

Supporting Information for

Unlocking Rooftop Potential for Sustainable Cities: A Systematic Review

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Contents

1. Methods for estimating rooftop resources

1.1 Methods for estimating rooftop stock in sub-regions

1.2 Methods for evaluating the distribution of rooftops in different climate zones

1.3 Methods for evaluating the distribution of rooftops in different LCZs

2. The stock and distribution of rooftop resources

Table S4 The distribution of rooftops in different climate zones

Table S5 The distribution of rooftops in different LCZs

3. List of articles and cases

Table S6 List of reviewed articles

Table S7 Rooftop area in different regions

Table S8 UHI mitigation potential of green roofs

Table S9 Energy saving potential of green roofs

Table S10 Stormwater reduction potential of green roofs

Table S11 UHI mitigation potential of white roofs

Table S12 Energy saving potential of white roofs

Table S13 Energy supply potential of solar roofs

Table S14 UHI mitigation potential of solar roofs

Table S15 Stormwater reduction potential of blue roofs

Table S16 Water saving potential of blue roofs

Table S17 Energy supply potential of wind turbine roofs

Table S18 The investment payback period of rooftop engineering

Table S19 The carbon payback period of rooftop engineering

4. References

1 Methods for estimating rooftop resources

1.1 Methods for estimating rooftop stock in sub-regions

Roof stock data for each sub-region was obtained by averaging the roof stock from different studies.

$$RTS_i = \frac{\sum_k RTS_{ik}}{k} \quad (1)$$

Where RTS_i represents the rooftop stock (billion m^2) in sub-regions i ; RTS_{ik} represents the rooftop stock value of case k in sub-regions i .

1.2 Methods for evaluating climatic characteristics of rooftop resources

We divided the global climate into eleven major categories (**Table S1**) and estimated the area of rooftops distributed in various climatic zones within different sub-regions.

Table S1 Classification of climate zones

Climate zone	Temperature	Precipitation
Tundra	Cold climate throughout the year, with average annual temperatures below 0°C , and average temperatures in the hottest months above 0°C but still below 10°C .	Annual precipitation is all below 250 mm and most of the precipitation is snow.
Subarctic	The average temperature in the coldest month of the year is below 0°C and above -38°C , and the average temperature in the hottest month is 10°C and above and below 22°C .	Total annual precipitation in the subarctic is fairly small, amounting to no more than 380 mm to 500 mm over the year.
Humid continental	The average temperature in the coldest month of the year is below 0°C and above -38°C , and the average temperature in the hottest month is 22°C and above.	Precipitation is relatively evenly distributed, slightly less in winter and slightly more in summer.
Highlands	The average temperature in the coldest month of the year is 0°C and above and below 18°C , and the average temperature in the hottest month is 10°C and above and below 22°C .	The amount of precipitation in the month with the highest precipitation in the summer half-year is ten times or more the amount of precipitation in the month with the lowest precipitation in the winter half-year.
Humid subtropical	The average temperature in the coldest month of the year is 0°C and above and below 18°C , and the average temperature in the hottest month is 22°C and above.	The amount of precipitation in the month with the highest precipitation in the summer half-year is ten times or more the amount of precipitation in the month with the lowest precipitation in the winter half-year.

Mediterranean	The average temperature in the coldest month of the year is 0°C and above and below 18°C, and the average temperature in the hottest month is 22°C and above.	The amount of precipitation in the month with the highest precipitation in the winter half-year is three times or more the amount of precipitation in the month with the lowest precipitation in the summer half-year.
Marine	The average temperature in the coldest month of the year is 0°C and above and below 18°C, the average temperature in the hottest month is 10°C and above and below 22°C.	Precipitation is more evenly distributed among the months of the year.
Semi-arid	The average annual temperature is above 18°C and the average temperature of the coldest month is below 18°C.	Annual precipitation (mm) is higher than 50 percent of the drought indicator value.
Arid	The average annual temperature is above 18°C and the average temperature of the coldest month is below 18°C.	Annual precipitation (mm) is lower than 50 percent of the drought indicator value.
Tropical dry	Monthly average temperatures above 18°C throughout the year.	With distinct dry and wet seasons.
Tropical wet	Monthly average temperatures above 18°C throughout the year.	Average monthly precipitation is above 60mm throughout the year.

The area of rooftops distributed in various climatic zones within different sub-regions is estimated by equation (1):

$$RTS_{climate_{ij}} = \frac{RTC_{climate_{ij}}}{RTC_{climate_i}} * RTS_i \quad (1)$$

Where $RTS_{climate_{ij}}$ represents the rooftop stock (billion m²) in climate zone j within sub-regions i ; $RTC_{climate_{ij}}$ is the number of rooftops in climate zone j within sub-regions i ; $RTC_{climate_i}$ is the total number of rooftops in sub-region i ; RTS_i is the average rooftop stock (billion m²) of sub-regions i , which came from our reviewed articles.

In ArcGIS software, we inputted boundary lines of nine sub-regions, overlaid with climate zones classification data (<https://datacatalog.worldbank.org/search/dataset/0042325>) and Microsoft global building dataset (<https://minedbbuildings.blob.core.windows.net/global-buildings/buildings-coverage.geojson>), then can obtain the value of $RTC_{climate_i}$ and $RTC_{climate_{ij}}$.

