The Innovation, Volume *5*

Supplemental Information

Urban heat mitigation by green and blue infrastructure: Drivers, effectiveness, and future needs

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Supplementary Information (SI)

for

Urban heat mitigation by green and blue infrastructure: a review of drivers, effectiveness, and future needs

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S1 Methodology

We screened studies based on the following criteria: (a) addressing urban heat mitigation using one or more GBGI types, (b) clear identification of at least one GBGI sub-category under investigation, (c) a clear link between the primary GBGI category and heat mitigation performance, including temperature reduction and associated co-benefits, and (d) accessibility of full-text articles from the databases for further review and data extraction.

After removing duplicates, 25,974 publications that didn't meet these criteria were eliminated, leaving 1,512 publications for further screening (Figure 2b). We retrieved and assessed the full text of each paper for eligibility (Figure 2c). Articles not meeting inclusion criteria, such as those mainly focusing on heat causes and impacts, methodological aspects of heat mitigation without a direct GBGI connection, or discussions limited to general green and blue spaces without specific GBGI details and cooling effectiveness, were excluded. After this additional screening, 1,250 more papers were discarded, resulting in 262 publications for final review. Out of these, 60 more publications were excluded due to insufficient performance reporting or a failure to mention the GBGI used. In the end, 202 publications (1.8% of the originally identified 27,486 publications) were chosen for meta-analysis and further consideration in this review (Figure 2d, e). First we cataloged data from the selected studies, extracting information from 202 of them, including (1) the study's location (site, city, country, and region), (2) the specific type of GBGI, (3) the nature of the study (monitoring, modeling, remote sensing, or a combination), (4) whether single or multiple GBGIs were studied, (5) qualitative or quantitative data on co-benefits, air temperature, land surface temperature (LST) reduction (in °C), and day or night air temperature reduction (in °C), (6) any identified knowledge gaps, and (7) key findings. We developed a data form to capture this essential information from the selected studies (Table S1). This information was used to address key objectives, including when and where previous articles were published, the types of GBGIs used for urban heat mitigation, and the nature of co-benefits and maximum temperature reductions reported. Following this, we analysed and synthesised the data from selected studies to address the specific review objectives. The information on the benefits of various GBGI subcategories was examined using descriptive statistics with R-project software. To create an evaluation framework for GBGI types and their services in addressing heat-related challenges and associated co-benefits, we used a min-max normalization approach, scaling the data from 1 (none) to 6 (very high) (see Table 2). This standardized method was then applied to the relevant publications within each GBGI category. Out of the 202 publications, 64.7% primarily focused on heat mitigation as their main ecosystem service, while the remaining 35.3% discussed co-benefits alongside direct heat mitigation benefits.

The review proceeds with a summary of how GBGI mitigates heat stress, followed by mapping study origins, exploring GBGI interventions, and presenting evidence of their cooling advantages and co/dis-benefits. It also provides a conceptual framework for GBGI implementation and addresses existing knowledge gaps. The review concludes with major findings and recommendations for effective GBGI implementation to mitigate urban heat.
Five additional co-benefits are identified, including enhanced recreational opportunities and improvements in air/water quality.

S1.1 GBGI classification, scope, and outline

The conceptualisation and classification of GBGI types can differ due to varying interpretations from country to country, contingent on research contexts and the primary objective of studies. Sustainability objectives are selectively applied within different GBGI development frameworks, leading to a plethora of definitions and interpretations.[1] These variations depend on whether GBGI is applied to ecological resources[2] or includes natural green spaces, or is confined to highly altered landscapes intended for public benefit.[3] Consequently, it becomes challenging to specifically distinguish between green and grey infrastructure, such as cycle paths passing through green areas that provide additional recreational benefits. Often, scientists categorise non-ecological resources as GBGI, for example, permeable pavements, rainwater barrels, and rain gardens. For this review, we adopt the GBGI classification presented by Jones et al.[4] and expand it further by introducing two new categories, mixed (blue-green) and backyard irrigation,[5-7] giving a total of 51 GBGI types. This classification uses a green-blue-grey continuum to cover natural green or blue, engineered green, blue, or hybrid (green-blue-grey) combinations. The typology was designed to flexibly incorporate all GBGI types within a typical urban environment. Within the scope of this review, we examined 51 GBGI types grouped under 10 broad categories: gardens, parks, amenity areas, linear features/routes, constructed GI on infrastructure, hybrid GI (for water), water bodies, other non-sealed urban areas, other public spaces, and mixed – (green-blue).

The task of examining and integrating the diverse benefits of GBGIs was challenging due to their complex interactions and discipline-specific applications. For instance, public health is directly or indirectly tied to almost all evaluated benefits, encompassing psychological, social, and economic aspects.[8] Therefore, this study focuses on the direct GBGI cooling benefits (heat mitigation), whilst indirect benefits such as management of other natural hazards (floods, droughts), the creation of new infrastructure (such as interconnected green infrastructure corridors to support active travel; Rogers and Hunt[9]) or associated social costs avoided by using specific GBGI types are considered as a secondary objective. In the course of this review, five more co-benefits were identified: (1) enhanced recreational opportunities, (2) ambient noise reduction, (3) flood and drought risk mitigation, (4) improvements in air/water quality, and (5) biodiversity (Section 3.3.2). Detailed GBGI design and implementation principles, along with global GBGI challenges, have been covered in earlier reviews (Table 1) and therefore were beyond the scope of this paper.

The review commences with a concise summary of how GBGI mitigates heat stress (Section 3), followed by a spatial and temporal mapping of study origins, an exploration of various GBGI interventions, and a presentation of quantitative evidence supporting the direct cooling advantages and other co/dis-benefits (Section 4). Section 5 provides a nine-stage conceptual framework for GBGI implementation for heat mitigation based on the qualitative analysis of the reviewed literature and discusses practical recommendations for the design, implementation, monitoring, evaluation, and upscaling of GBGI to mitigate heat risks. Section 6 highlights the existing knowledge gaps. The review culminates with major conclusions and lays out a series of recommendations for the effective implementation of GBGI to mitigate urban heat (Section 7).

S1.2 Search and selection of relevant studies

The goal of this review was to offer an in-depth assessment review and analysis of GBGI's functions and benefits concerning urban cooling, as well as their potential co-benefits and drawbacks. This approach led to an expansion of the scope beyond that of previous reviews covered, enables us to uncover overlooked geographical patterns and examine the temporal trends in the origin of studies, and knowledge voids in the existing literature. PRISMA methodology was adopted for this systematic review.[10] Figure 1 provides a flowchart depicting our search and evaluation methodology, including its resultant findings. Our literature search consisted of five stages:

(1) Development of search terms: To identify a comprehensive range of studies related to urban heat mitigation, relevant search terms were determined based on research gaps, objectives, and predetermined categories and subcategories within the GBGI framework. This approach ensures the inclusion of a diverse set of studies that are pertinent to the field of heat mitigation. A range of relevant search terms based on keywords for urban heat mitigation was identified based on research gaps, objectives, and predetermined GBGI categories and subcategories to allow the identification of a wide range of studies relevant to heat mitigation. Search term combinations of GBGI type and heat are listed in Supplementary Information (SI) Table S1.

(2) Search and identification of relevant studies: A peer-reviewed literature search was conducted via Boolean search term combinations (Table S1) utilising Web of Science (WoS), as the most comprehensive database with the ability to handle complex keyword searches. Studies published between 2010 and 2023 were included. The chosen timeframe was specifically selected to effectively manage the substantial number of search results, preventing an overwhelming amount of hits. Moreover, this time frame enables a more comprehensive examination, particularly in relation to the GBGI, which gained increased recognition as "nature-based solution" after the year 2010. Cross-checks were performed using other databases such as Science Direct, Scopus, and Google Scholar to verify that no relevant studies were missed from the analysis. To ensure inclusivity, we used the same keywords as in WoS (Table S1) when searching on Google Scholar. We reviewed multiple pages of search results initially, but the relevance of studies decreased as we continued. Therefore, we concluded the search after examining the first 20 pages. Finally, we compared the results with papers from WoS and included any relevant publications that were missed in our analysis. After excluding articles not written in English, the search terms yielded a total of 27,486 publications, including review and research papers (Figure 2a).

(3) Selection of studies: The identified studies were screened against the following criteria: (a) addresses mitigation and/or adaptation to urban heat using one or several types of GBGI,

(b) distinctly identifies at least one GBGI sub-category under investigation, (c) the main GBGI category is clearly linked with heat mitigation performance, including actual or percentage temperature reduction, and any associated co-benefits, (d) the full texts were accessible from the databases for further review and data extractions. After removing duplicates, the remaining articles were reviewed and 25,974 publications that did not meet inclusion criteria were removed, leaving 1512 publications for further screening (Figure 2b). The full text of each paper was retrieved and assessed for eligibility (Figure 2c). Any articles not meeting the inclusion criteria, like those majorly focusing on causes and impacts of heat, methodological aspects of heat mitigation benefits without a direct tie to GBGI categories and temperature reductions or discussions confined to general green and blue spaces or green corridors without specific descriptions of GBGI types and cooling efficacy, were excluded. After this further screening, an additional 1250 papers were discarded, leaving 262 publications for final screening. Out of these, 60 more publications were excluded due to non-reporting of performances or failure to mention the utilised GBGI. Eventually, a set of 202 publications (1.8% of the originally identified 27,486 publications) was chosen for meta-analysis and subsequent deliberation in this review (Figure 2d, e).

<u>(4) Cataloguing the data</u>: Relevant data (e.g., location, type of GBGI, co-and dis-benefits, and knowledge gaps; Section 2.3) were extracted from the selected studies. The following data were extracted from the selected 202 studies: (1) the location of the GBGI study including the site, city, country, and region, (2) the specific type of GBGI, (3) the nature of the study, whether it was monitoring, modelling, remote sensing, or a combination of these, (4) either single or multiple GBGI, (5) qualitative or quantitative information on co-benefits, air temperature and land surface temperature (LST) reduction (in °C), and a day or night time air temperature reduction (in °C), (6) any identified knowledge gaps, and (7) key findings.

This process involved developing a data form to capture key information from the selected studies (Table S1). This extracted information was used to address the key objectives including when and where previous articles were published, the types of GBGI they utilised as mitigation measures for urban heat and the nature of co-benefits and maximum temperature reductions they reported.

