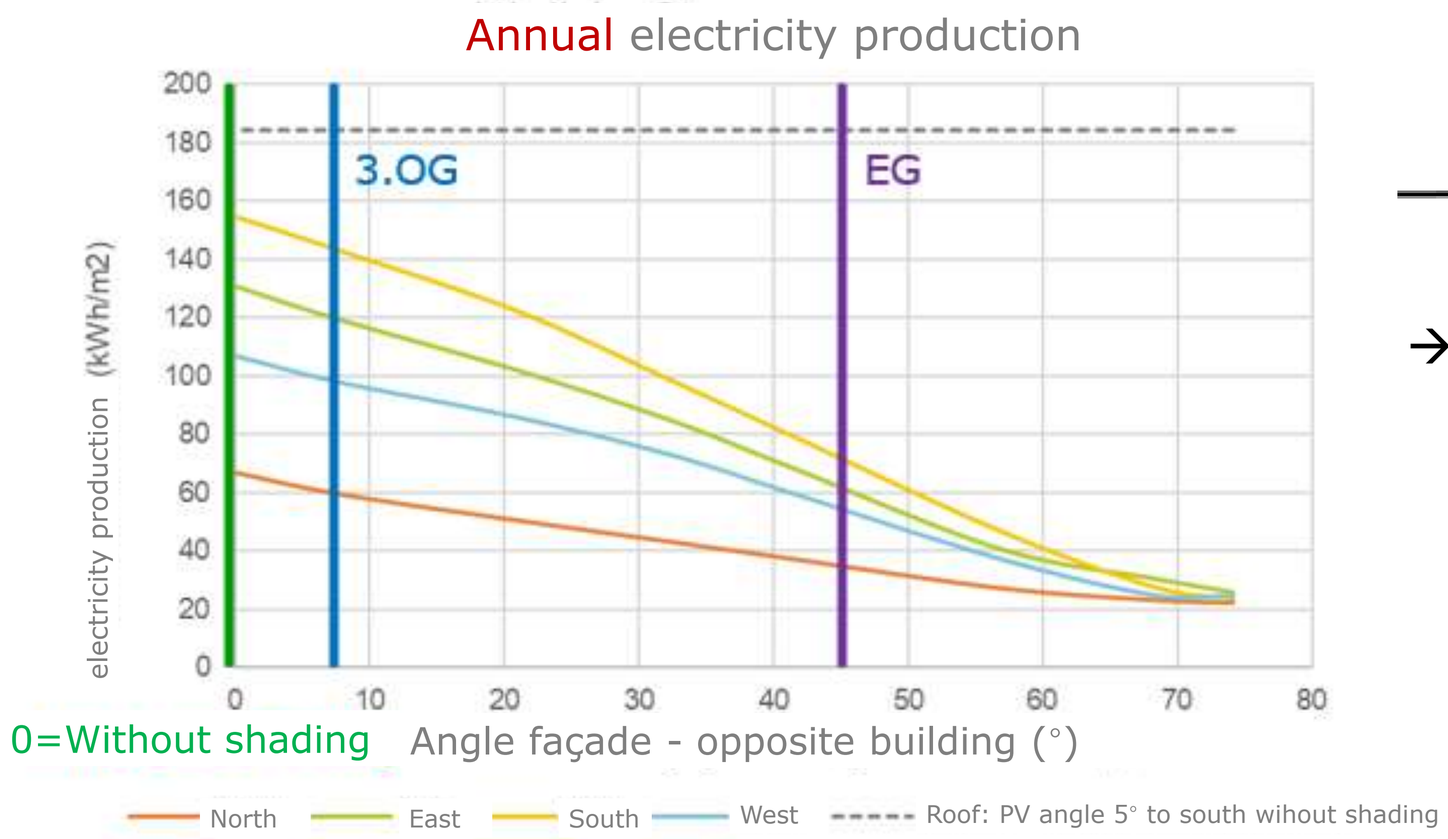
Simulation of PV electricity production potential

定量方面 – 模拟光伏发电潜力

PV - electricity production (opaque module, efficiency 20%)

光伏 – 发电（不透明组件，效率 20%）





→ The ***efficiency*** of ***PV modules*** is strongly dependent on orientation and shading by buildings, topography, etc.

光伏组件的效率在很大程度上取决于朝向、建筑物遮挡、地形等因素

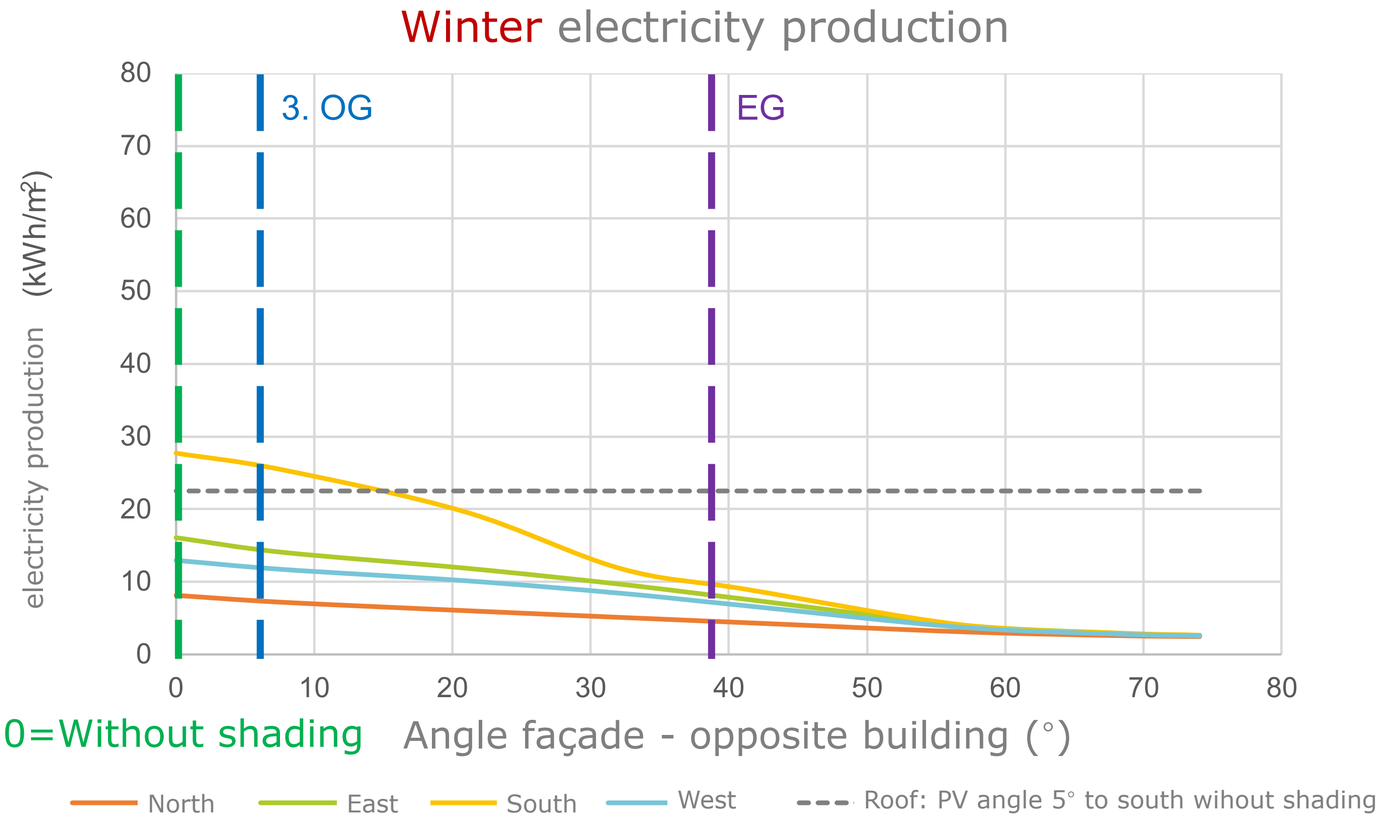
Quantitative aspects –

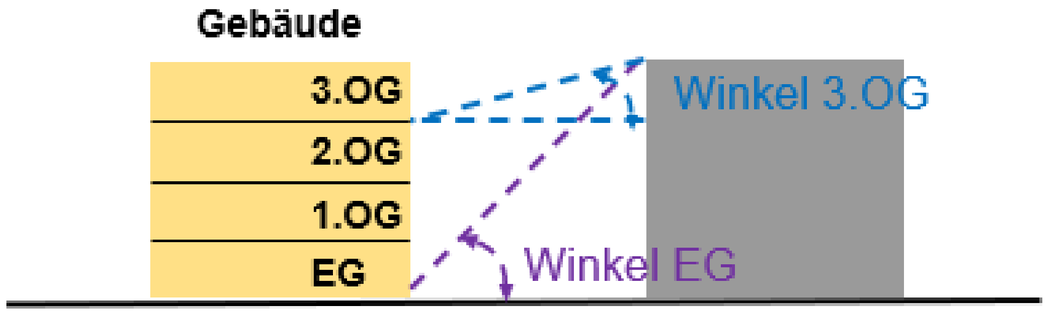
Simulation of PV electricity production potential