However, because the information on China is lacking in the global building dataset, we denoted the number of rooftops in ESEA except China as $RTC_{climate_{ESEAexceptCHN}}$ and the number of rooftops in climate zone j within ESEA except Chian as $RTC_{climate_{ESEAexceptCHNj}}$. The ESEA data can be supplemented by equation (2-3):

$$RTC_climate_{ESEA} = RTC_climate_{CHN} + RTC_climate_{ESEAexceptCHN} \quad (2)$$

$$RTC_climate_{ESEAj} = RTC_climate_{CHNj} + RTC_climate_{ESEAexceptCHNj} \quad (3)$$

Where $RTC_climate_{CHN}$ is the number of rooftops in China, which can be estimated from the proportion of rooftop area in China and ESEA, according to equation (4); where $RTC_climate_{CHNj}$ is the number of rooftops in climate zone j within China, which can be estimated through equation (5):

$$RTC_climate_{CHN} = \frac{\frac{RTS_{CHN}}{RTS_{ESEA}} * RTC_climate_{ESEAexceptCHN}}{1 - \frac{RTS_{CHN}}{RTS_{ESEA}}} \quad (4)$$

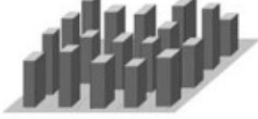

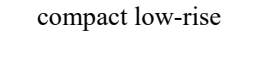
$$RTC_climate_{CHNj} = \frac{RTC_{CHNCTj}}{RTC_{CHNCT}} * RTC_climate_{CHN} \quad (5)$$





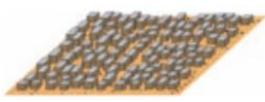



Where $RTC_climate_{CHNCTj}$ represents the number of rooftops located in climate zone j within some typical cities of China, $RTC_climate_{CHNCT}$ represents the total number of rooftops in some typical cities of China. These data can be obtained through overlay analysis in ArcGIS using the China Building Dataset from Nanjing Normal University (covering 90 cities across 5 climate zones) and vector data of climate zones.

1.3 Methods for evaluating architectural characteristics of rooftop resource

We divided the global building types into ten major categories (Table S2) and estimated the area of rooftops of each LCZ within different sub-regions.

Table S2 Classification of building types (Stewart and Oke 2012)

LCZ	Built types	Description
LCZ1	Compact high-rise 	A dense mix of tall buildings to tens of stories, Few or no trees, Land cover mostly paved. Concrete, steel, stone, and glass construction materials.
LCZ2	compact mid-rise 	A dense mix of midrise buildings (3-9 stories). Few or no trees. The land cover is mostly paved. Stone, brick, tile, and concrete construction materials.
LCZ3	compact low-rise 	A dense mix of low-rise buildings (1-3 stories). Few or no trees. The land cover is mostly paved. Stone. brick, tile. And concrete

		construction materials.
LCZ4	<p>open high-rise</p> 	An open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.
LCZ5	<p>open mid-rise</p> 	An open arrangement of midrise buildings (3-9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.
LCZ6	<p>open low-rise</p> 	An open arrangement of low-rise buildings (1-3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.
LCZ7	<p>lightweight low-rise</p> 	A dense mix of single-story buildings. Few or no trees. The land cover is mostly hard-packed. Lightweight construction materials (e.g. wood, thatch, corrugated metal).
LCZ8	<p>large low-rise</p> 	An open arrangement of large low-rise buildings (1-3 stories). Few or no trees. The land cover is mostly paved. Steel, concrete, metal, and stone construction materials.
LCZ9	<p>sparsely built</p> 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).
LCZ10	<p>heavy industry</p> 	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. The land cover is mostly paved or hard-packed. Metal, steel, and concrete construction materials.

The area of rooftops of each LCZ within different sub-regions is estimated by equation (6):

$$RTS_LCZ_{ik} = Average\left(\frac{\sum_{m_i} BTL_{m_i n}}{BLT_n}\right) * RTS_i \quad (6)$$

Where RTS_LCZ_{ik} represents the rooftop stock (billion m^2) in LCZ k within sub-regions i ; BLT_n is the total number of built landscape units in a typical city n ; $BTL_{m_i n}$ is the number of built landscape units m within a typical city n ; $\sum_{m_i} BTL_{m_i n}$ is the number of rooftops in a typical city n that belong to LCZ i , the correspondence between LCZ and built landscape type is shown in **Table**

S3.

Table S3 The correspondence between LCZ and built landscape types

LCZ	Built landscape types (Wheeler 2015)
LCZ1	apartment blocks, quasi grid, superblocs
LCZ2	incremental mixed, long blocks
LCZ3	degenerate grid, hillside, land of the dead
LCZ4	urban grid
LCZ5	garden apartments
LCZ6	allotment gardens, country roads, garden suburbs, upscale enclave
LCZ7	trail
LCZ8	malls and boxes, workplace boxes, airports, campus, civic, commercial strip
LCZ9	rural
LCZ10	heavy industry

2 The stock and distribution of rooftop resources

Table S4 The distribution of rooftops in different climate zones (billion m²)