(5) Collating, summarising, and reporting the results: The data obtained from the selected studies were analysed and synthesised in a way that addressed the specific questions raised as a part of the review objectives (Section 1). The extracted information on the (co-)benefits of various subcategories of GBGI was analysed using descriptive statistics using R-project software.[11] To develop an evaluation framework for GBGI types and the services offered to tackle heat-related challenges and their associated co-benefits, we adopted a min-max normalisation approach.[12] This approach, also referred to as feature scaling, included a linear transformation of the original data on a scale ranging from 1 (none) to 6 (very high) (see Table 2). Subsequently, this standardised methodology was applied to the pertinent publications within each GBGI category. Of the 202 publications, 64.7% discussed heat mitigation as their main ecosystem service. The remaining 35.3% discussed the co-benefits alongside the direct heat mitigation benefits (Section 3).

S2 Mechanisms of temperature and heat stress regulation by GBGI

S2.1 Mechanisms of temperature and heat stress regulation by green infrastructure

The mechanisms by which GI such as street trees, parks, green roofs, and green walls reduce heat are multifaceted and interconnected. Trees and plants help in the reduction of heat by providing shade and reducing the amount of direct sunlight reaching the ground, therefore lowering surface temperatures and mitigating the urban heat island (UHI) effect via creating a cooler microclimate.[13-15] Additionally, during evapotranspiration plants release moisture which further cools the surrounding air by converting sensible heat into latent heat.[16] Parks can act as natural air conditioners through several mechanisms,[17-19] including the formation of microscale centripetal thermal system (park-breeze) that generate low-level advection currents which draw air from cooler green towards warmer urban areas.[20] Other GI elements such as green roofs, green walls, and roof gardens provide insulation, reduce heat absorption by buildings, and promote evaporative cooling (heat absorption, as water changes from liquid to a gas state in the air stream.[21-24] Vegetation also contributes to the dissipation of heat by acting as windbreaks, modifying airflow patterns, and facilitating natural ventilation.

S2.2 Mechanisms of temperature and heat stress regulation by blue infrastructure

Blue infrastructure (BI), in the form of water-based natural or constructed features including ponds and wetlands, actively mitigates heat effects by cooling the surrounding environment.[20] This is achieved through processes such as evapotranspiration, shading, the albedo effect, groundwater recharge, and temperature buffering.[25,26] BI can provide cooling during the day (acts as a heat sink by absorbing and storing heat from the surrounding environment) whereas it may lead to warming at night (re-releasing the heat due to water's higher heat capacity compared to the land surface).[27] Evaporation from water bodies also helps cool the air, creating a microclimate with lower temperatures and thereby helping to mitigate the UHI effect.[28] Larger urban water bodies can also generate cool breezes that further lower the ambient temperature and provide relief during hot weather through evaporative cooling.[20] Furthermore, surfaces of blue infrastructure are often highly reflective, especially under calm conditions, thereby increasing surface reflectivity which, in turn, contributes to the reduction of heat absorption,[29] thus helping to mitigate heat build-up and contributing to the cooling of the surrounding area. Some of the blue infrastructure such as wetlands, ponds/lakes, swales, and rain gardens also act as natural sponges, storing water and releasing it during high air temperatures, thereby moderating temperatures in the vicinity by increasing water availability for evaporation through groundwater recharge.[30]

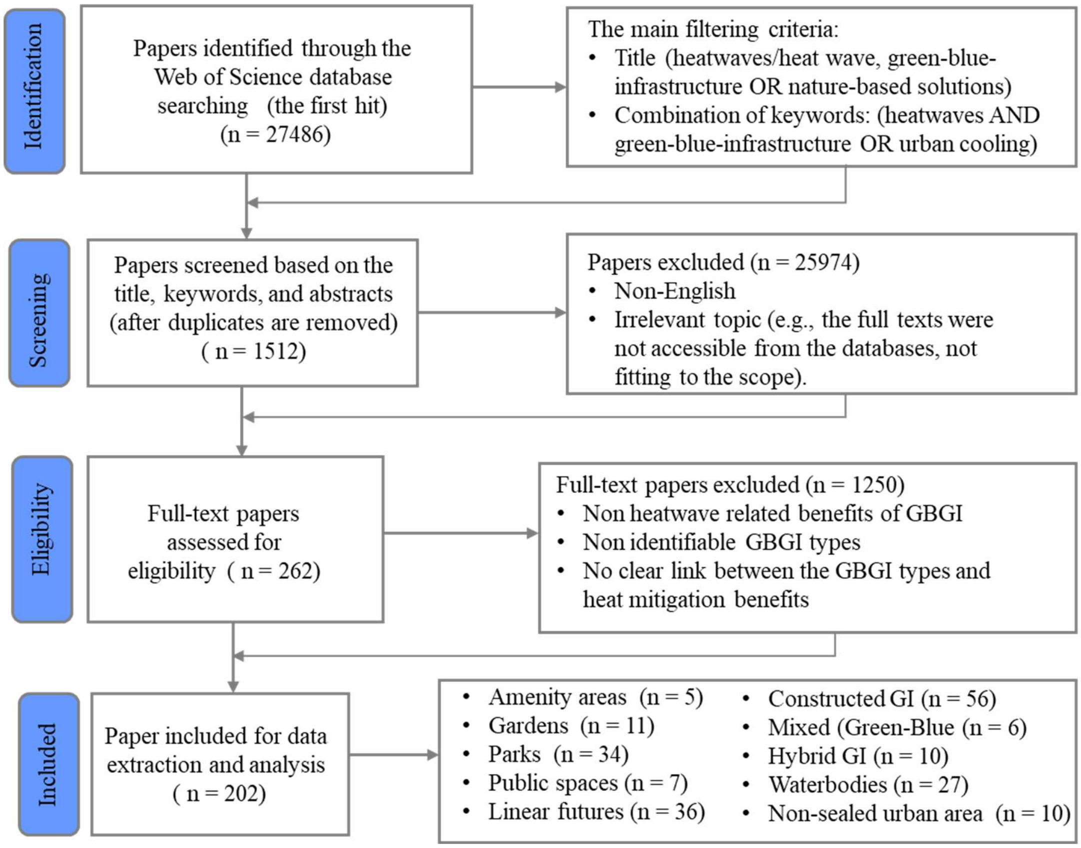
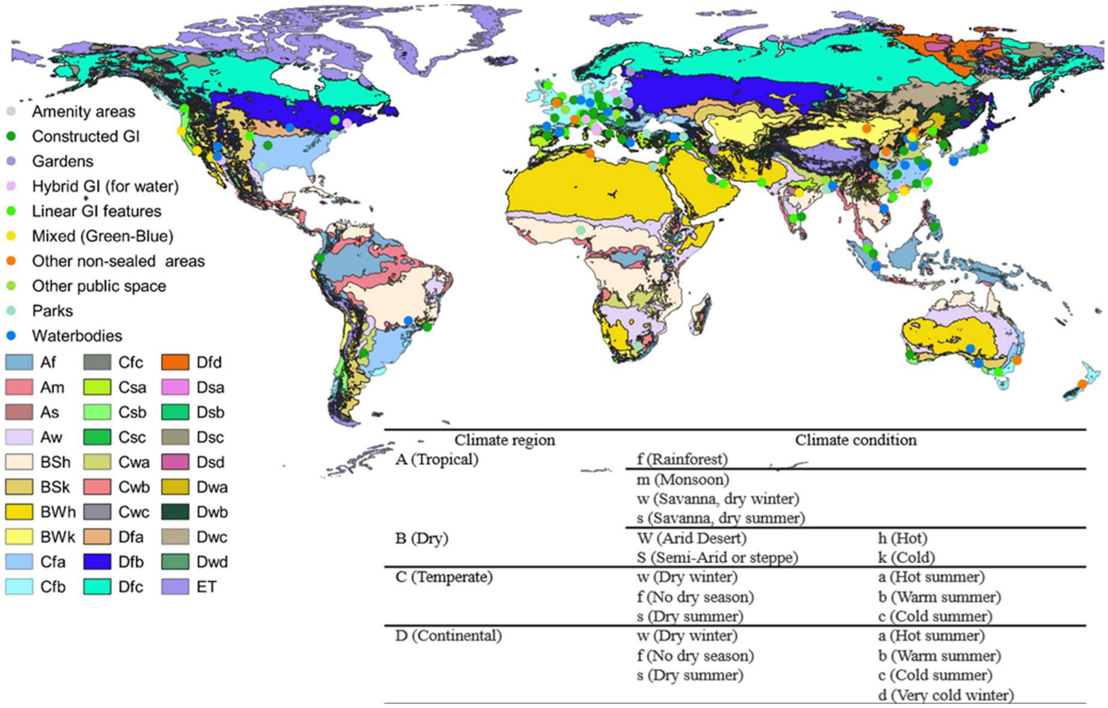


Figure S1. Flowchart of the inclusion and exclusion criteria (e.g. article identification, screening, eligibility check, and inclusion) process and the number of GBGI main categories included.



Climate region	Climate condition	
A (Tropical)	f (Rainforest)	
	m (Monsoon)	
	w (Savanna, dry winter)	
	s (Savanna, dry summer)	
B (Dry)	W (Arid Desert)	h (Hot)
	S (Semi-Arid or steppe)	k (Cold)
C (Temperate)	w (Dry winter)	a (Hot summer)
	f (No dry season)	b (Warm summer)
	s (Dry summer)	c (Cold summer)
D (Continental)	w (Dry winter)	a (Hot summer)
	f (No dry season)	b (Warm summer)
	s (Dry summer)	c (Cold summer)
		d (Very cold winter)

269 **Figure S2**. Köppen-Geiger climate classification: the main climate region (A-D) and detailed

270 climate conditions (right column) where GBGs are implemented.