定量方面 – 模拟光伏发电潜力

PV - electricity production (opaque module, efficiency 20%)

光伏 – 发电（不透明组件，效率 20%）



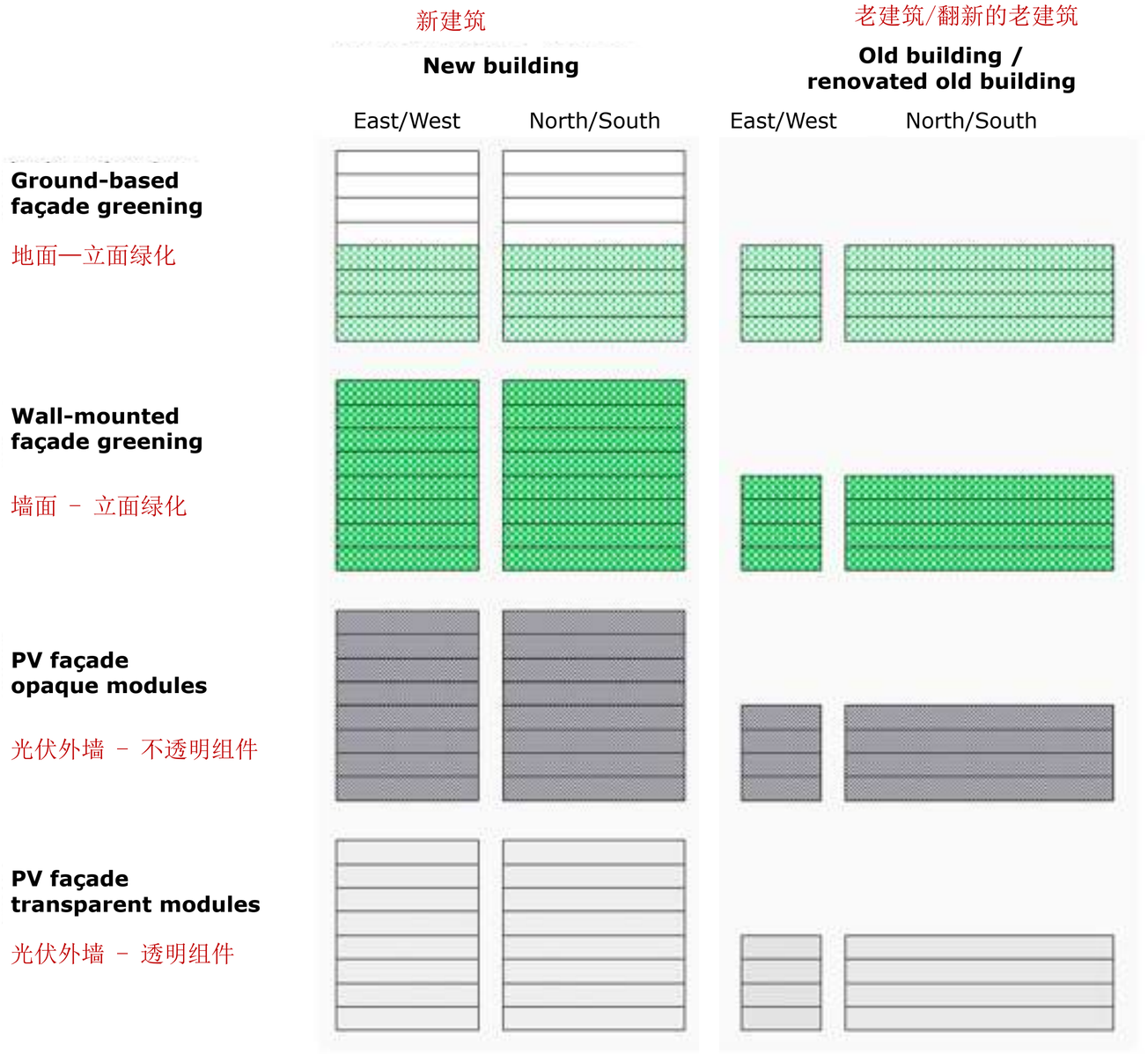


→ In winter, the PV output on the ***south façade*** can be ***higher than*** the output on the ***roof***

冬季，南立面的光伏发电量可能高于屋顶的发电量

Quantitative aspects – different scenarios
定量方面--不同的方案

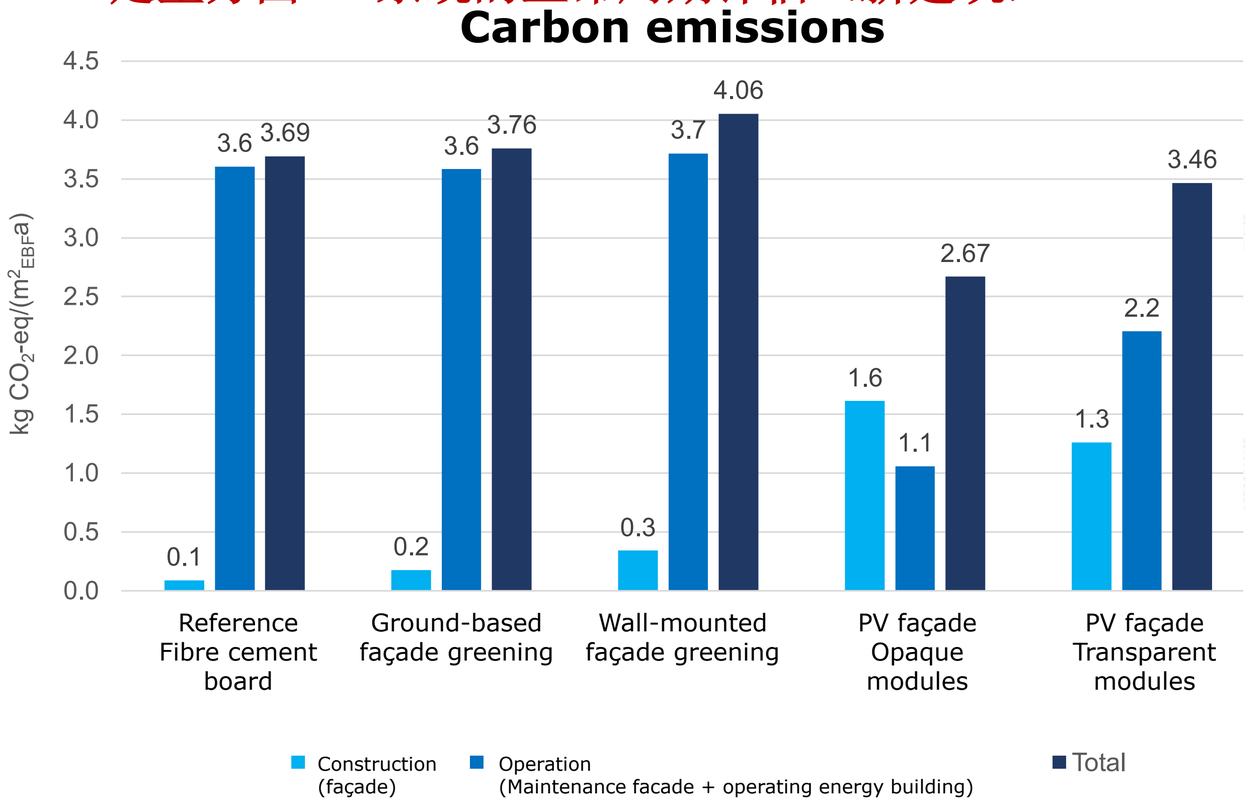
Investigation of the systems

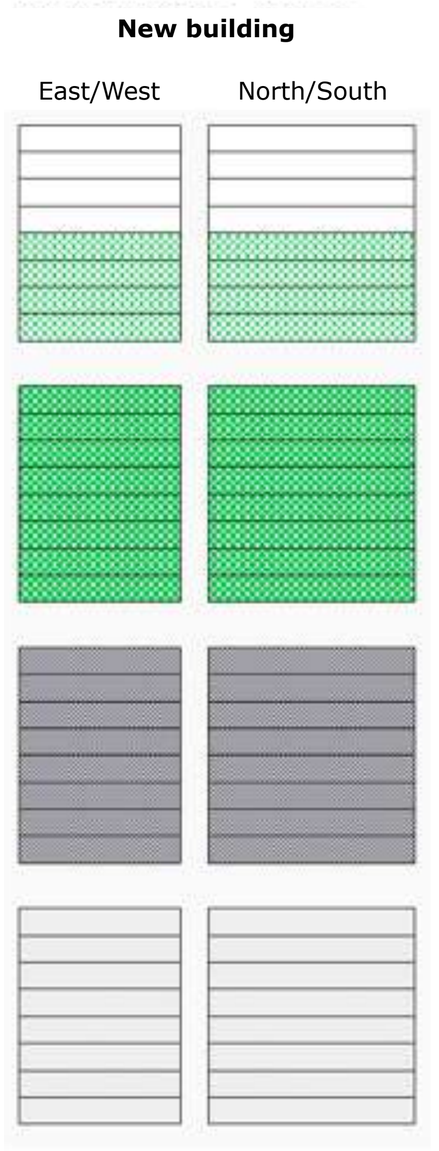


Quantitative aspects –

Life cycle assessment of systems (new building)