	Arid	Highlands	Humid Continental	Humid Subtropical	Marine	Mediterranean	Semi-arid	Subarctic	Tropical Dry	Tropical Wet	Tundra
ESEA	0.87	3.84	14.01	23.69	0.00	0.00	6.10	0.00	4.21	9.83	0.00
EUR	0.00	0.41	11.09	1.93	15.97	4.53	1.19	0.60	0.00	0.01	0.03
CAUS	0.96	0.48	14.68	10.15	1.19	2.85	2.45	0.96	0.11	0.00	0.00
SOA	0.00	0.22	0.00	11.83	0.00	0.77	11.47	0.00	3.71	3.00	0.00
LAM	0.00	2.70	0.00	4.41	0.81	0.59	2.81	0.00	5.74	3.44	0.00
OCE	0.00	0.00	0.00	5.78	9.00	3.88	1.26	0.00	0.07	0.18	0.00
SSA	0.23	1.21	0.00	0.45	1.70	0.14	2.44	0.00	6.79	2.23	0.00
MENA	0.00	0.22	0.00	0.15	0.00	6.54	6.34	0.00	0.00	0.00	0.00
RFCA	0.00	0.44	7.61	0.00	0.00	0.00	4.76	0.35	0.00	0.00	0.01

Table S5 The distribution of rooftops in different LCZs (billion m²)

	LCZ1	LCZ2	LCZ3	LCZ4	LCZ5	LCZ6	LCZ7	LCZ8	LCZ9	LCZ10
ESEA	15.45	5.47	17.45	0.84	2.52	1.67	0.00	14.89	0.28	4.00
EUR	3.80	3.73	3.87	0.28	4.63	9.26	0.01	5.87	2.71	1.61
CAUS	3.60	3.53	3.66	0.26	4.38	8.77	0.01	5.56	2.57	1.53

SOA	1.27	2.05	20.02	0.03	1.53	0.98	0.00	3.54	1.01	0.58
LAM	1.99	1.65	8.21	0.59	4.10	1.20	0.00	1.57	0.39	0.81
OCE	0.11	0.13	6.73	0.05	2.00	5.19	0.00	1.97	3.62	0.36
SSA	0.18	1.74	6.46	0.07	0.63	3.13	0.00	1.27	1.39	0.32
MENA	0.80	1.11	3.47	0.09	2.14	2.39	0.00	2.24	0.01	1.00
RFCA	2.81	0.86	4.68	0.03	0.44	1.78	0.00	1.49	0.07	1.02

3 List of articles and cases

Table S6 List of reviewed articles

No.	Fist Author	PY	Title
1	Elena Cristiano	2023	How much green roofs and rainwater harvesting systems can contribute to urban flood mitigation?
2	Silvia Di Turi	2023	Towards the objective of Net ZEB: Detailed energy analysis and cost assessment for new office buildings in Italy
3	Sajith Wijesuriya	2022	Potential energy savings benefits and limitations of radiative cooling coatings for US residential buildings
4	Salem Algarni	2022	Investigating the performance of energy management in office buildings by using a suitable green roof design to reduce the building's energy consumption
5	Cian Twohig	2022	Can green roofs help with stormwater floods? A geospatial planning approach
6	Peng Wang	2022	An integrated technical, economic, and environmental framework for evaluating the rooftop photovoltaic potential of old residential buildings
7	Jin Zuo	2022	Quantitative valuation of green roofs? cooling effects under different urban spatial forms in high-density urban areas
8	Xiaoran Fu	2022	Community Scale Assessment of the Effectiveness of Designed Discharge Routes from Building Roofs for Stormwater Reduction
9	Hasan Nasrallah	2022	Lebanon Solar Rooftop Potential Assessment Using Buildings Segmentation From Aerial Images
10	Muhammad Talut	2022	Solar Power Potential from Industrial Buildings and Impact on Electricity Supply in Bangladesh
11	A. Vallejo-Diaz	2022	Wind energy potential assessment of selected locations at two major cities in the Dominican Republic, toward energy matrix decarbonization, with resilience approach

12	Changping Liu	2022	A comprehensive study of the potential and applicability of photovoltaic systems for zero carbon buildings in Hainan Province, China
13	Lijian Sun	2022	Potential estimation of rooftop photovoltaic with the spatialization of energy self-sufficiency in urban areas
14	Mohan Rawat	2022	Techno-economic analysis of cool roof materials in a composite climatic zone
15	Ying-Chu Chen	2022	Increasing water retention capacity via Grey roof to green roof transformation
16	Zihao Li	2022	A comprehensive life cycle assessment study of innovative bifacial photovoltaic applied on building
17	Wen Liu	2022	Identifying city-scale potential and priority areas for retrofitting green roofs and assessing their runoff reduction effectiveness in urban functional zones
18	Enrique Fuster-Palop	2021	Innovative regression-based methodology to assess the techno-economic performance of photovoltaic installations in urban areas
19	Helen L. Macintyre	2021	Comparing temperature-related mortality impacts of cool roofs in winter and summer in a highly urbanized European region for present and future climate
20	Joan Gilabert	2021	Abating heat waves in a coastal Mediterranean city: What can cool roofs and vegetation contribute?
21	Seongeun Jeong	2021	Modeling potential air temperature reductions yielded by cool roofs and urban irrigation in the Kansas City Metropolitan Area
22	Michael Blackhurst	2020	Empirically Modeling the Energy Implications of Cool Roof Retrofits
23	Ying Yang	2020	Potential analysis of roof-mounted solar photovoltaics in Sweden
24	Barry H. Lynn	2020	The impact of cool and green roofs on summertime temperatures in the cities of Jerusalem and Tel Aviv
25	Yasin Movahed	2021	Investigation of single-storey residential green roof contribution to buildings energy demand reduction in different climate zones of Iran
26	Cheng He	2020	Potential impacts of cool and green roofs on temperature-related mortality in the Greater Boston region