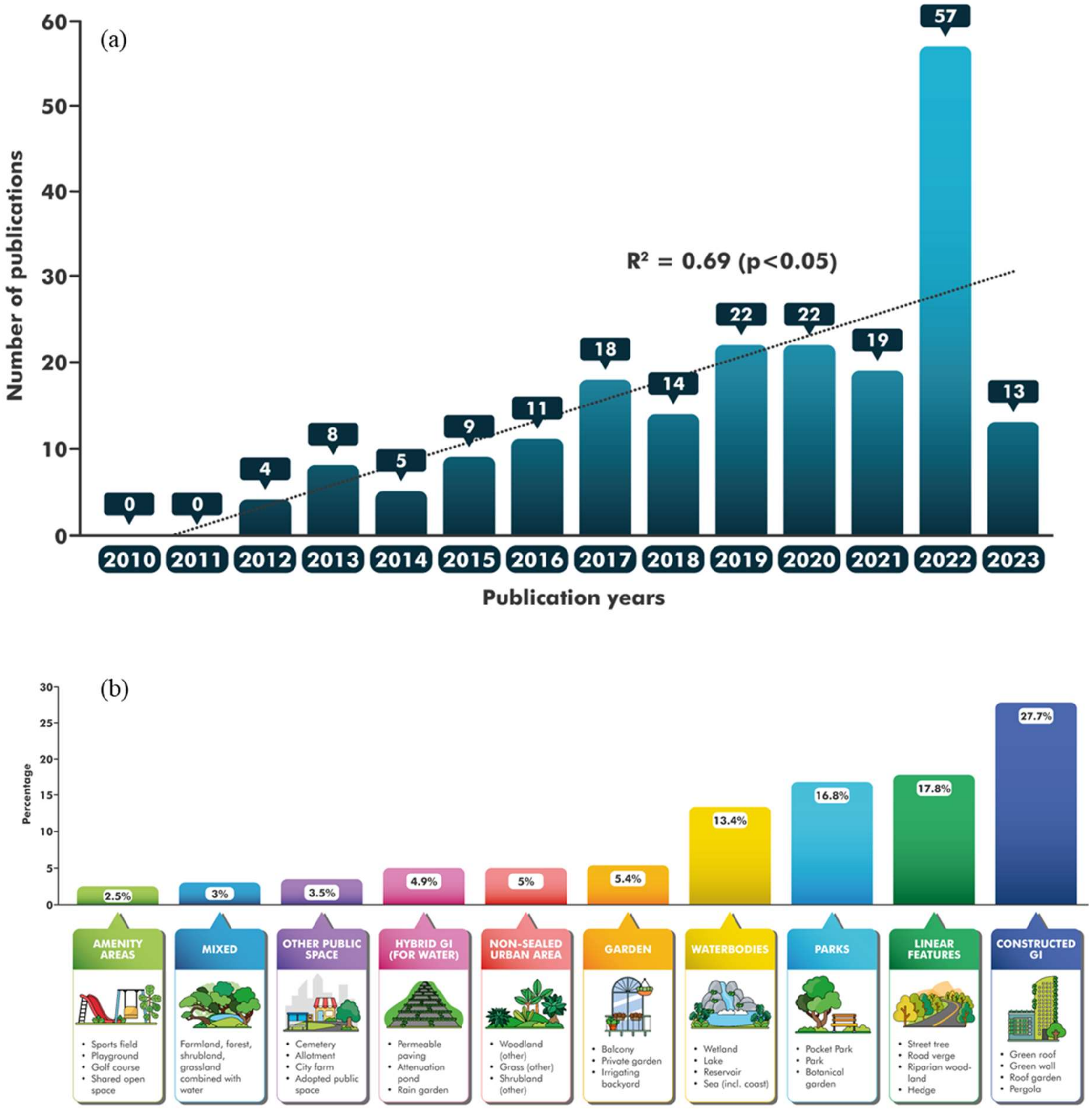


Figure S3. (a) The number of publications exhibiting a significant linear increase over time, with the linear trend (R^2=0.69; p=0.00043) providing the best fit among the various trends (exponential, linear, polynomial, power functions) analysed. Our search in 2023 was limited to the month of 30 March 2023, and the trend line did not incorporate the 2023 data as it did not cover the entire year. (b) The number of publications in each of the 10 main GBGI categories. The number of publications covering all the GBGI sub-categories is shown in Figure 1a.

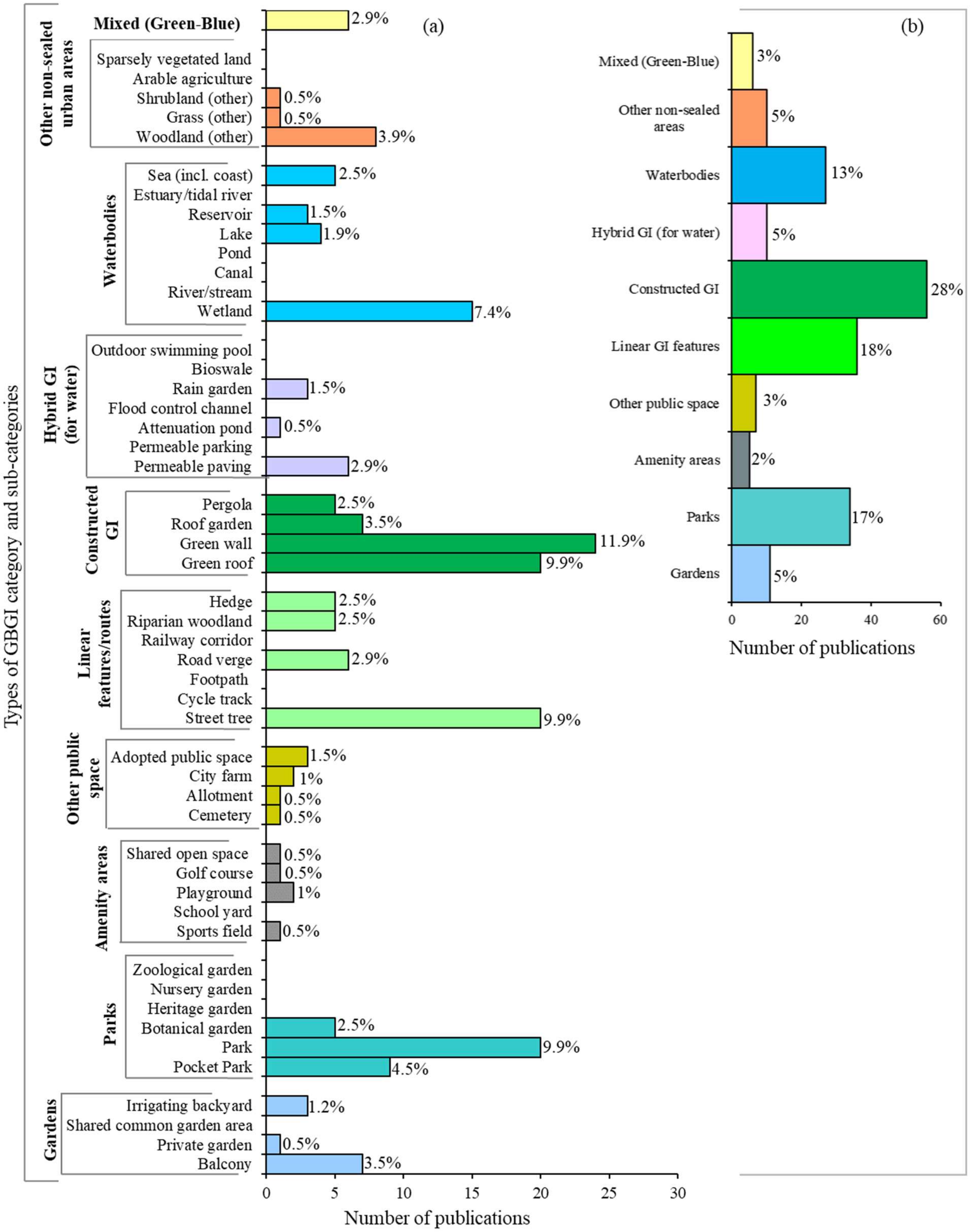


Figure S4. Relevant publications on the benefits of GBGI for heat adaptation and mitigation evidence gathered from the literature: (a) number of publications covering the main categories and sub-categories and (b) number of publications covering the main category (shown by the bold coloured text). The percentage values are printed on the top of each bar.

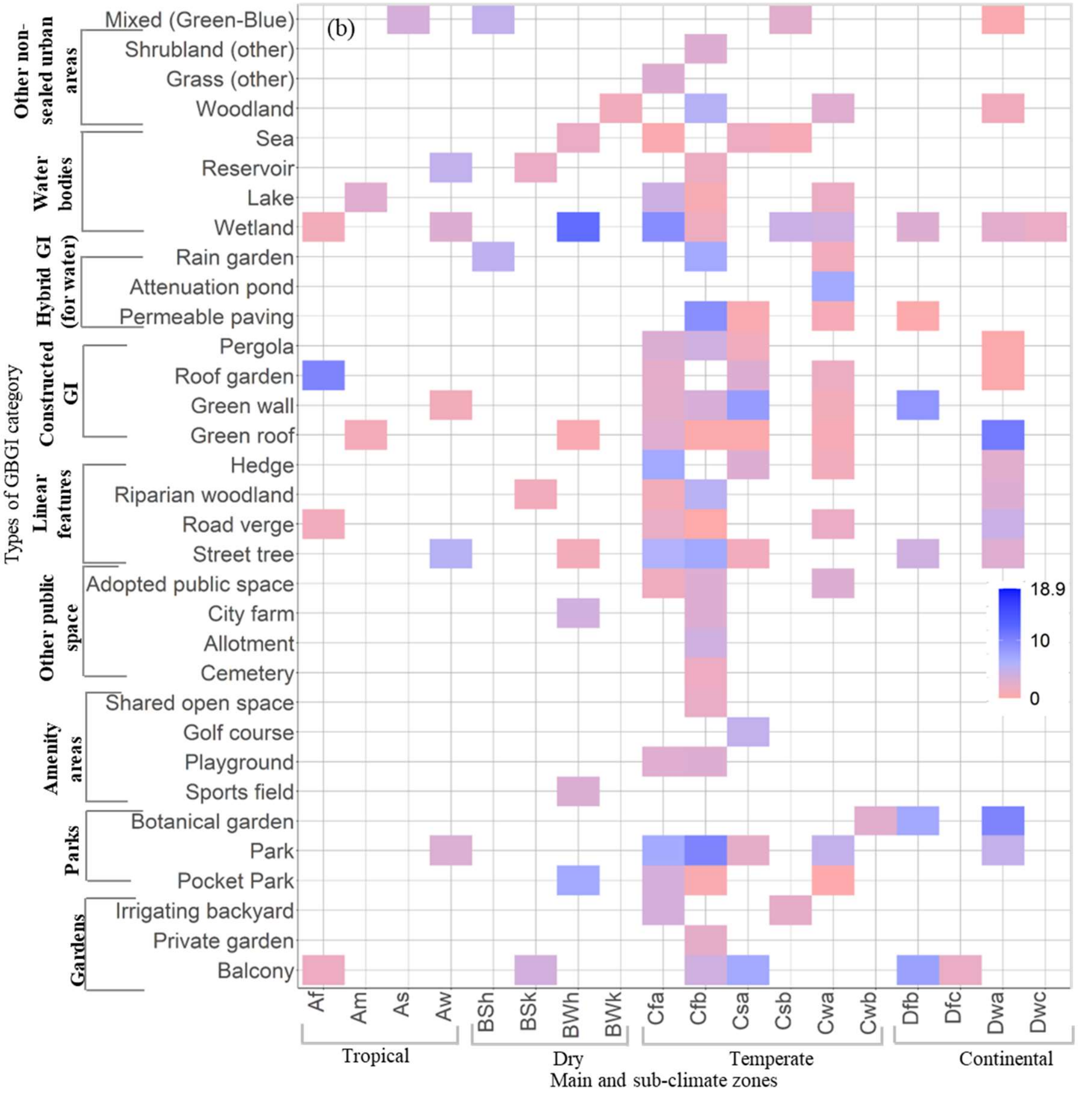


Figure S5. The effectiveness of the main and sub-GBGI categories implemented in tropical (n = 16), dry (n = 15), temperate (n = 137), and continental (n = 34) climate zones of Köppen-Geiger climate classification.