定量方面 – 系统的生命周期评估（新建筑）





Ground-based façade greening

地面—立面绿化

Wall-mounted façade greening

墙面 – 立面绿化

PV façade opaque modules

光伏外墙 – 不透明组件

PV façade transparent modules

光伏外墙 – 透明组件

Quantitative aspects –

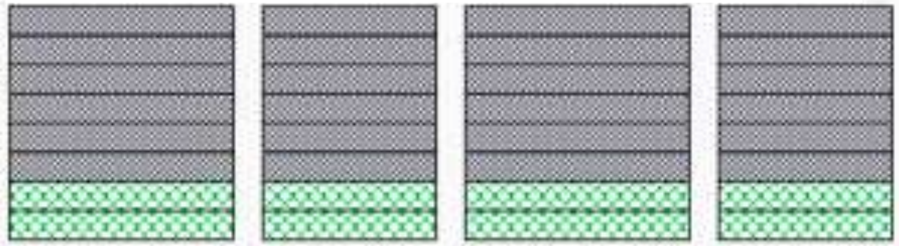
Different scenarios or layouts of greening and PV (new building)

定量方面 – 绿化和光伏发电的不同方案或布局（新建筑）

Scenario 1:
top PV / bottom green, all façades*

方案 1： 顶部光伏/底部绿色，所有外墙

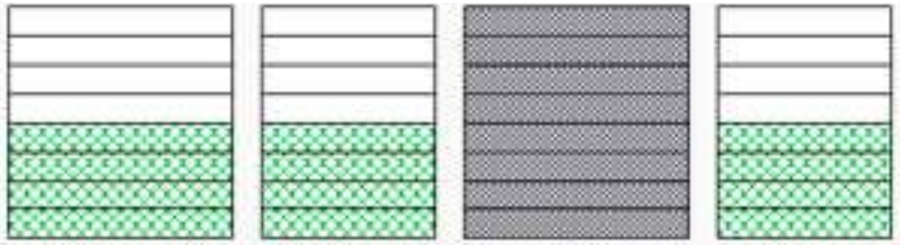
North East South West



Scenario 3:
South façade PV / other façades green*

方案 3：南立面光伏/其他立面绿色

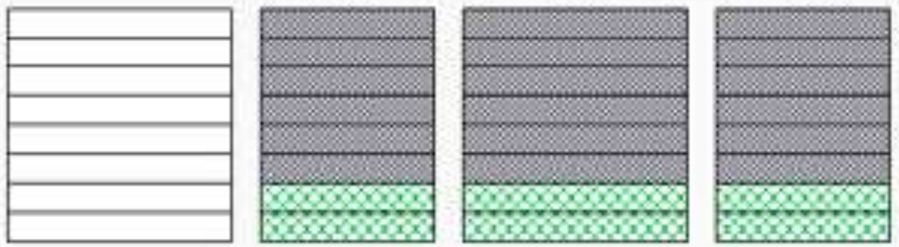
North East South West



Scenario 2:
top PV / bottom green, without north façade*

方案 2： 顶部光伏/底部绿色，没有外墙

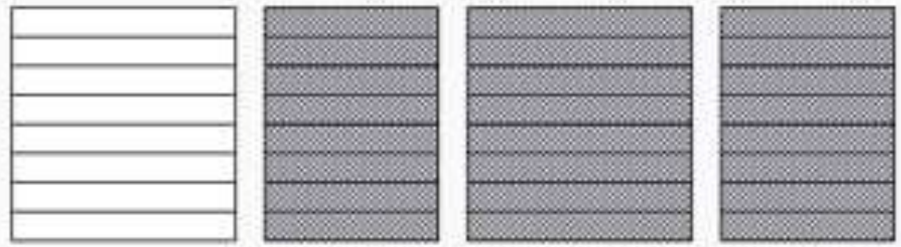
North East South West



Scenario 4: (Focus on energy production)
east, south, west façade PV; no green*

方案 4：方案 4：（注重能源生产）东、南、西立面光伏，无绿化

North East South West

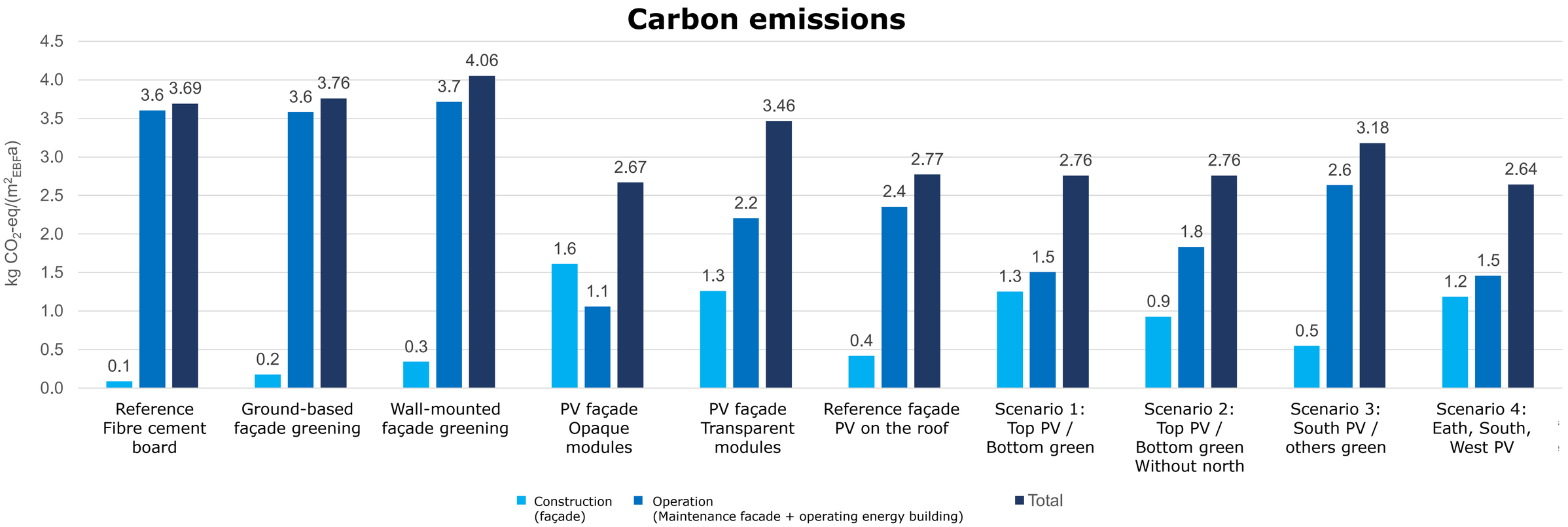


*: PV always opaque / greenery always ground-based / white cement fibre board.