27	Ashley M. Broadbent	2020	Efficacy of cool roofs at reducing pedestrian-level air temperature during projected 21st century heatwaves in Atlanta, Detroit, and Phoenix (USA)
28	Jing Dong	2020	Quantitative study on the cooling effect of green roofs in a high-density urban Area-A case study of Xiamen, China
29	Hongying Zhao	2019	Effects of design parameters on rooftop photovoltaic economics in the urban environment: a case study in Melbourne, Australia
30	H. L. Macintyre	2019	Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city
31	M. Asif	2019	Techno-economic assessment of application of solar PV in building sector A case study from Saudi Arabia
32	Demin Zhou	2019	Assessing the hydrological behaviour of large-scale potential green roofs retrofitting scenarios in Beijing
33	Ammar H. A. Dehwah	2019	Assessment of net energy contribution to buildings by rooftop photovoltaic systems in hot-humid climates
34	H. M. Imran	2018	Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia
35	Takanori Kuronuma	2018	CO2 Payoff of Extensive Green Roofs with Different Vegetation Species
36	Mohammad Zobair Ibne Bashar	2018	Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh
37	M. J. Sorgato	2018	Technical and economic evaluation of thin-film CdTe building-integrated photovoltaics (BIPV) replacing facade and rooftop materials in office buildings in a warm and sunny climate
38	Maja Zuvella-Aloise	2018	Modelling reduction of urban heat load in Vienna by modifying surface properties of roofs
39	Robert Margolis	2017	Using GIS-based methods and lidar data to estimate rooftop solar technical potential in US cities
40	Laura Romero Rodriguez	2017	Assessment of the photovoltaic potential at urban level based on 3D city models: A case study and new methodological approach

41	P. Vahmani	2016	Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California
42	Pablo Campos	2016	Potential of distributed photovoltaics in urban Chile
43	Jiachen Zhang	2016	Revisiting the climate impacts of cool roofs around the globe using an Earth system model
44	A. Sharma	2016	Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model
45	Umberto Berardi	2016	The outdoor microclimate benefits and energy saving resulting from green roofs retrofits
46	Andreas Molin	2016	Assessing a regional building applied PV potential - Spatial and dynamic analysis of supply and load matching
47	Pierre-Antoine Versini	2016	Use of green roofs to solve storm water issues at the basin scale - Study in the Hauts-de-Seine County (France)
48	B. R. Karthikeya	2016	Wind resource assessment for urban renewable energy application in Singapore
49	Meichun Cao	2015	Cool Roofs in Guangzhou, China: Outdoor Air Temperature Reductions during Heat Waves and Typical Summer Conditions
50	Chr Lamnatou	2015	Evaluation of photovoltaic-green and other roofing systems by means of ReCiPe and multiple life cycle-based environmental indicators
51	Antonio Gagliano	2015	A multi-criteria methodology for comparing the energy and environmental behavior of cool, green and traditional roofs
52	Amir Hossein Refahi	2015	Investigating the effective factors on the reduction of energy consumption in residential buildings with green roofs
53	Rhythm Singh	2015	Estimation of rooftop solar photovoltaic potential of a city
54	Dan Li	2014	The effectiveness of cool and green roofs as urban heat island mitigation strategies
55	Haider Taha	2013	The potential for air-temperature impact from large-scale deployment of solar photovoltaic arrays in urban areas

56	Issa Jaffal	2012	A comprehensive study of the impact of green roofs on building energy performance
57	Aneta Strzalka	2012	Large scale integration of photovoltaics in cities
58	J. H. Jo	2010	An integrated empirical and modeling methodology for analyzing solar reflective roof technologies on commercial buildings
59	Nalanie Mithraratne	2009	Roof-top wind turbines for microgeneration in urban houses in New Zealand
60	Cynthia Rosenzweig	2009	MITIGATING NEW YORK CITY'S HEAT ISLAND Integrating Stakeholder Perspectives and Scientific Evaluation
61	Corrie Clark	2008	Green roof valuation: A probabilistic economic analysis of environmental benefits
62	Jeroen Mentens	2006	Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?
63	NH Wong	2003	The effects of rooftop garden on energy consumption of a commercial building in Singapore
64	Nida Chaimoon	2013	The Observation of Rainwater Harvesting Potential in Mahasarakham University (Khamriang Campus)
65	Narges Jalili Kolavani	2019	Technical feasibility analysis of rainwater harvesting system implementation for domestic use
66	Xuan Cuong Nguyen	2021	Status of water use and potential of rainwater harvesting for replacing centralized supply system in remote mountainous areas: a case study
67	Deniz Yildirim	2021	Rooftop photovoltaic potential in Istanbul: Calculations based on LiDAR data, measurements and verifications
68	L.K. Wiginton	2010	Quantifying rooftop solar photovoltaic potential for regional renewable energy policy
69	Dev Millstein	2018	Preparatory meteorological modeling and theoretical analysis for a neighborhood-scale cool roof demonstration
70	MOTASEM N. SAIDAN	2015	Potential Rainwater Harvesting: An Adaptation Measure for Urban Areas in Jordan
71	Samuel M. Nthuni	2014	Modelling the potential of rainwater harvesting in western Kenya using remote sensing and GIS techniques
72	Dan Assouline	2018	Large-scale rooftop solar photovoltaic technical potential estimation using Random Forests