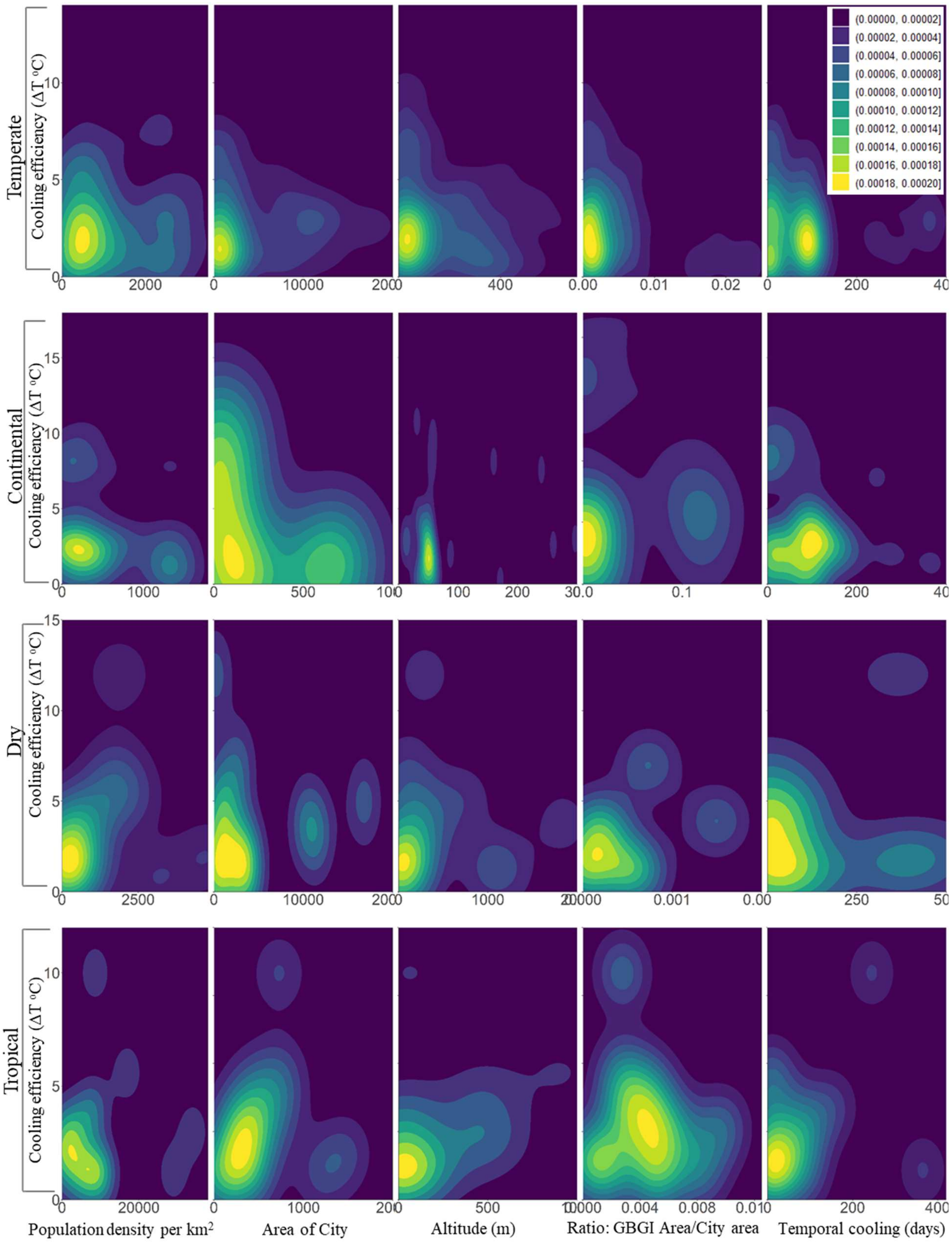
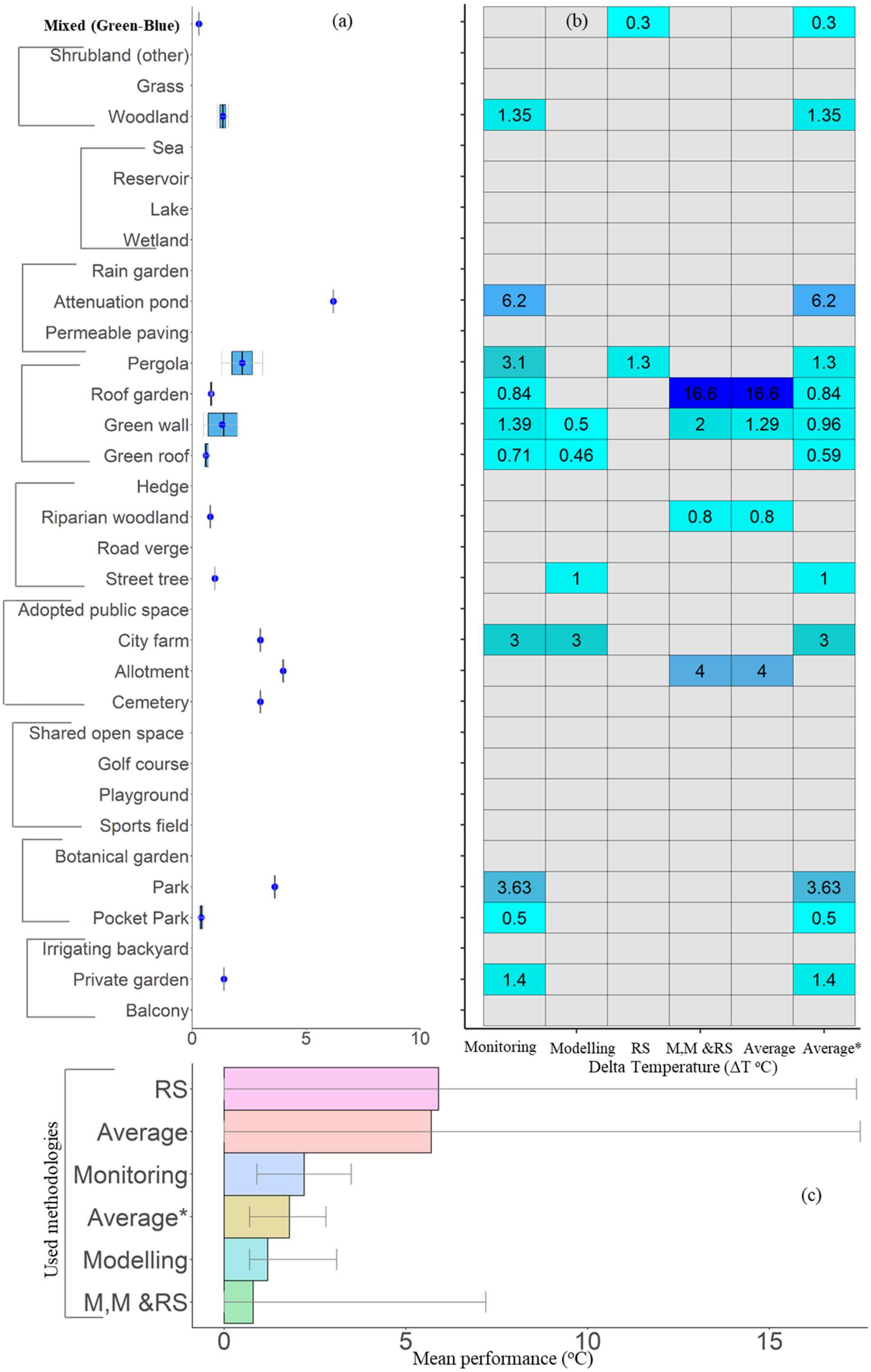