Quantitative aspects –

Life cycle assessment of systems and scenarios (new building)

定量方面 – 生命周期评估（新建筑）

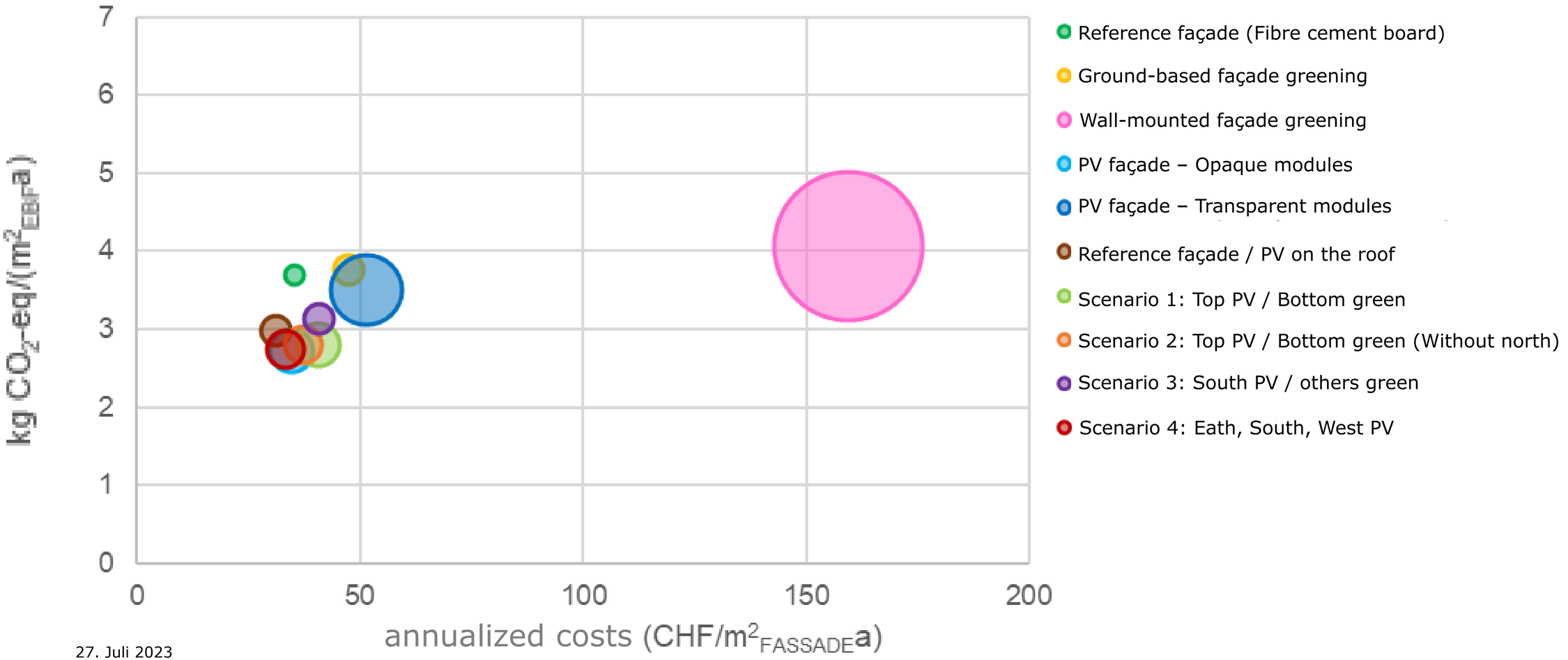


Quantitative aspects –

greenhouse gas emissions / life cycle costs / initial costs

定量方面 – 温室气体排放/生命周期成本/初始成本

Carbon emissions vs. LCC



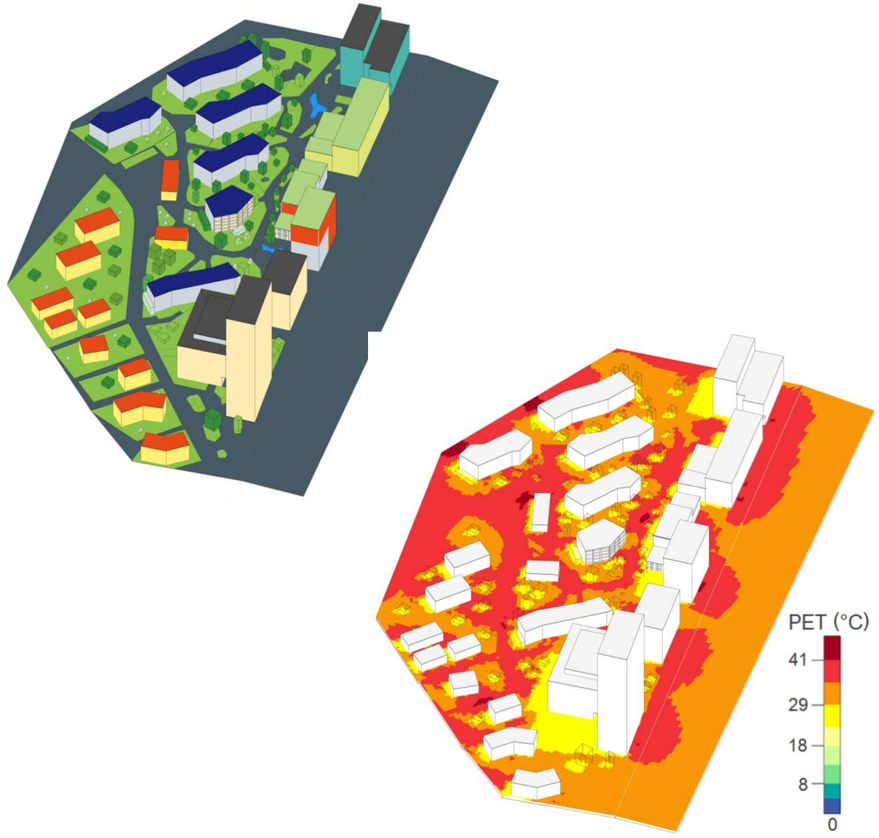
Quantitative aspects

District climate modelling

定量方面 – 地区气候建模

What does GreenPV mean for the environment?

绿色光伏对环境意味着什么？



New software: *Media release 20.7.2023*

→ Preventing heat islands at the planning stage

Urban and district planning takes on a new dimension in times of climate change. A question that urgently arises: How do you prevent heat accumulation through buildings? The Lucerne University of Applied Sciences and Arts has developed a tool that can calculate the microclimate in existing and planned neighbourhoods within seconds.

新软件发布
在规划阶段预防热岛问题在气候变化时期，城市和地区规划面临新的挑战。
如何通过建筑物防止热量积聚？卢塞恩应用科学与艺术大学开发了一种工具，
可以在几秒钟内计算出现有和规划街区的微气候

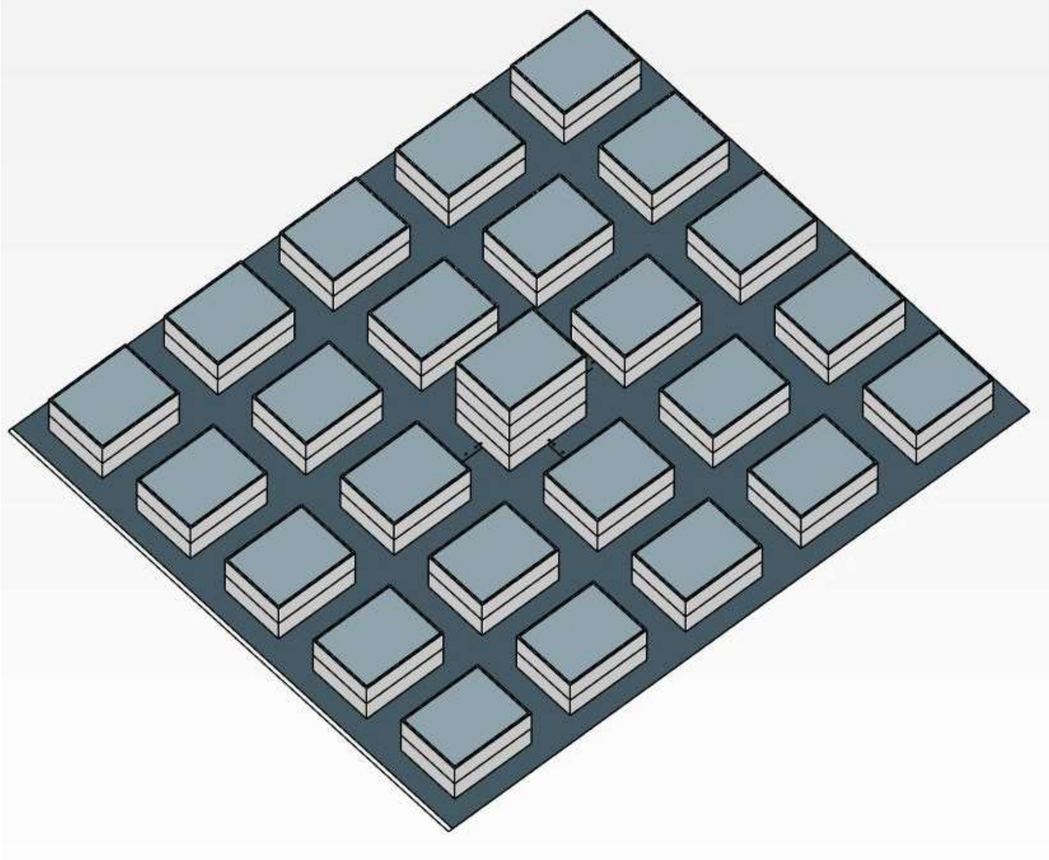
Quantitative aspects

District climate modelling

定量方面 – 地区气候建模

What does GreenPV mean for the environment?