73	Marija D. LALOŠEVIĆ	2018	GREEN ROOFS AND COOL MATERIALS AS RETROFITTING STRATEGIES FOR URBAN HEAT ISLAND MITIGATION Case Study in Belgrade, Serbia
74	Yin M. Naing	2017	Green Roof Retrofitting: Assessment of the Potential for Academic Campus
75	Fariborz Mansouri Kouhestani	2019	Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada
76	Alexandra L. E. Litofsky	2014	Evaluating Rain Barrel Storm Water Management Effectiveness across Climatology Zones of the United States
77	Lado Kurdgelashvili	2016	Estimating technical potential for rooftop photovoltaics in California, Arizona and New Jersey
78	Pieter Gagnon	2018	Estimating rooftop solar technical potential across the US using a combination of GIS-based methods, lidar data, and statistical modeling
79	Alina Walch	2020	Big data mining for the estimation of hourly rooftop photovoltaic potential and its uncertainty
80	Tripti Mishra	2020	Assessment of solar power potential in a hill state of India using remote sensing and Geographic Information System
81	Antonio Gagliano	2013	Assessment of micro-wind turbines performance in the urban environments: an aided methodology through geographical information systems
82	Abdolrahim Rezaeiha	2020	A framework for preliminary large-scale urban wind energy potential assessment: Roof-mounted wind turbines
83	Caleb Phillips	2019	A data mining approach to estimating rooftop photovoltaic potential in the US
84	Jung Eun Kim	2021	Optimal storage sizing for indoor arena rainwater harvesting: Hydraulic simulation and economic assessment
85	Mohammed Almutairi	2017	Residential Wind Turbine Design Decision Support System
86	A. Ávila-Hernández	2020	Test box experiment and simulations of a green-roof: Thermal and energy performance of a residential building standard for Mexico
87	Amir Mahdiyar	2019	A probabilistic financial feasibility study on green roof installation from the private and social perspectives

88	Riccardo Battisti	2003	Evaluation of technical improvements of photovoltaic systems through life cycle assessment methodology
89	Siddharth Joshi	2021	High resolution global spatiotemporal assessment of rooftop solar photovoltaics potential for renewable electricity generation
90	Thomas Esch	2022	World Settlement Footprint 3D - A first three-dimensional survey of the global building stock
91	Gergely Molnár	2022	Estimating the global technical potential of building-integrated solar energy production using a high-resolution geospatial model
92	Mengmeng Li	2022	Global maps of 3D built-up patterns for urban morphological analysis
93	Sebastiaan Deetman	2020	Modelling global material stocks and flows for residential and service sector buildings towards 2050
94	Nikola Milojevic-Dupont	2023	EUBUCCO v0.1: European building stock characteristics in a common and open database for 200+ million individual buildings
95	Sylvia Marinova	2020	Global construction materials database and stock analysis of residential buildings between 1970-2050
96	Robert Margolis	2017	Using GIS-based methods and lidar data to estimate rooftop solar technical potential in US cities
97	Mengmeng Li	2020	Continental-scale mapping and analysis of 3D building structure

Table S7 Rooftop area in different regions

Study area	Rooftop area (billion m ²)	Ref.	Average rooftop area (billion m ²)
world	193.9	Joshi et al., 2021	245
	220.0	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
	264.0	Li et al., 2022	
	291.6	Esch et al., 2022	

CAUS	36	Li et al., 2022	33.85
	31.7	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
LAM	24	Li et al., 2022	20.5
	27	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
	10.5	Sebastiaan Deetman et al., 2020	
RFCA	13	Li et al., 2022	13.17
	13	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
	13.5	Sebastiaan Deetman et al., 2020	
ESEA	54.1	Joshi et al., 2021	62.55
	71	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
OCE	37	Li et al., 2022	20.15
	3.3	Esch et al., 2022	
SSA	23	Li et al., 2022	15.2
	7.4	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
MENA	13	Li et al., 2022	13.25
	13.5	Molnár, Ürge-Vorsatz and Chatterjee, 2022	
SOA	31	Li et al., 2022	31
EUR	19.5	Molnár, Ürge-Vorsatz and Chatterjee, 2022	35.76
	28.2	Sebastiaan Deetman et al., 2020	

	30.1	Milojevic-Dupont et al., 2023	
	39	Li et al., 2022	
	62	Esch et al., 2022	
China	35.2	Joshi et al., 2021	43.2
	46	Li et al., 2022	
	48.5	Sebastiaan Deetman et al., 2020	