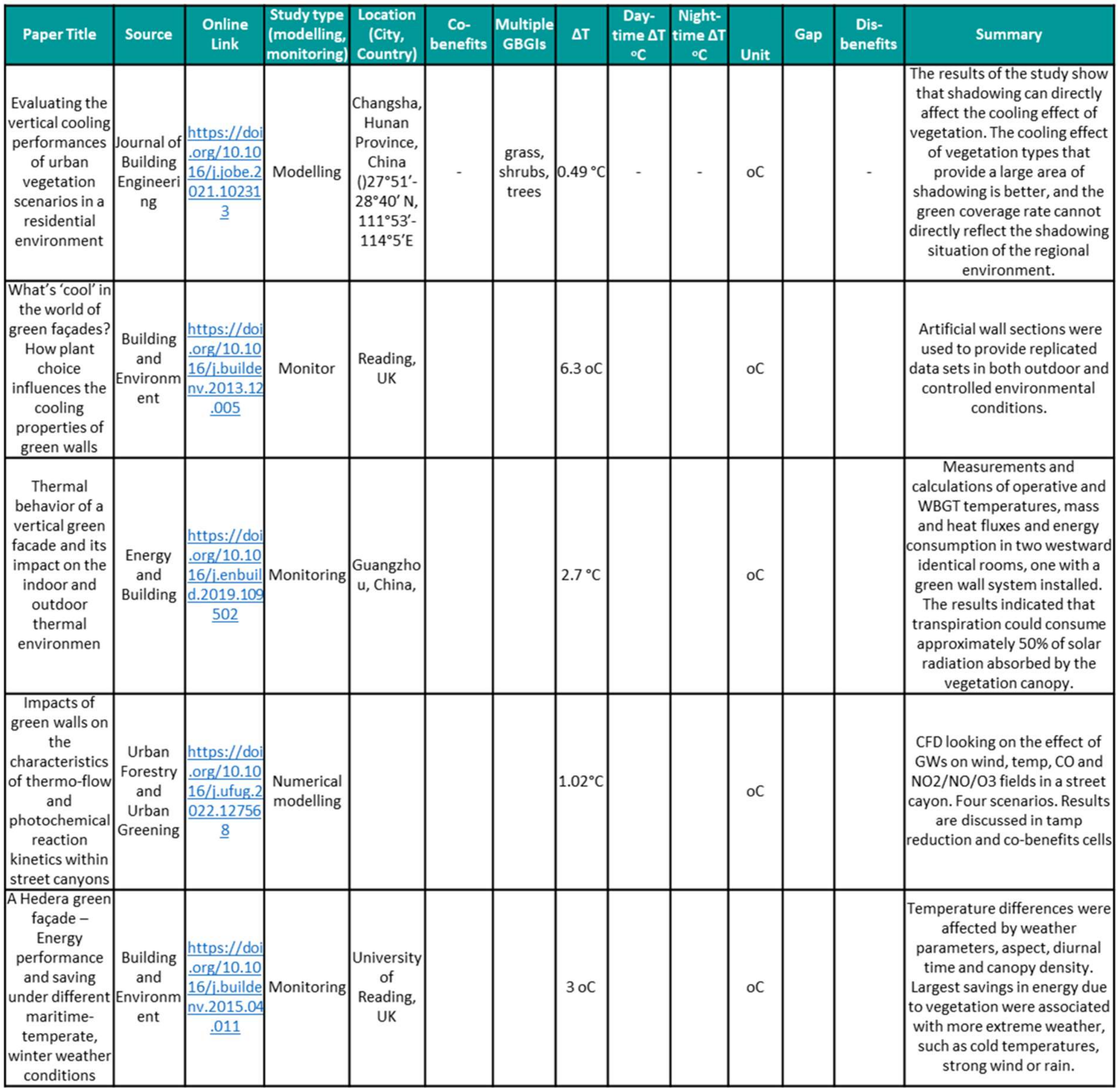
Figure S6. The density of GBGI cooling efficiency in different climate zones and against population density, area of the city, altitude, ratio: area of GBGI/area of the city, and temporal scale of cooling.



	Monitoring	Modelling	RS	M,M &RS	Average	Average*
Mixed (Green-Blue)			0.3			0.3
Shrubland (other)						
Grass						
Woodland	1.35					1.35
Sea						
Reservoir						
Lake						
Wetland						
Rain garden						
Attenuation pond	6.2					6.2
Permeable paving						
Pergola	3.1		1.3			1.3
Roof garden	0.84			16.6	16.6	0.84
Green wall	1.39	0.5		2	1.29	0.96
Green roof	0.71	0.46				0.59
Hedge						
Riparian woodland				0.8	0.8	
Road verge						
Street tree		1				1
Adopted public space						
City farm	3	3				3
Allotment				4	4	
Cemetery						
Shared open space						
Golf course						
Playground						
Sports field						
Botanical garden						
Park	3.63					3.63
Pocket Park	0.5					0.5
Irrigating backyard						
Private garden	1.4					1.4
Balcony						

Figure S7. Night-time temperature reduction efficiency of GBGI sub-categories: (a) a summary of the overall performance of different GBGI types from all studies, (b) heatmap showing GBGI performances from for different methods and the average values, and (c) overall average of GBGI efficiency for urban heat mitigation. The 'Average' and 'Average*' values represent the average of all study types with and without RS data, respectively. M&M denotes combined monitoring and modelling studies. The colour gradient represents the performance, with grey cells representing studies that did not consider either monitoring, modelling, M&M, or RS. The figure uses a boxplot representation with the median indicated by a thick vertical black line, the mean represented by blue dots, and the upper and lower quartiles indicated by the box boundaries. The circle with a vertical line represents the GBGI categories with only one publication.

Table S1. The table below serves as a sample for organising the datasets obtained from the reviewed papers for each of the 51 sub-categories.



Paper Title	Source	Online Link	Study type (modelling, monitoring)	Location (City, Country)	Co-benefits	Multiple GBGIs	ΔT	Day-time ΔT °C	Night-time ΔT °C	Unit	Gap	Dis-benefits	Summary
Evaluating the vertical cooling performances of urban vegetation scenarios in a residential environment	Journal of Building Engineering	https://doi.org/10.1016/j.jobe.2021.102313	Modelling	Changsha, Hunan Province, China ()27°51′-28°40′ N, 111°53′-114°5′E	-	grass, shrubs, trees	0.49 °C	-	-	oC		-	The results of the study show that shadowing can directly affect the cooling effect of vegetation. The cooling effect of vegetation types that provide a large area of shadowing is better, and the green coverage rate cannot directly reflect the shadowing situation of the regional environment.
What's 'cool' in the world of green façades? How plant choice influences the cooling properties of green walls	Building and Environment	https://doi.org/10.1016/j.buildenv.2013.12.005	Monitor	Reading, UK			6.3 oC			oC			Artificial wall sections were used to provide replicated data sets in both outdoor and controlled environmental conditions.
Thermal behavior of a vertical green facade and its impact on the indoor and outdoor thermal environmen	Energy and Building	https://doi.org/10.1016/j.enbuild.2019.109502	Monitoring	Guangzhou, China,			2.7 °C			oC			Measurements and calculations of operative and WBGT temperatures, mass and heat fluxes and energy consumption in two westward identical rooms, one with a green wall system installed. The results indicated that transpiration could consume approximately 50% of solar radiation absorbed by the vegetation canopy.
Impacts of green walls on the characteristics of thermo-flow and photochemical reaction kinetics within street canyons	Urban Forestry and Urban Greening	https://doi.org/10.1016/j.ufug.2022.127568	Numerical modelling				1.02°C			oC			CFD looking on the effect of GWs on wind, temp, CO and NO2/NO/O3 fields in a street cayon. Four scenarios. Results are discussed in tamp reduction and co-benefits cells
A Hedera green façade – Energy performance and saving under different maritime-temperate, winter weather conditions	Building and Environment	https://doi.org/10.1016/j.buildenv.2015.04.011	Monitoring	University of Reading, UK			3 oC			oC			Temperature differences were affected by weather parameters, aspect, diurnal time and canopy density. Largest savings in energy due to vegetation were associated with more extreme weather, such as cold temperatures, strong wind or rain.

Table S2. The string of keywords used to record literature for the review of the efficiency of 51 GBGI categories to mitigate heat.

GBGI Type	**Keywords**	**Number of publications Identified**
		Web of Science
Pocket park	pocket park AND heat waves	-
	pocket park AND urban heat island	14
	pocket park AND temperature reduction	3
	pocket park AND cooling	10
	Pocket Park (Total)	27
Park	park NOT pocket park AND heat waves	1623
	park NOT pocket park AND urban heat island	907
	park NOT pocket park AND temperature reduction	6804
	park NOT pocket park AND cooling	9741
	Park (Total)	**19075**
Botanical garden	botanical garden OR arboretum AND heat waves	1
	botanical garden OR arboretum AND urban heat island	10
	botanical garden OR arboretum AND temperature reduction	10
	botanical garden OR arboretum AND cooling	20
	Botanical garden (Total)	**41**
Heritage garden	heritage garden AND heat waves	3
	heritage garden AND urban heat island	3
	heritage garden AND temperature reduction	1
	heritage garden AND cooling	6
	Heritage garden (Total)	13

Nursery garden	nursery garden AND heat waves	-
	nursery garden AND urban heat island	-
	nursery garden AND temperature reduction	12
	nursery garden AND cooling	3
	Nursery garden (Total)	15
Zoological garden	zoo OR zoos OR zoological garden AND heat waves	2
	zoo OR zoos OR zoological garden AND urban heat island	1
	zoo OR zoos OR zoological garden AND temperature reduction	12
	zoo OR zoos OR zoological garden AND cooling	31
	Zoological garden (Total)	46
Street Tree	street tree AND heat waves	51
	street tree AND urban heat island	326
	street tree AND temperature reduction	123
	street tree AND cooling	246
	Street Tree (Total)	746
Cycle track	cycle path OR cycle track AND heat waves	6
	cycle path OR cycle track AND urban heat island	14
	cycle path OR cycle track AND temperature reduction	421
	cycle path OR cycle track AND cooling	896
	Cycle track (Total)	1337
Footpath	footpath AND heat waves	-
	footpath AND urban heat island	6
	footpath AND temperature reduction	0
	footpath AND cooling	1
	Footpath (Total)	7

Road verge	roadside OR verge AND heat waves	6
	roadside OR verge AND urban heat island	26
	roadside OR verge AND temperature reduction	48
	roadside OR verge AND cooling	103
	Road verge (Total)	183
Railway corridor	rail AND heat waves	31
	rail AND urban heat island	7
	rail AND temperature reduction	300
	rail AND cooling	456
	Railway corridor (Total)	794
Riparian woodland	riparian tree OR riparian wood OR riparian forest AND heat waves	4
	riparian tree OR riparian wood OR riparian forest AND urban heat island	4
	riparian tree OR riparian wood OR riparian forest AND temperature reduction	16
	riparian tree OR riparian wood OR riparian forest AND cooling	28
	Riparian woodland (Total)	52
Hedge	hedge AND heat waves	3
	hedge AND urban heat island	9
	hedge AND temperature reduction	47
	hedge AND cooling	52
	Hedges (Total)	111
Green Roof	green roof AND heat waves	104
	green roof AND urban heat island	806
	green roof AND temperature reduction	360
	green roof AND cooling	886

	Green Roof (Total)	2156
Green Wall	green wall OR green facade AND heat waves	57
	green wall OR green façade AND urban heat island	295
	green wall OR green façade AND temperature reduction	298
	green wall OR green façade AND cooling	536
	Green Wall (Total)	1186
Roof garden	roof garden OR roof terrace AND heat waves	12
	roof garden OR roof terrace AND urban heat island	57
	roof garden OR roof terrace AND temperature reduction	22
	roof garden OR roof terrace AND cooling	80
	Roof garden (Total)	171
Pergola	pergola AND heat waves	-
	pergola AND urban heat island	5
	pergola AND temperature reduction	5
	pergola AND cooling	7
	Pergola (Total)	17
Road verge	Road verge AND heat waves	0
	Road verge AND urban heat island	0
	Road verge AND temperature reduction	1
	Road verge AND cooling	2
	(roadside* OR verge*) AND cooling	207
	(roadside* OR verge*) AND heat waves	12
	(roadside* OR verge*) AND urban heat island	29
	(roadside* OR verge*) AND temperature reduction	62
	Road verge (Total)	313