绿色光伏对环境意味着什么？



Assumptions:

- ***Urban context***, but the surrounding buildings were assumed to have a lower height in order to simulate direct solar radiation on the façade.
- ***Sunny summer day:*** max. air temperature of approx. 35 °C / min. air temperature approx. 18 °C (night)

假设：
城市环境，但假定周围建筑物的高度较低，以模拟太阳直接辐射对建筑物外墙的影响
夏季晴天：最高气温约 35 ° C，最低气温约 18 ° C（夜间）

Quantitative aspects

District climate modelling

定量方面 – 地区气候建模

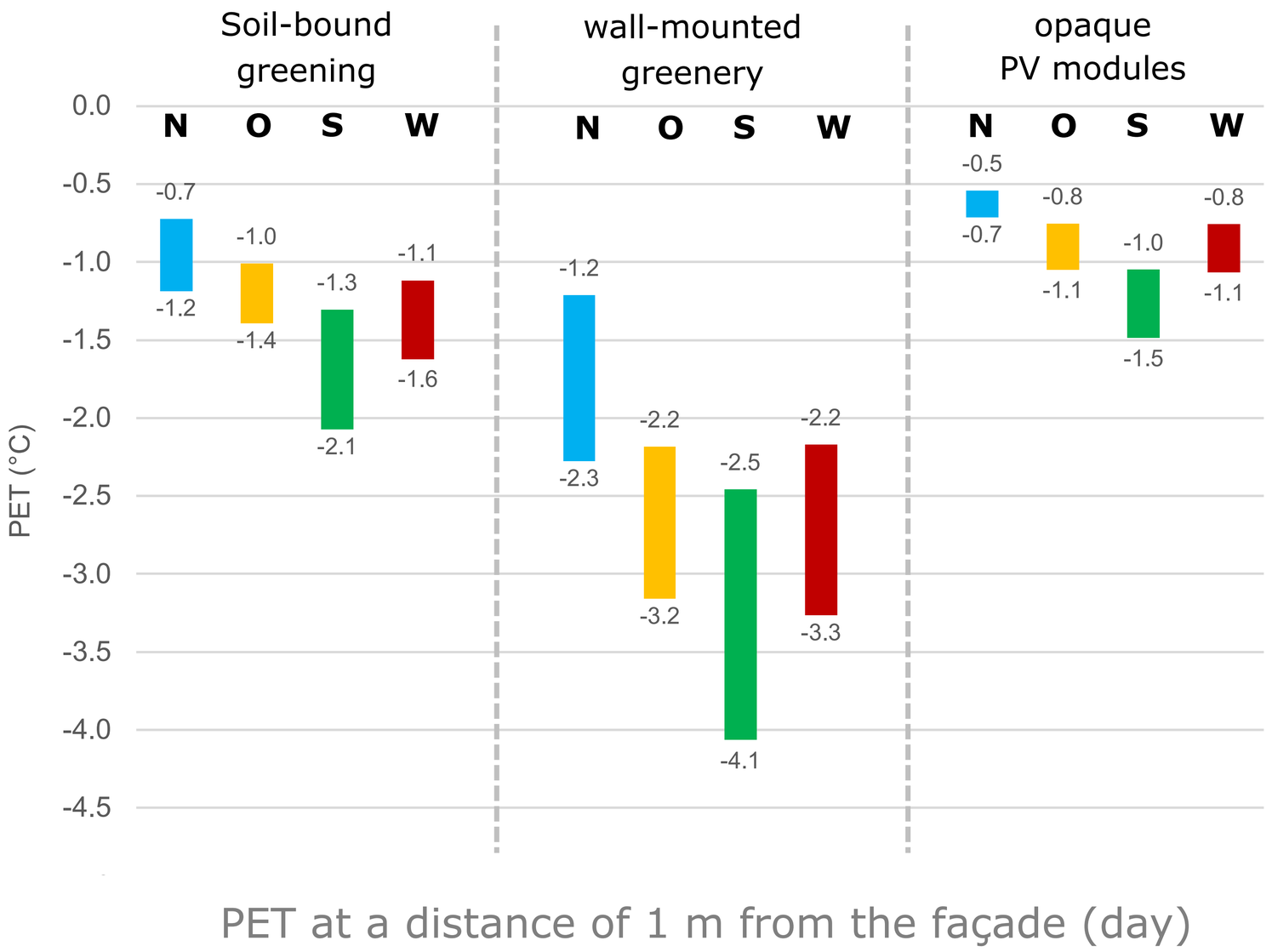
PET = Physiologically equivalent temperature

The PET describes the thermal sensation of a "standard person", which represents an average thermal sensitivity. Air temperature, air humidity, wind speed and direct solar radiation are particularly relevant for thermal sensation. (Source: Canton of Zurich)

PET 描述的是 "标准人 "的热感觉，代表平均热敏感度。空气温度、空气湿度、风速和太阳直射辐射与热感尤为相关

Shown are the ***mean values in the different orientations*** without shading of the façade compared to a rear-ventilated façade (fibre cement board, albedo: 0.45). Assumption wind: 1 m/s, values show ***a "favourable" and "unfavourable" wind*** direction.

图中显示的是不同朝向、无遮阳外墙与后通风外墙（水泥纤维板，反照率：0.45）相比的平均值。假设风速：1 米/秒，数值显示 "有利 "和 "不利 "风向



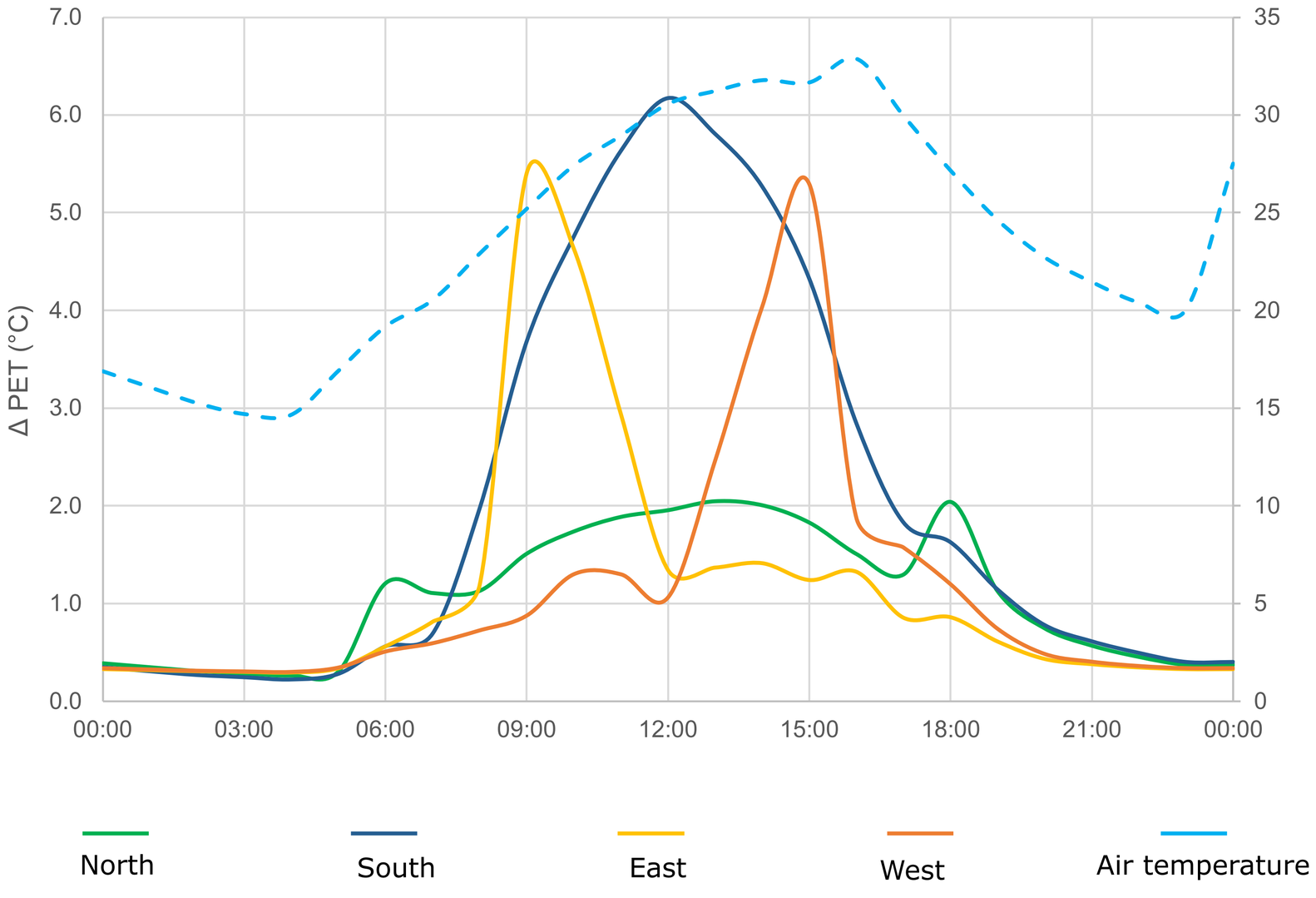
PET at a distance of 1 m from the façade (day)

Quantitative aspects

District climate modelling

定量方面 – 地区气候建模

PET difference compared to the reference façade



Diurnal course of the PET difference of a ***wall-mounted greenery*** in comparison to the reference façade at a distance of ***1 m from the façade*** depending on the orientation (assumption wind: N→S of 1 m/s).