Table S8 UHI mitigation potential of green roofs

Study area	UR	Plant conditions	Summer temperature (°C)	Temperature reduction (°C)	Ref.
ESEA-Chengdu	100%	extensive	25	0.43°C	Zuo et al. 2022
ESEA-Xiamen	100%	extensive	28	0.91°C	Dong et al. 2020
CAUS-Chicago	25%	extensive	25	0.15°C	Sharma et al. 2016
CAUS-Chicago	100%	extensive	25	0.58°C	Sharma et al. 2016
CAUS-Baltimore and Washington	90%	extensive	28	0.5°C	Li, Bou-Zeid, and Oppenheimer 2014
CAUS-Greater Boston and New England	80%	extensive	22	0.35°C	He et al. 2020
CAUS-NewYork	100%	extensive	25	0.4°C on average	Rosenzweig et al. 2009
OCE-Melborune	50%	extensive	25	0.6°C	H.M. Imran et al. 2018

OCE-Melbourne	100%	extensive	25	1.5°C	H.M. Imran et al. 2018
EUR-Vienna	45%	extensive	22	0.1°C	Žuvela-Aloise et al. 2018
EUR-Serbia	100%	extensive	24	0.47°C at max	Lalosevic et al. 2018
EUR-Serbia	100%	intensive	24	1.51°C at max	Lalosevic et al. 2018

Table S9 Energy saving potential of green roofs

Study area	UR	Plant conditions	Annual temperature (°C)	Energy saving (%)	Ref.
MENA	\	extensive	30	3.60%	Algarni, Almutairi, and Alqahtani 2022
MENA-Tehran	100%	extensive	19	6.19%	Yasin Movahed et al. 2020
MENA-Tabriz	100%	extensive	16	2.07%	Yasin Movahed et al. 2020
MENA-Bandar Abbas	100%	extensive	32	9.45%	Yasin Movahed et al. 2020
MENA-Bandar Abbas	\	extensive	32	8.50%	Refahi and Hossein Talkhabi 2015
MENA-Isfahan	\	extensive	33	9.20%	Refahi and Hossein Talkhabi 2015
MENA-Tabriz	\	extensive	28	6.60%	Refahi and Hossein Talkhabi 2015
CAUS-Toronto	100%	semi-extensive	10	3.00%	Berardi 2016
EUR-France	\	extensive	15	6.00%	Jaffal, Ouldboukhite, and Belarbi 2012
ESEA-Thailand	\	extensive	33	2.00%	Naing, Nitivattananon, and Shipin 2017
ESEA-Singapore	100%	extensive	31	1%-3%	Wong et al. 2003

Table S10 Stormwater reduction potential of green roofs

Study area	UR	Plant conditions	Precipitation (mm)	Stormwater reduction (%)	Ref.
EUR-London	100%	extensive	584	0.79%	Cristiano et al. 2023
EUR-Cagliari	100%	extensive	510	1.88%	Cristiano et al. 2023
EUR-Helsinki	25%	extensive	686	1.00%	Twohig, Casali, and Aydin 2022
EUR-Helsinki	60%	extensive	686	13.00%	Twohig, Casali, and Aydin 2022
EUR-France	100%	extensive	600	6.00%	Versini et al. 2016
EUR-Germany	10%	extensive	800	2.70%	Mentens, Raes, and Hermy 2006
CAUS-Waterloo	100%	extensive	950	1.60%	Cristiano et al. 2023
CAUS-Montreal	100%	extensive	1050	5.00%	Cristiano et al. 2023
CAUS-Vancouver	100%	extensive	1150	0.86%	Cristiano et al. 2023
CAUS-Airdrie	100%	extensive	406	6.51%	Cristiano et al. 2023
ESEA-Beijing	100%	extensive	600	13.9-17.3%	Fu et al. 2022
ESEA-Beijing	10%	extensive	600	1.34-2.73%	Liu et al. 2022
ESEA-Beijing	100%	extensive	600	9.17-19.05%	Liu et al. 2022
ESEA-Taipei	10-24%	extensive	2000	16.10%	Chen, Chen, and Chen 2022
ESEA-Beijing	19.60%	extensive	600	6.13-9.38%	Zhou et al. 2019
LAM-PortAuPrince	100%	extensive	1600	1.56%	Cristiano et al. 2023

OCE-Auckland	100%	extensive	1300	0.78%	Cristiano et al. 2023
OCE-Wellington	100%	extensive	1400	0.63%	Cristiano et al. 2023

Table S11 UHI mitigation potential of white roofs

Study area	UR	Albedo	Summer temperature (°C)	Temperature reduction (°C)	Ref.
CAUS-Baltimore and Washington	95%	0.7	26	0.5°C	Li, Bou-Zeid, and Oppenheimer 2014
CAUS-Atlanta	100%	0.88	28	0.38°C on average in daytime	Broadbent, Krayenhoff, and Georgescu 2020
CAUS-Detroit	100%	0.88	24	0.42°C on average in daytime	Broadbent, Krayenhoff, and Georgescu 2020
CAUS-Phoenix	100%	0.88	37	0.66°C on average in daytime	Broadbent, Krayenhoff, and Georgescu 2020
CAUS-Kansas	100%	0.6	29	0.08°C in normal summer	Seongeun Jeong, Dev Millstein, and Ronnen Levinson 2021
CAUS-Los Angeles and San Diego	100%	0.85	25	0.9°C on average	Vahmani et al. 2016
CAUS-Greater Boston and New England	100%	0.88	22	0.35-0.40°C on average	He et al. 2020
CAUS-US	100%	0.9	25	0.11	Zhang et al. 2016