Permeable paving	Permeable Paving AND Heatwaves	0
	Permeable Paving AND Urban Heat Island	26
	Permeable Paving AND cooling	18
	Permeable Paving AND Temperature reduction	8
	Permeable parking/roadway AND Heatwaves	0
	Permeable parking/roadway AND Urban Heat Island	0
	Permeable parking/roadway AND Temperature reduction	0
	"permeable park*" OR "permeable road Heatwaves reduction"*	13
	"permeable park*" OR "permeable road Urban Heat Island"*	13
	Permeable park*" OR "permeable road Temperature reduction	13
	Permeable Paving AND cooling	18
	Permeable Paving (Total)	109
Attenuation pond	Attenuation pond AND Heatwaves	0
	Attenuation pond AND Urban Heat Island	1
	Attenuation pond AND Temperature reduction	8
	Attenuation pond AND cooling	6
	Permeable Paving (Total)	15
Permeable paving	Flood control channel AND Heatwaves	0
	Flood control channel AND Urban Heat Island	1
	Flood control channel AND Temperature reduction	22
	flood* OR channel or Heatwaves*	1
	flood* OR channel or Urban Heat Island*	2
	flood* OR channel or Temperature reduction*	35
	Flood control channel AND cooling	30
	Flood Control Channel (Total)	91

Rain garden	Rain garden AND Heatwaves	2
	Rain garden AND Urban Heat Island	23
	Rain garden AND Temperature reduction	22
	Rain garden AND cooling	14
	Rain Garden (Total)	61
Bioswale	Bioswale AND cooling	1
	Bioswale AND Heatwaves	0
	Bioswale AND Urban Heat Island	1
	Bioswale AND Temperature reduction	1
	Bioswale (Total)	3
Outdoor swimming pool	Outdoor swimming pool AND cooling	16
	Outdoor swimming pool AND Heatwaves	0
	Outdoor swimming pool AND Urban Heat Island	3
	Outdoor swimming pool AND Temperature reduction	3
	Outdoor swimming pool (Total)	22
Canal	Canal AND cooling	338
	Canal AND Heatwaves	1
	Canal AND Urban Heat Island	4
	Canal AND Temperature reduction	160
	Canal (Total)	503
Estuary/ tidal river	Estuary/tidal river AND cooling	0
	Estuary/tidal river AND Heatwaves	0
	Estuary/tidal river AND Urban Heat Island	0
	Estuary/tidal river AND Temperature reduction	0
	Estuary/ tidal river (Total)	0
River/ Stream	River/stream AND cooling	8
	River/stream AND Heatwaves	0

	River/stream AND Urban Heat Island	0
	River/stream AND Temperature reduction	7
	river* OR stream* AND Heatwaves	0
	river* OR stream* AND Urban Heat Island	0
	river* OR stream*AND Temperature reduction	0
	River/ Stream (Total)	15
River/ Stream	Reservoir AND cooling	3955
	Reservoir AND Heatwaves	15
	Reservoir AND Urban Heat Island	44
	Reservoir AND Temperature reduction	0
	Reservoir (Total)	4014
Lake	Lake AND Heatwaves	53
	Lake AND Urban Heat Island	167
	Lake AND Temperature reduction	0
	Lake AND cooling	4715
	Lake (Total)	4935
Sea	Sea (incl. coast) AND Heatwaves	0
	Sea (incl. coast) AND Urban Heat Island	495
	Sea (incl. coast) AND Temperature reduction	6957
	Sea AND cooling	15381
	(sea OR seaside OR coast* OR beach* OR shore and Heatwaves*)	0
	Sea (Total)	22833
Pond	Pond AND Heatwaves	0
	Pond AND Urban Heat Island	0
	Pond AND cooling	945
	Pond AND Temperature reduction	0

	Pond (Total)	945
Balcony/terrace	Balcony AND Heatwaves	1
	Balcony AND Urban Heat Island	7
	Balcony AND Temperature reduction	21
	terrace AND Urban Heat Island	16
	terrace AND Urban Heatwaves	1
	terrace AND Temperature reduction	233
	Balcony/terrace (Total)	279
Road verge	Riparian woodland AND heat waves	1
	Riparian woodland AND urban heat island	0
	Riparian woodland AND temperature reduction	7
	Riparian woodland AND cooling	20
	("riparian tree*" OR "riparian wood*" OR "riparian forest*") AND cooling	66
	("riparian tree*" OR "riparian wood*" OR "riparian forest*") AND heat waves	3
	("riparian tree*" OR "riparian wood*" OR "riparian forest*") AND urban heat island	4
	("riparian tree*" OR "riparian wood*" OR "riparian forest*") AND temperature reduction	30
	Riparian woodland (Total)	131
Playground	Playground AND Heatwaves	1
	Playground AND Urban Heat Island	9
	Playground AND Temperature reduction	19
	Playground AND cooling	33
	Playground (Total)	62
Golf course	Golf course AND Heatwaves	0
	Golf course AND Urban Heat Island	4

	Golf course AND Temperature reduction	11
	Golf course AND cooling	111
	Golf course(Total)	126
Shared open space	Shared open space AND Heatwaves	1
	Shared open space AND Urban Heat Island	4
	Shared open space AND Temperature reduction	10
	Shared open space AND cooling	44
	Shared open space(Total)	59
Cemetery	Cemetery AND Heatwaves	0
	Cemetery AND Urban Heat Island	5
	Cemetery AND Temperature reduction	1
	Cemetery AND cooling	12
	Cemetery (Total)	18
Allotment	Allotment AND Temperature reduction	5
	Allotment AND Urban Heat Island	6
	Allotment AND Temperature reduction	5
	Allotment AND cooling	15
	Allotment (Total)	31
City farm	City farm AND Heatwaves	1
	City farm AND Urban Heat Island	23
	City farm AND Temperature reduction	20
	City farm AND cooling	44
	City farm (Total)	88
Adopted public space	Adopted public space AND Heatwaves	1
	Adopted public space AND Urban Heat Island	13
	Adopted public space AND Temperature reduction	8

	Adopted public space AND cooling	18
	Adopted public space (Total)	40
Woodland	Woodland (other) AND Heatwaves	3
	Woodland (other) AND Urban Heat Island	8
	Woodland (other) AND Temperature reduction	34
	Woodland AND cooling	457
	Woodland (Total)	502
Grass (other)	Grass (other) AND Heatwaves	9
	Grass (other) AND Urban Heat Island	40
	Grass (other) AND Temperature reduction	155
	Grass (other) AND cooling	3041
	Grass (other) (Total)	3245
Arable agriculture	Arable agriculture AND Heatwaves	0
	Arable agriculture AND Urban Heat Island	0
	Arable agriculture AND Temperature reduction	0
	Arable agriculture AND cooling	24
	Arable agriculture (Total)	24
Private Garden	Private garden AND Heatwaves	0
	Private garden AND Urban Heat Island	5
	Private garden AND Temperature reduction	1
	Private garden AND cooling	13
	Private Garden (Total)	19
Shared common garden	Shared common garden area AND Heatwaves	0
	Shared common garden area AND Urban Heat Island	1
	Shared common garden area AND Temperature reduction	0

	Shared common garden area AND cooling	0
	Shared Common garden (Total)	1
Wetland	Wetland AND Heatwaves	15
	Wetland area AND Urban Heat Island	55
	Wetland AND Temperature reduction	589
	Wetland AND cooling	587
	Wetland (Total)	1246
Estuary	Estuary AND Heatwaves	22
	Estuary AND Urban Heat Island	13
	Estuary AND Temperature reduction	474
	Estuary AND cooling	428
	Estuary (Total)	937
Sports fields	Sports field AND Heatwaves	1
	Sports field AND Urban Heat Island	2
	Sports field AND Temperature reduction	25
	Sports field AND cooling	102
	Sports field (Total)	130
School yard	School yard AND Heatwaves	0
	School yard AND Urban Heat Island	2
	School yard AND Temperature reduction	0
	School yard AND cooling	3
	School yard (Total)	5
Shrubland	Shrubland (other) AND Heatwaves	0
	Shrubland (other) AND Urban Heat Island	0
	Shrubland (other) AND Temperature reduction	0
	Shrubland (other) AND cooling	16

	Shrubland (Total)	16
Sparsely vegetated land	Sparsely vegetated land AND Heatwaves	0
	Sparsely vegetated land AND Urban Heat Island	0
	Sparsely vegetated land AND Temperature reduction	0
	Sparsely vegetated land AND cooling	8
	Sparsely vegetated land (Total)	8

Table S3. Classification matrix to categorise the number of studies available for each of the GBGI sub-categories in terms of heat mitigation. Zero values indicate that there is negligible empirical evidence available for GBGI's against urban heat mitigation, including heatwaves.

Scale	Conditional performance (%)[a]	Evidence-based classification (%)[b]	Number of GBGI types[c]
1	None	0	18
2	Very low	≥0 ≤20	15
3	Low	≥20 ≤40	9
4	Medium	≥40 ≤ 60	4
5	High	≥60 ≤80	1
6	Very High	≥80	4

[a]The number of publications from negligible to very high under the six-classification scale. [b]The percentage availability of publications for each classification scale. [c]The number of GBGI types found in each of the classification scales.

Table S4. The best performing GBGI types in each climate zone and sub-climate type with reported magnitude and measured scale (i.e. inside/outside of GBGI) of cooling providing details of surroundings.

	GBGI (Sub climate#1, and del T)	GBGI (sub climate#2, and del T)	Inside/outside (scale)	Nearby surrounding
Temperate	Wetland (Cfa, 10)	Park (Cfb, 9.2)	Wetland works well at meso scale (mostly	Near built-up area (park),

			inside) than micro, on the contrary park works better on micro-scale (inside and outside both).	Near nature (wetland)
Continental	Greenwall, Botanical garden (Dfb, 8.7 & 10)	Green roof and Botanical garden (Dwa, 10.8 & 10)	Works well at Microscale but not at meso and macro but the park can be suggested at the mesoscale. Green roof (inside, outside and top) botanical garden (inside-outside), green wall (near)	Built-up area (green wall and botanical garden) Green roof (mixed environment of grey and nature)
Dry	Wetland, Pocket park (BWh, 12 & 7))	-	Microscale wetland (inside) pocket park (inside-outside)	Wetland (near nature) Pocket park (built-up area)
Tropical	Roof garden (Af, 10)	-	Microscale (inside and top)	Built up area

Table S5. Sample size (n), correlation of population and p-value density, city area, altitude, ratio of GBGI and city area, and temporal cooling with reported cooling by GBGI in four different climatic conditions i.e. continental, dry, temperate and tropical.