根据朝向（假设风速：N　S，1 m/s），在距离墙面 1 米处，墙面绿植与参考墙面的 PET 差值的昼夜变化情况

→ The ***cooling effect*** occurs in particular with ***direct solar radiation*** and can be higher or lower in the various ***orientations*** at certain ***times of day***.

→ Most effective on the ***south and west facades*** (highest air temperatures at these times of day).

降温效果在太阳直射时尤为明显，在一天中的某些时段，不同朝向的降温效果会有高有低。南面和西面的效果最好（这两个时间段的气温最高）

Quantitative aspects

District climate modelling

定量方面 – 地区气候建模

Difference in PET temperature between the ***wall-mounted greenery*** and the ***reference façade*** at ***different day times***.

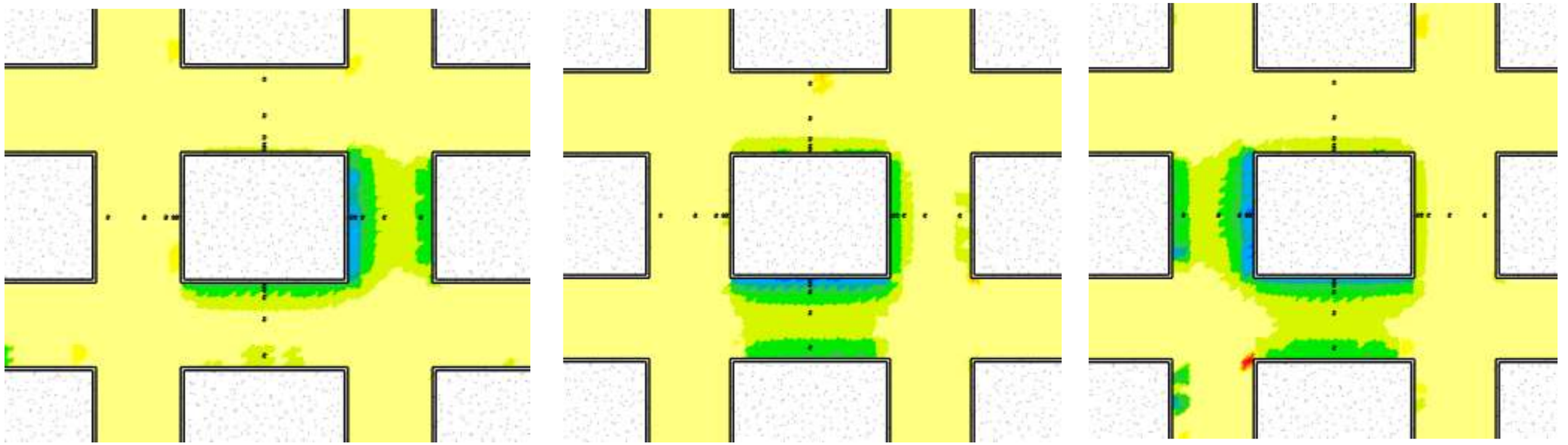
Assumptions: direct sunlight on the façade (without shading), no wind.

在不同的白天时间，墙面绿化与参考外墙之间的 PET 温度差。假设：阳光直射外墙（无遮挡），无风

9:00 am

12:00 am

3:00 pm



approx. 12 m distance between the buildings

→ The cooling effect is greatest **directly on the façade** and decreases with increasing distance

冷却效果直接作用于建筑物外立面最大，随着距离的增加而减弱

Quantitative aspects

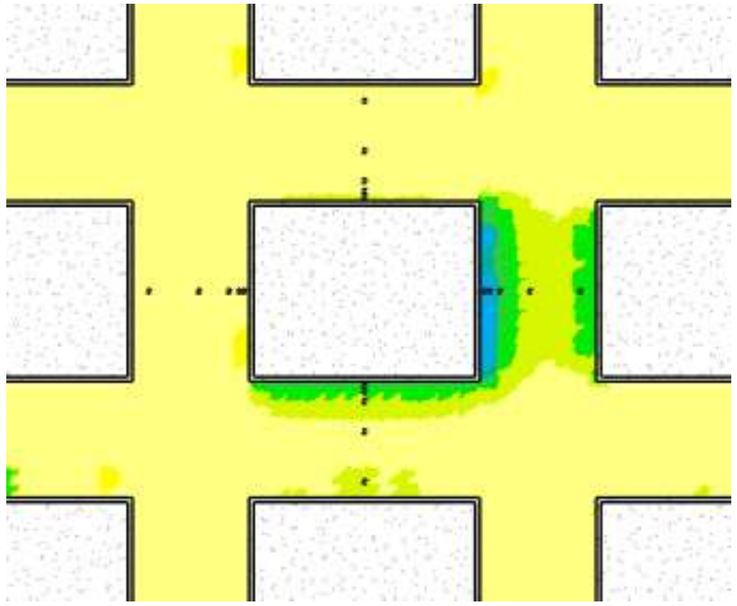
District climate modelling

定量方面 – 地区气候建模

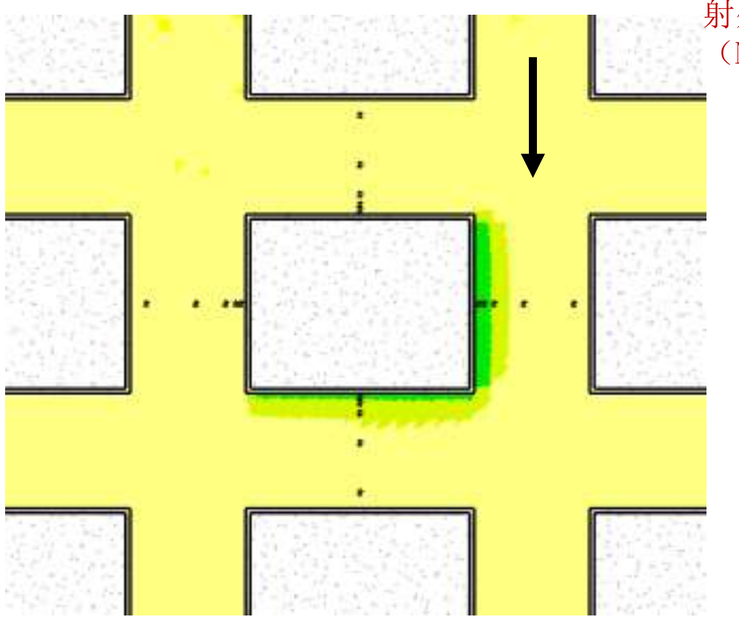
Difference in PET temperature between the wall-mounted greenery and the reference façade at 9:00 am.

Assumptions: direct solar radiation on the façade (without shading), ***with and without wind*** (N→ S, 1m/s).