OCE-Melbourne	100%	0.5	25	1°C at max	H.M. Imran et al. 2018
OCE-Melbourne	100%	0.85	25	2.4°C at max	H.M. Imran et al. 2018
EUR-Vienna	100%	0.45	23	0.25°C on average	Žuvela-Aloise et al. 2018
EUR-Vienna	100%	0.7	23	0.5°C on average	Žuvela-Aloise et al. 2018
EUR-Barcelona	100%	0.85	28	0.67°C on average and 2.22°C at max	Gilabert et al. 2021
EUR-UK	100%	0.7	20	0.05°C on average	Helen L. Macintyre et al. 2021
EUR-WestMidlands	100%	0.7	19	0.5°C on average and 3°C at max	H.L. Macintyre and C. Heaviside 2019
EUR	100%	0.9	18	0.07	Zhang et al. 2016
ESEA-Guangzhou	100%	0.55	30	0.8°C in normal summer	Cao et al. 2015
ESEA-Guangzhou	100%	0.65	30	0.5°C on average	Dev Millstein and Ronnen Levinson 2018
ESEA-China	100%	0.9	28	0.14	Zhang et al. 2016
MENA-Isreal	100%	0.8	30	0.4°C on average	Barry H. Lynn and Icrat M. Lynn 2020
SOA-India	100%	0.9	37	0.08	Zhang et al. 2016

Table S12 Energy saving potential of white roofs

Study area	UR	Albedo	Annual temperature (°C)	Energy saving (%)	Ref.
CAUS-1A, 2A, 2B	100%	0.9	26	5%	Li, Bou-Zeid, and Oppenheimer 2014
CAUS-3B	100%	0.9	20	3-4%	Sajith Wijesuriya et al. 2022
CAUS-3A	100%	0.9	16	2%	Sajith Wijesuriya et al. 2022
CAUS-4	100%	0.9	11	0%	Sajith Wijesuriya et al. 2022
CAUS-5B, 6B,7	100%	0.9	5.3	-3%	Sajith Wijesuriya et al. 2022
CAUS-Arizona	50%	0.72	23	2.6-3.8%	J.H. Jo et al. 2010

Table S13 Energy supply potential of solar roofs

Study area	UR	Conversion efficiency	Solar radiation intensity (KJ/m ²)	Energy supply (%)	Ref.
SOA-Bengal	15%	20%	1600-2200	6.00%	Talut, Bahaj, and James 2022
SOA-Mumbai	28%	14.5%	1600-2200	15.70%	Singh and Banerjee 2015
SOA-India	25%	15%	1600-2200	57.00%	Mishra et al. 2020
EUR-Germany	\	16%	900-1200	77.00%	Romero Rodriguez et al. 2017
EUR-Germany	54%	\	900-1200	35.00%	Strzalka et al. 2012
EUR-Sweden	70%	18%	900-1200	55-70%	Yang et al. 2020

EUR-Sweden	100%	15.5%	900-1200	88.00%	Molin et al. 2016
EUR-Switzerland	17%	17%	900-1200	25.30%	Dan Assouline, Nahid Mohajeri, and Jean-Louis Scartezzini 2018
EUR-Switzerland	55%	17%	900-1200	40.00%	Walch et al. 2020
LAM-Chile	32%	\	1800-2800	22.00%	Campos et al. 2016
MENA-Lebanon	50%	20.2%		100.00%	Nasrallah et al. 2022
MENA-SaudiArabia	25%	15.2%	2000-2800	19.00%	Dehwah and Asif 2019
MENA-Turkey	\	15%		67.00%	Yildirim, Büyüksalih, and Şahin 2021
CAUS	32%	16%	1800-2500	43.90%	Margolis et al. 2017
CAUS-NewJersey	18% for pitch roof and 65% for flat roof	16%	1200-2800	60.82%	Kurdgelashvili et al. 2016
CAUS-Arizona	24% for pitch roof and 60% for flat roof	16%	1200-2800	42.69%	Kurdgelashvili et al. 2016
CAUS-NewJersey	24% for pitch roof and 60% for flat roof	16%	1200-2800	35.32%	Kurdgelashvili et al. 2016
CAUS-US	100%	16%	1200-2800	38.60%	Gagnon et al. 2018
CAUS-Canada	100%	15%	1200-2800	38.00%	Mansouri Kouhestani et al. 2019
CAUS-US	26%	15%	1200-2800	25.00%	Phillips et al. 2019
CAUS-Ontario	19%	22.9%	1200-2800	30.00%	Wiginton, Nguyen, and Pearce 2010
ESEA-Hainan	\	15%	1600-2200	86.90%	C. Liu et al. 2019

ESEA-wuhan	45% for residence and 0.71 for non-residence	15%	1600-2200	31.83%	Sun et al. 2022
ESEA-Nanjing	61%	15%	1600-2200	17.7-20%	Wang et al. 2022

Table S14 UHI mitigation potential of solar roofs

Study area	UR	Albedo	Summer temperature (°C)	Temperature reduction (°C)	Ref.
CAUS-LosAngeles	20%	0.18-0.23	28	0.2°C at max	Taha 2013