Climate Zone		Correlation	P-value
Population density (n = 34)	Continental	0.0183	0.919
(n = 15)	Dry	0.193	0.4791
(n = 137)	Temperate	-0.013	0.8827
(n = 16)	Tropical	0.2241	0.404
City Area	Continental	0.018	0.9189

(n = 15)	Dry	0.1981	0.4791
(n = 137)	Temperate	-0.013	0.8827
(n = 16)	Tropical	0.22	0.404
Altitude	Continental	0.135	0.4449
(n = 15)	Dry	0.0158	0.9552
(n = 137)	Temperate	-0.089	0.2975
(n = 16)	Tropical	0.325	0.2188
Ratio GBGI/city	Continental	0.0917	0.606
(n = 15)	Dry	-0.117	0.6768
(n = 137)	Temperate	-0.017	0.8386
(n = 16)	Tropical	-0.328	0.2142
Temporal cooling	Continental	0.208	0.2367
(n = 15)	Dry	0.1132	0.6879
(n = 137)	Temperate	0.0399	0.6427
(n = 16)	Tropical	0.2824	0.2892

Table S6. The location, study types (in-situ, modelling, combined (in-situ and modelling), and remote sensing), and performance in reducing temperature **(ΔT °C)**) of different types of GBGI categories against extreme heat extracted from 202 papers.

GBGI Type		GBGI Categories	Location (city, country)	Study type	Performance ΔT (°C)	Reference (Year)
Gardens		Balcony	Vienna	Monitoring	4	Teichmann et al.[31]
			Malaysia	Monitoring	1.7	Toe and Kubota[32]
			Tehran, Iran	Modelling	7	Aghasizadeh et al.[33]
			China	Modelling	3.8	Cui and Zheng[34]
			Lublin,	Monitoring	0.22	Grudzińska[35]

			Poland			
			Tampere, Finland	Monitoring	2	Hilliaho et al.[36]
			Zamo, Poland	Modelling	7.6	Grudzińska[37]
		Private garden	Melbourne, Australia	Monitoring	2.3	Cheung et al.[38]
		Irrigating backyard	Sydney, Australia	Modelling	3	Gao et al.[39]
			Adelaide, Australia	Modelling	2.3	Broadbent et al.[40]
			United States	Remote Sensing	3.74	Wang et al.[41]
Parks		Pocket Park	Hong Kong	Monitoring	0.38	Lau et al.[42]
			Hong Kong	Monitoring	1.09	Lin et al.[433]
			New York	Monitoring	0.5	Rosso et al.[44]
			Veszprém, Hungary	Modelling	0.6	Trájer et al.[45]
			Xi'an, China	Modelling	1.1	Hou et al.[46]
			Xi'an, China	Monitoring & Modelling	0.43	Ma et al.[47]
			Shanghai, China	Monitoring	3.6	Wu et al.[48]
			Cairo Metropolitan Area, Egypt	Modelling	7	Ibrahim[49]
			Hong Kong	Monitoring & Modelling	0.13	Huang et al.[50]
		Park	Chongqing, Southwest China	Modelling	0.8	Lu et al.[51]

			Abuja, Nigeria	Remote Sensing	2.04	Chibuike et al.[52]
			Shenzhen City, China	Monitoring	5.15	Zhang et al.[53]
			Yreb, China	Remote Sensing	2.34	Shi et al.[54]
			Xian, China	Monitoring	0.78	Du et al.[55]
			Shenzhen, China	Remote Sensing	3.02	Peng et al.[56]
			Taipei, Taiwan	Monitoring & Modelling	2.42	Yang et al.[57]
			Wuhan, China	Monitoring	3.5	Chen et al.[58]
			Kolkata Metropolitan Area, India	Remote Sensing	3.15	Das et al.[59]
			Beijing, China	Monitoring	1.38	Zhou et al.[60]
			Melbourne, Australia	Remote Sensing	3.28	Algretawee[61]
			Beijing, China	Remote Sensing	1.71	Qiu and Jia[62]
			Beijing, China	Monitoring	1.09	Li et al.[63]
			Austin, US	Remote Sensing	6.89	Gao et al.[64]
			Taiwan	Monitoring & Modelling	2.42	Yang et al.[65]
			Özgürlük Park, Istanbul, Turkey	Monitoring & Modelling	2.3	Şimşek et al.[66]
			Beijing, China	Monitoring	2.71	Li et al.[67]

			Hong Kong	Monitoring	4.9	Cheung er al.[68]
			Melbourne, Australia	Remote Sensing	10	Algretawee[69]
			Beijing, China	Monitoring	4.8	Yan et al.[70]
		Botanical garden	Baoji, China	Monitoring	2.7	Chang and Li[71]
			Erzurum, Turkey	Monitoring	2.6	Irmak et al.[72]
			Beijing, China	Monitoring	10	Su [73]
			Erzurum, Turkey	Monitoring & Modelling	2.2	Yilmaz et al.[74]
			Erzurum, Turkey	Monitoring	7.1	Yilmaz et al.[75]
Amenity areas		Sports field	Khalifa stadium in Doha, Qatar	Monitoring & Modelling	3.1	Ghani et al.[76]
		Playground	Warsaw, Poland	Monitoring	5	Kuchcik et al.[77]
			United States	Remote Sensing	5.5	Vanos et al.[78]
		Golf course	Perth, Australia	Remote Sensing	6	Nguyen et al.[79]
		Shared open space	Maxvorstadt, Munich	Modelling	2.1	Zölch et al.[80]
Other public spaces		Cemetery	Budapest's, Hungary	Monitoring	1.7	Sallay et al.[81]
		Allotment	Berlin, Germany	Remote Sensing	4	Rost et al.[82]
		City farm	Phoenix, Arizona	Monitoring	3.9	Hawkins et al.[83]
			Paris, France	Modelling	3	Masson et al.[84]

		Adopted public space	Raiganj, West Bengal, India	Monitoring & Modelling	3	Basu and Das[85]
			Bologna, Italy	Modelling	3	Boeri et al.[86]
			Liverpool, NSW, Australia	Modelling	1.5	Abdollahzadeh and Biloria[87]
Linear features/routes		Street tree	Hangzhou city, Zhejiang Province, China	Monitoring	1.8	Cai et al.[88]
			Turin, Italy	Monitoring	0.5	Morabito et al.[89]
			Florence, Italy	Modelling	9.4	Napoli et al.[90]
			Nanjing , Jiangsu Province, China	Modelling	5.5	Xi et al.[91]
			Karachi, Pakistan	Modelling	1.2	Zeeshan et al.[92]
			Abu Dhabi	Monitoring & Modelling	0.9	Abu Ali et al.[93]
			Rome, Italy	Remote Sensing	3.2	Marando et al.[94]
			Karachi, Pakistan	Modelling	1.2	Zeeshan et al.[95]
			Montreal, Canada	Modelling	4	Wang et al.[96]
			Vancouver, Canada	Remote Sensing	12	Lachapelle et al.[97]
			Barcelona, Spain	Modelling	1.3	Segura et al.[98]
			Shenyang,	Monitoring	2.9	Miao et al.[699]

			China			
			Prague Czech Republic	Modelling	5	Geletic et al.[100]
			Basel, Switzerland	Monitoring & Modelling	2	Mussetti et al.[101]
			Bangalore, India	Monitoring	5.6	Valishery et al.[102]
			Dresden, Germany	Monitoring	2.22	Gillner et al.[103]
			Melbourne, Australia	Monitoring	1.5	Coutts et al.[104]
			Richmond, Australia	Monitoring	2.1	Sanusi et al.[105]
			Vancouver, Canada	Modelling	7.1	Aminipour et al.[106]
			Tsukuba City, Japan	Monitoring	5.9	Kusaka et al.[107]
		Road verge	Jongro, Seoul, Republic of Korea	Monitoring	4.44	Cho[108]
			Taipei, Taiwan	Monitoring	0.68	Huang and Li[109]
			New Belgrade, Serbia	Monitoring	2.1	Stojanovic et al.[110]
			Kuala Lumpur, Malaysia	Monitoring	1.3	Zaki et al.[111]
			Haikou, China	Modelling	2	Zheng et al.[8112]
			Czech Republic	Monitoring & Modelling	0.05	Žižlavská et al.[113]

		Riparian woodland	Sydney, Australia	Monitoring	1.16	Adams and Smith[1144]
			Ejina basin, China	Monitoring	1.28	Yonghong et al.[115]
			Yorkshire, England	Monitoring	3	Tsai et al.[116]
			Glen Girnock, UK	Remote sensing	5.4	Dugdale et al.[117]
			Beijing, China	Monitoring	3	Zheng et al.[118]
		Hedge	Beijing, China	Modelling	2.68	Zhang and Hu[119]
			Lazio, Italy	Modelling	3	Peluso et al.[120]
			Rome, Italy	Modelling	3	Del Serrone et al.[121]
			Shenzhen, China	Monitoring & Modelling	1.29	Zou et al.[1222]
			Sakai, Japan	Remote Sensing	7	Yoshida et al.[123]
		Green roof	Berlin, Germany	Modelling	0.44	Wang et al.[124]
			Mandaue, Philippines	Modelling	1.1	Cortes et al.[125]
			Sydney, Australia	Monitoring	9.63	Fleck et al.[126]
			Xiamen, China	Remote Sensing	0.91	Dong et al.[127]
			Belgrade, Serbia	Monitoring	5.5	Kostadinovic et al.[128]
			Nanjing, China	Monitoring	1.1	Peng et al.[129]
			Tseung Kwan O New Town,	Monitoring	4.9	Lee and Jim[130]