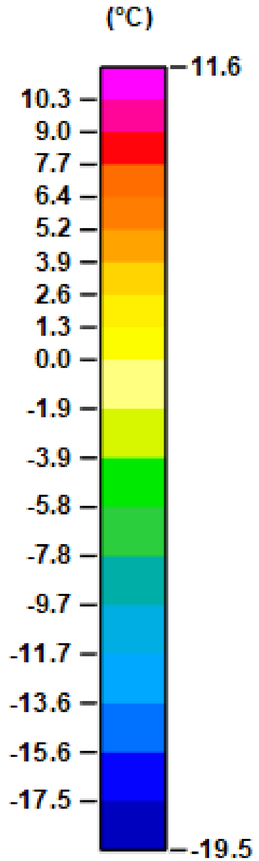
9:00 am, without wind



9:00 am, with light wind



上午 9:00 时，墙面绿化与参考外墙之间的 PET 温度差。假设：太阳直射外墙（无遮阳），有风和无风（N　S，1m/s）



→ ***Wind*** can influence / reduce the effect of façade greening. 风会影响/降低外墙绿化的效果

The basics in a nutshell

基础知识简述

- ***PV*** is preferable on surfaces with high electricity generation potential, i.e. on south, east and west-facing surfaces without shading → *rural*

  农村地区：光伏发电设备最好安装在发电潜力大的地面上，即朝南、朝东和朝西且无遮挡的地面上

- ***Greening*** is generally preferable in areas that are close to people and therefore add value to the quality of stay and wind protection is provided! → *urban*

  城市：绿化最好在靠近居民的地方进行，这样可以提高居民的居住质量，并提供防风保护

- The ***decision*** depends on many factors:

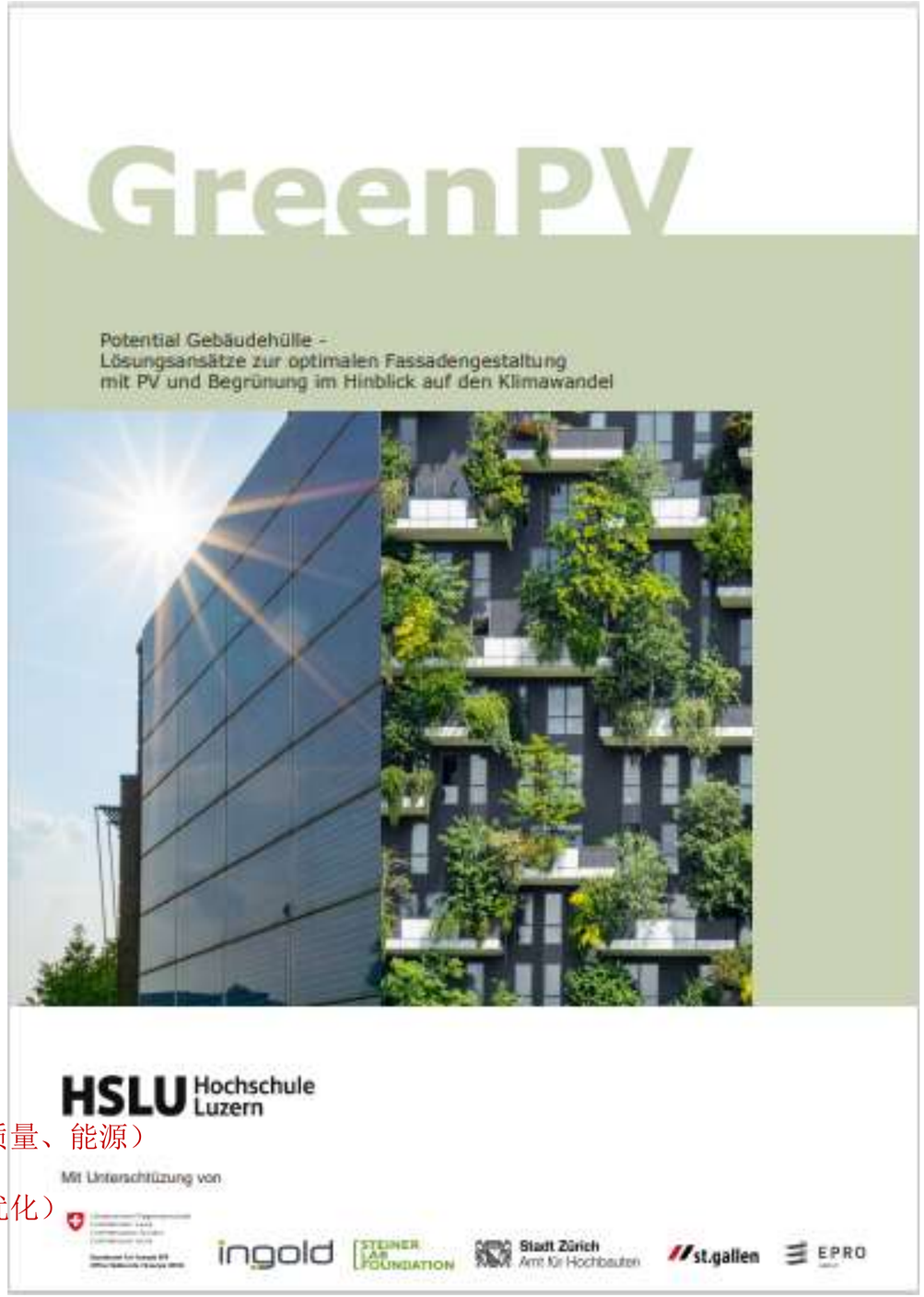
  决定取决于许多因素：

  - ***Local needs*** (noise, climate, biodiversity, air quality, energy...)
  - ***Weighting*** between the relevant (qualitative / quantitative) aspects
  - ***Orientation, shading, floor-by-floor and seasonal analysis*** (energetic and qualitative optimisation)
  - ***System boundary*** of the consideration (socio-economic balancing)

- The ***combination of systems*** can make sense both economically and ecologically.

  各种系统的结合在经济和生态方面合理

  当地需求（噪音、气候、生物多样性、空气质量、能源）相关（定性/定量）方面的权重
  朝向、遮阳、逐层和季节分析（能量和质量优化）
  考虑的系统边界（社会经济平衡）



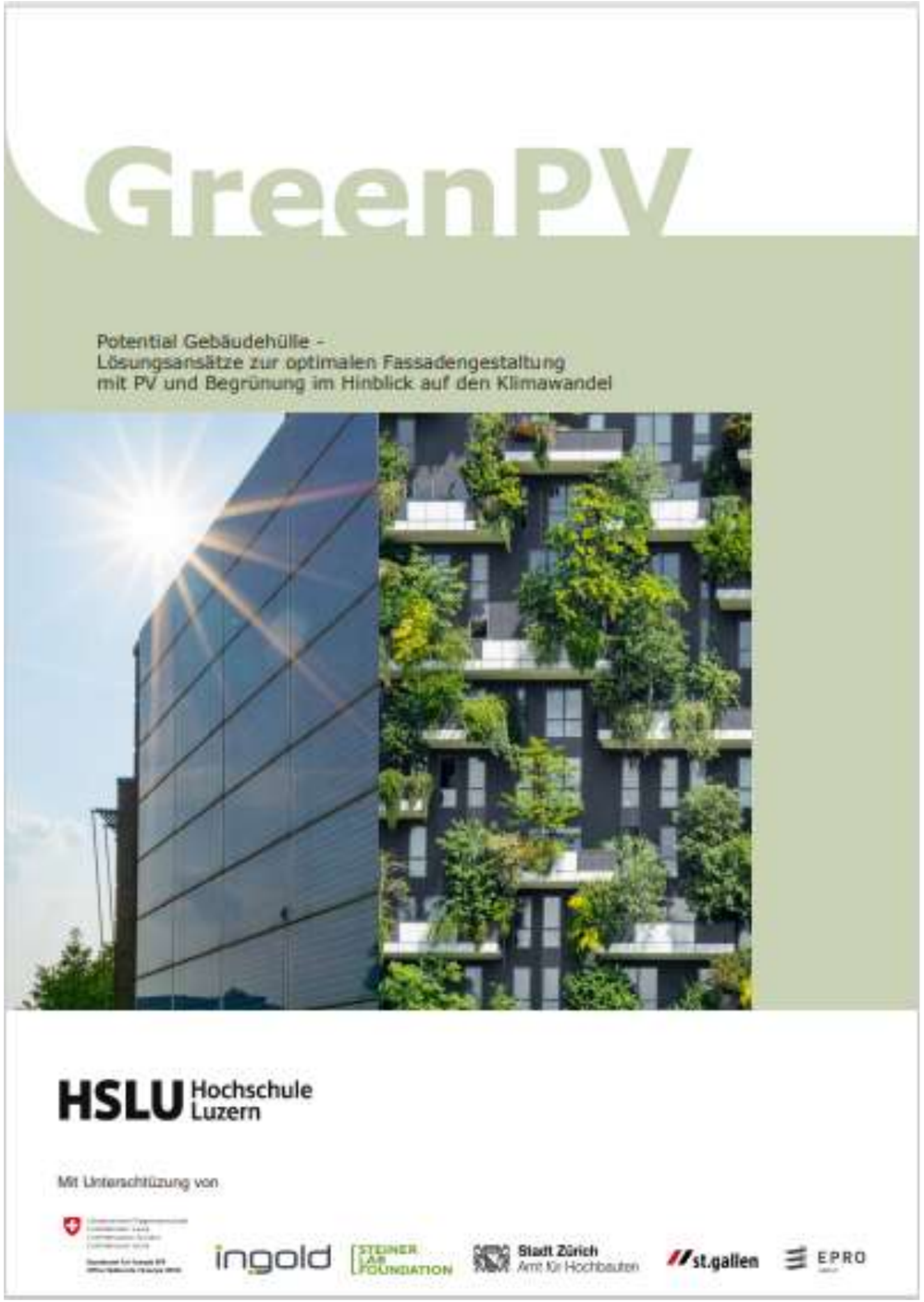
→ Challenges

挑战

- **Fire protection**
  no clear regulations for PV and greening
  no planning certainty
  消防
  没有明确的光伏和绿化规定，没有规划确定性