Table S15 Stormwater reduction potential of blue roofs

Study area	UR	Precipitation (mm)	Stormwater reduction (%)	Ref.
EUR-London	\	754	16.95%	Cristiano et al. 2023
EUR-Wellington	\	1325	18.11%	Cristiano et al. 2023
EUR-Cagliari	\	450	18.12%	Cristiano et al. 2023
CAUS-Waterloo	\	681	12.20%	Cristiano et al. 2023
CAUS-Montreal	\	864	8%	Cristiano et al. 2023
CAUS-Airdrie	\	355	7.74%	Cristiano et al. 2023
CAUS-Vancouver	\	1115	16.28%	Cristiano et al. 2023
CAUS-Yuma	\	53	44.50%	Alexandra L. E. Litofsky and Aaron A. Jennings 2014

CAUS-LosAngeles	\	280	20.30%	Alexandra L. E. Litofsky and Aaron A. Jennings 2014
CAUS-Chicago	\	945	10.70%	Alexandra L. E. Litofsky and Aaron A. Jennings 2014
CAUS-Tillamook	\	2086	3.00%	Alexandra L. E. Litofsky and Aaron A. Jennings 2014
OCE-Auckland	\	1250	13.32%	Cristiano et al. 2023
LAM-PortAuPrince	\	894	36.86%	Cristiano et al. 2023

Table S16 Water saving potential of blue roofs

Study area	UR	Precipitation (mm)	Water saving (%)	Ref.
SSA-Kenya	\	2000	100%	Nthuni, Lübker, and Schaab 2014
ESEA-Thailand	\	1030	7.00%	Chaimoon 2013
ESEA-Vietnam	\	2700	9.90%	Nguyen et al. 2021
MENA-Jordan	\	250-600	1.00%	Saidan, Al-Weshah, and Obada 2015
MENA-Anzali	\	1720	19.13-25.06%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Rasht	\	1386	18.56-19.62%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Nowshahr	\	1284	17.92-19.21%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Ramsar	\	1205	16.13-16.9%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Astara	\	1198	16.91-24.8%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Babolsar	\	928	15.51-19.26%	Kolavani and Nasrin Jalili Kolavani 2020
MENA-Gorgan	\	523	17.76-18.82%	Kolavani and Nasrin Jalili Kolavani 2020

Table S17 Energy supply potential of wind turbine roofs

Study area	UR	Wind speed	Energy saving	Ref.
EUR-Italy	\	2.20-2.91 m/s	40% of the annual energy demand of a single domestic household	Gagliano et al. 2013
LAM-Dominican Republic	\	2.08-2.50 m/s	1152.7 kWh/building/year	Vallejo-Díaz et al. 2022
ESEA-Singapore	\	2.0-3.4m/s	1533-1916 kWh/building/year	B.R. Karthikeya, Prabal S. Negi, and N. Srikanth 2016
EUR-Netherlands	\	<7m/s	99206.9 kWh/building/year	Rezaeiha, Montazeri, and Blocken 2020

Table S18 The investment payback period of rooftop engineering

Rooftop engineering	Study area	Payback period	Ref.
white roofs	CAUS-Texas	1	Blackhurst 2020
white roofs	SOA-India	2	Rawat and Singh 2022
white roofs	CAUS-Arizona	9	J.H. Jo et al. 2010
blue roofs	SOA-Bangladesh	2-6	Mohammad Zobair Ibne Bashar, Md. Rezaul Karim, and Monzur Alam Imteaz 2018
blue roofs	EUR-US	10–11	Kim et al. 2021
blue roofs	SSA-Kenya	1.67	Samuel M. Nthuni 2014
solar roofs	LAM-Brazil	6, 9, 7	M.J. Sorgato, K. Schneider, and R. Rütther 2018
solar roofs	OCE-Melbourne	13-15	Zhao et al. 2019

solar roofs	EUR-Spain	7-15	Fuster-Palop et al. 2021
solar roofs	EUR-Italy	5.53	Di Turi, Ronchetti, and Sannino 2023
wind turbine roofs	EUR-Sicilian	14	Gagliano et al. 2013
wind turbine roofs	ESEA-Singapore	14.4-19.3	B.R. Karthikeya, Prabal S. Negi, and N. Srikanth 2016
wind turbine roofs	CAUS-Maryland	76	Almutairi et al. 2017
green roofs	CAUS-Michigan	14-22	Clark, Adriaens, and Talbot 2008
green roofs	MENA-Iran	25-57	Refahi and Hossein Talkhabi 2015
green roofs	LAM-Mexico	8.8	A. Ávila-Hernández et al. 2020
green roofs	ESEA-Kuala Lumpur	1-9	Amir Mahdiyar et al. 2021

Table S19 The carbon payback period of rooftop engineering

Rooftop engineering	Study area	Payback period	Ref.
green roofs	ESEA-Japan	5.8-15.9	Kuronuma et al. 2018
solar roofs	EUR-Italy	3-4	Battisti and Corrado 2005
solar roofs	EUR-Catalonia Spain	5.46-5.5	Chr. Lamnatou and D. Chemisana 2015
solar roofs	ESEA-Chengdu	1.7-2.3	Z. Li et al. 2022
wind turbine roofs	OCE-New Zealand	10-16	Mithraratne 2009

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