- **Care and maintenance**
  Initial costs, maintenance
  Effort (organisation, time)
  维护和保养初始成本、维护费用（组织、时间）

- **Lack of know-how**
  Architecture, Technology, Implementation
  缺乏技术诀窍架构、技术、实施



→ **Challenges** Fire protecton 挑战 → 消防

FIRE
GOOD-
of green and PV façades
PRACTICE

RULES AND REGULATIONS

In Switzerland, fire protection is **regulated** on a **cantonal basis.** 19 cantons have the **VKF** as their umbrella organisation. Fire protection regulations and application examples with state-of-the-art papers are published by the VKF. There is currently **no separate set of regulations** for green and PV façades.

Fig. 14 Hunzikerplatz in Zurich. The greening of the façade is interrupted in regular sections so that the spread of fire across the entire façade is prevented. (© SGG photography)

Fire protection requirements increase with the **height of the building**. Figure 2 provides an overview of how buildings are classified according to VKF and what requirements are imposed.
The building façade has to meet certain requirements.

Fig. 15 Different requirements are placed on fire protection depending on the height of the building. According to VKF, a distinction is made between buildings of low height (up to 11m), medium height (up to 30m) and high-rise buildings (over 30m).

- **High-rise buildings:** Building materials of reaction to fire group RF1 are to be used. Concepts must be discussed with the fire protection authorities.
- Buildings of **medium height:** Materials of reaction to fire group RF2 are to be used. The façade must be accessible to the fire brigade. The fire must be limited to two storeys above the source of the fire.
- **Buildings of low height:** Building materials of reaction to fire group RF3 may be used.

- **Structural measures.** These include protective distances between buildings, bulkheads, material specifications, emergency exits or escape routes.
- **Technical measures.** These include fire alarm and fire extinguishing systems or safety lighting (systems that contribute to limitation in the event of fire).
- **Organisational measures.** These include controls and quality assurance of measures and facilities (maintenance of structural and technical facilities) or evacuation plans.
- **Defence measures** are used in the event of a fire. These include active and passive measures by the fire brigade (i.e. extinguishing work, evacuations, etc.).

GREEN FACADES: IMPORTANT ASPECTS

Through various tests on greened façades, e.g. by the City of Vienna (study "**Fire behaviour of green facades** in large-scale tests"), the following findings could be obtained:

- Practically no lateral fire expansion
- Vertical fire expansion due to short-time "Runaway ignition" possible
- Vertical fire propagation via wooden roots not observable
- Secondary fire hazard due to falling parts not given

rain. (© NODER "Begrünte Fassaden aus brandschutztechnischer Sicht", 2019).

Fig. 16 Dead plant remains increase the risk of fire and are to be removed regularly. (© gartenjournal.net)

Various factors play a role in the fire behaviour of greened façades:

Plant species

The flammability depends on the water content, the proportion of essential oils and whether the plant is deciduous.

According to a study by the City of Vienna, ivy burns the most because it contains highly flammable oils and its foliage does not shed, but a vital layer grows over it.

Maintenance and care

The thicker the green layer, the more dead plant material can be present on the façade, which worsens the fire behaviour. Fire protection can be ensured by regular maintenance and removal of dead plant material.

Substrate selection

The choice of a substrate made of mineral materials positively affects the fire behaviour.

→ **Challenges** Fire protecton 挑战 → 消防

FIRE PROTECTION MEASURES

Various protective measures can be taken to prevent the spread of fire over several floors:

- Minimum distance of planting 1 m from wall / roof flashing
- Horizontal fire bars with a projection of 20 cm (greenery must not grow beyond this).
- Wall-bound systems: continuous fire bars between floors (Fig. 17, left)
- Floor-bound systems: Fire bars can be restricted to the window lintels (Fig. 17, right)

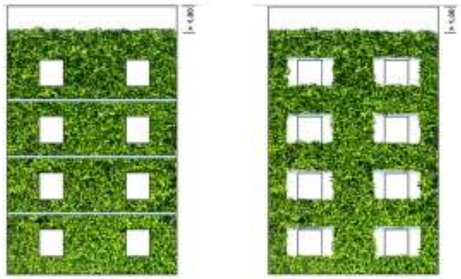


Fig. 17 Horizontal fire bars (left) and fire bars restricted to windows (right). (© Bachmeier "Brandschutz großflächig begrünter Fassaden", 2020)

The use of façade greening restricted by fire protection, e.g. in escape routes such as arcades, should also be reviewed.

Fig. 18 Alternative protective measures to fire barriers. (© Bachmeier "Brandschutz großflächig begrünter Fassaden", 2020)

- Non-planted façade sections of the height of a full storey (Fig. 18, top left)
- Sections of façade not planted around openings in the façade (Fig. 18, top right)
- Strip-like planting of the façade with 0.5 m distance to the openings (Fig. 18, bottom left)
- Cassette type planting (Fig. 18, bottom right)

PV FACADES: IMPORTANT ASPECTS & FIRE PROTECTION MEASURES

PV modules can be assigned to **reaction to fire group** RF218. Thus, there are no special restrictions for **low-rise buildings** (Fig. 15). For all other building categories, appropriate measures must be implemented.

For **buildings of medium height,** PV modules achieve the requirements for the building materials to be used (RF2). However, additional measures must be taken to limit the fire to two storeys above the source of the fire (according to VKF, Fig. 15). In order to prevent the vertical transmission of fire, the **façade** must **be divided into corresponding fire compartments.** This can be done, for example, by using metal profiles or ventilated cavity partitions (Fig. 19).

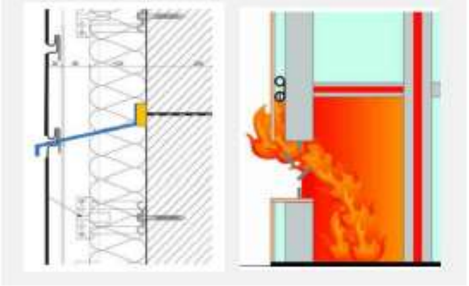


Fig. 19 Structural measures to prevent the vertical spread of fire in case of fire: Metal profiles (left) or ventilated cavity partitions (right).
(© Solarwall, Pierre-Olivier Cuche)

Fig. 20 PV façades can also be used on buildings < 30 m. Object-specific solutions must be developed in cooperation with experts.
(© Malley Phare CCHE, Prilly/Lausanne)

According to the VKF, building materials of fire resistance group RF1 must be used in **high-rise buildings** (Fig. 15). Standard modules (RF2) do not meet this requirement, but **glass-glass modules19 ,** for example, can be used alternatively, which meet the highest safety requirements in case of fire. There are various solutions to guarantee safety in case of fire, to ensure the fire resistance of the exterior wall and to reduce fire loads. In order to **develop a fire protection concept, it** is recommended to involve **experts in the** early planning phase in order to work out a project-specific solution together.

18 Pierre-Olivier Cuche, lecture "Fire protection for PV facades", 17.11.2022
19 energy-experts.org

Discussion…

讨论

Examples
→ Actuality…

案例

在 Schwamendingen 的 Luchswiese 项目（Aita Flury，2022 年）的竞赛设计中，绿色外墙与建筑设计开发的阳台框架融为一体，覆盖下四层，而光伏板则以最佳的朝向和角度安装在阳光充足的上层

In the ***competition design*** for the Luchswiese in Schwamendingen (Aita Flury, 2022), a ***green façade*** is integrated into the architecturally developed balcony framework ***over the lower four storeys*** and ***PV panels*** are integrated into the ***upper, well-sunned storeys*** at an optimal orientation and angle.

Discussion items 讨论

- ***GreenPV in China?***
  Reasonable
  Challenges
  Potential of combination
  …

绿色光伏在中国？
合理性
挑战性
结合潜力

- ***Areas / buildings / people***
  who is responsible for what?

谁负责哪些区域/建筑/人员？

- …

HSLU Lucerne University of Applied Sciences and Arts

Thank you!

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