			Hong Kong, China			
			Neubrandenburg, Germany	Monitoring	1.5	Kohler and Kaiser[131]
			Gangnam-gu, Seoul, South Korea	Monitoring	10.8	Park et al.[132]
			Jerusalem and Tel Aviv	Monitoring & Modelling	0.4	Lynn and Lynn[133]
			Shenzhen, China	Monitoring	4.03	Chen et al.[134]
			Mandaue, Philippines	Modelling	1.1	Cortes et al.[135]
			Utrecht, The Netherlands	Monitoring	0.2	Solcerova[136]
			Lodz, Poland	Modelling	0.19	Bochenek and Klemm[137]
			Guangzhou, China	Modelling	0.1	Chen et al.[138]
			Hamad, Northern Bahrain	Modelling	0.72	Elnabawi and Saber[139]
			Chengdu, China	Monitoring	0.94	Zuo et al.[140]
			Rome, Italy	Modelling	0.16	Iaria and Susca[141]
			Sydney, Australia	Monitoring	2.92	Fleck et al.[142]
			Cordoba, Argentina	Monitoring	0.892	Robbiati et al.[143]
Constructed GI on infrastructure		Green wall	Changsha, Hunan Province, China	Modelling	0.49	Liao et al.[144]

			Reading, UK	Remote Sensing	6.3	Cameron et al.[145]
			Guangzhou, China	Monitoring	3.6	Zhang et al.[146]
			Shanghai, China	Modelling	1.02	Liu et al.[147]
			Reading, UK	Monitoring	3	Cameron et al.[148]
			Madrid, Spain	Monitoring	2.7	Jesus et al.[149]
			Hong-Kong	Monitoring	1.19	Lee and Jim[150]
			Rio de Janeiro, Brazil	Modelling	1.16	Feitosa and Wilkinson[151]
			Zürich, Switzerland	Modelling	0.1	Li et al.[152]
			Prague, Czech Republic	Monitoring & modelling	2	Geletič et al.[153]
			Ljubljana, Slovenia	Remote Sensing	18.9	Šuklje et al.[154]
			Tyrol, Austria	Monitoring	8.7	Medl et al.[155]
			Sydney, Australia	Monitoring	7.7	Feitosa and Wilkinson[156]
			Bari,Valenzano, Italy	Monitoring	7	Blanco et al.[157]
			Pertth, Western Australia	Monitoring	8.1	Bakhshoodeh et al.[158]
			Quito, Ecuador	Modelling	1.43	Davis et al.[159]
			London Olympic Park	Monitoring	1.5	Hosseinzadeh et al.[160]

			La Rochelle, France	Modelling	1.9	Djedjig et al.[161]
			Chennai, India	Modelling	1.2	Pragati et al.[162]
			Guangzhou, China	Monitoring	8	Lin et al.[163]
			United States	Monitoring	4.3	Price et al.[164]
			Hong Kong	Monitoring	1.2	Lee and Jim [165]
			Munich, Germany	Modelling	3.5	Lin et al.[166]
			Chenzhou, Hunan, China	Modelling	2.56	Li et al.[167]
		Roof garden	Nanjing, China	Monitoring	1	Peng et al.[168]
			Xinxiang, Henan, China	Monitoring	1	Shen [169]
			Duhok, Iraq	Monitoring	3	AbdulBaqi [170]
			Seoul, South Korea	Modelling	0.3	Kim et al.[171]
			Hong Kong	Monitoring	1.8	Lee and Jim [172]
			Singapore	Monitoring	17.7	Tan et al.[173]
			Singapore	Remote Sensing	10	Tan et al.[174]
		Pergola	Nagoya, Japan	Remote Sensing	16.2	Watanabe et al.[175]
			Arta, Greece	Monitoring & Modelling	1.3	Katsoulas et al.[176]
			Lleida, Spain	Monitoring	3.1	Chafer et al.[177]

			Suwon, Republic of Korea	Monitoring	0.2	Kong et al.[178]
			Vienna, Austria	Monitoring & Modelling	4	Teichmann et al.[179]
Hybrid GI		Permeable paving	Vertemate con Minoprio, CO, Italy	Monitoring	2.8	Fini et al.[180]
			Perugia, Italy	Monitoring	9.2	Kousis et al.[181]
			Zhouzhi County, Xi'An, Shaanxi, China	Monitoring	6	Lu et al.[182]
			Rome, Italy	Modelling	0.6	Moretti et al.[183]
			Guangzhou, China	Monitoring	1	Wang et al.[184]
			Changping China	Monitoring	0.19	Wang et al.[185]
		Attenuation pond	Guangzhou, China	Monitoring	7	Yang et al.[186]
		Rain garden	Yau Tsim Mong district, Hong Kong	Modelling	1.3	An et al.[187]
			Tucson, Arizona	Monitoring	5.2	Buzzard et al.[188]
			Gdansk, Poland	Monitoring	7	Kasprzyk et al.[189]
Waterbodies		Wetland	Zoige Plateau, China	Monitoring	2	Bai et al.[190]
			Beijing, China	Remote Sensing	7.83	Cai et al.[191]

			Vienna, Austria	Monitoring	3.4	Pucher et al.[192]
			Avondale, Arizona	Remote Sensing	12	Ruiz-Aviles et al.[193]
			Dhaka, Bangladesh, Anatolia	Modelling	3	Shahjahan et al.[194]
			Central Anatolia, Turkey	Remote Sensing	4.38	Şimşek and Ödül[195]
			Beijing, China	Monitoring	3.15	Sun et al.[196]
			Eastern Germany	Modelling	1.6	Sušnik et al.[197]
			Palembang City, Indonesia	Monitoring	1.2	Triyuly et al.[198]
			Chengdu, China	Monitoring	4.08	Wu et al.[199]
			Wuhan, China	Monitoring	4.8	Xu et al.[200]
			Hangzhou, China	Remote Sensing	9.27	Zhang et al.[201]
			Northeast China	Remote Sensing	8.15	Wenguang et al.[202]
			Prairie Pothole Region, North America	Remote Sensing	3	Zhang et al.[203]
			Beijing, China	Remote Sensing	2.6	Sun et al.[204]
		Lake	Hue Citadel, Hue City, Vietnam	Remote Sensing	2.82	Le Phuc et al.[205]
			Altenberge, Germany	Modelling	0.8	Theeuwes et al.[206]

			Wuhan, China	Monitoring	4.2	Xu et al.[207]
			Daming lake, Jinan, China	Monitoring	1.9	Yang et al.[208]
		Reservoir	São José do Rio Preto, Brazil	Monitoring	5	Masiero and de Souza[209]
			Northern, Spain	Monitoring	2	Novo et al.[210]
			Santander, Spain	Monitoring	1.82	Novo et al.[2111]
		Sea	Athens, Greece	Monitoring & Modelling	1.7	Dandou et al.[212]
			Sendai, Japan	Monitoring	1.3	Zhou et al.[213]
			Adelaide, Australia	Monitoring	0.9	Zhou et al.[214]
			South Australia	Monitoring	2	Zhou et al.[215]
			Wuhan, China	Modelling	0.4	Zhu et al.[216]
Other non-sealed urban area		Woodland	Guildford, UK	Monitoring	5.7	Sahani et al.[217]
			Hong Kong Golf Course	Monitoring	1.43	Fung and Jim[218]
			Hong Kong Golf Course	Monitoring	4.2	Fung and Jim[219]
			Ejina basin	Monitoring & Modelling	1.28	Yonghong et al.[220]
			Baoji Botanical Garden	Monitoring	2.7	Chang and Li[221]
			Beijing, China	Monitoring	1.32	Liu et al.[222]

			Xi’an, China	Remote Sensing	4.32	Ma et al.[223]
			Hong Kong	Monitoring	2.9	Fung and Jim[224]
		Grass (other)	Sydney, Australia	Monitoring	2.94	Adams and Smith[225]
		Shrubland (other)	Howard Valley, South Island, New Zealand	Monitoring	3	Callard et al.[226]
Mixed (Green-Blue)		Mixed (Green-Blue)	Olympic Forest Park, Beijing, China	Monitoring	0.4	Amani-Beni et al.[227]
			Beijing, China	Remote Sensing	1.32	Liu et al.[228]
			Nagpur, Maharashtra	Remote Sensing	3.6	Jain et al.[229]
			Igapó Lak, Latin American city	Monitoring	2.63	Targino et al.[230]
			Beijing, China	Monitoring & Modelling	0.4	Cheung and Jim[231]
			Olympic Area, Beijing, China	Remote Sensing	4.95	Dai et al.[232]

Table S7. The average performance of different types of GBGI categories, which were evaluated using in-situ, modelling, in-situ combined modelling, and remote sensing techniques for heat risk adaptation and mitigations. The '-' symbol indicates 'no data available'.

GBGI	GBGI Category	Monitoring ΔT (°C)	Modelling ΔT (°C)	RS ΔT (°C)	MM ΔT (°C)	Overall ΔT (°C)	Availability
Gardens	Balcony	2.0	6.1	-	-	4.06	Medium
	Private garden	2.3	-	-	-	2.30	Very low
	Irrigating backyard	-	2.7	3.7	-	3.20	Very low
Parks	Pocket Park	1.4	2.9	4.1	0.28	2.16	Medium
	Park	3.0	0.8	-	2.38	2.07	Very High
	Botanical garden	5.6	-	-	2.2	3.90	Low
Amenity areas	Sports field	-	-	-	3.1	3.10	Very low
	Playground	3.0	-	2.8	-	2.90	Very low
	Golf course	-	-	5.0	-	5.00	Very low
	Shared open space	-	2.1	-	-	2.10	Very low
Other public space	Cemetery	1.7	-	-	-	1.70	Very low
	Allotment	-	-	4.0	-	4.00	Very low
	City farm	3.9	3.0	-	-	3.45	Very low
	Adopted public space	-	2.3	-	3	2.63	Very low
Linear GI features/ routes	Street tree	2.8	4.3	7.6	1.45	4.05	Very High
	Road verge	2.1	2.0	-	0.05	1.39	Low

	Riparian woodland	2.1	-	5.4	-	3.76	Low
	Hedge	-	2.9	7.0	1.29	3.73	Low
Constructed GI on infrastructure	Green roof	3.9	0.5	0.9	0.4	1.43	Very High
	Green wall	4.7	1.5	12.6	2	5.21	Very High
	Roof garden	2.1	0.3	7.1	-	3.13	Medium
	Pergola	1.7	-	18.2	2.65	7.50	Low
Hybrid GI (for water)	Permeable paving	3.8	0.6	-	-	2.22	Low
	Attenuation pond	7.0	-	-	-	7.00	Very low
	Rain garden	6.1	1.3	-	-	3.70	Very low
Waterbodies	Wetland	3.1	2.3	6.7	-	4.05	High
	Lake	3.1	0.8	2.8	-	2.22	Low
	Reservoir	2.9	-	-	-	2.94	Very low
	Sea (incl. coast)	1.4	0.4	-	1.7	1.17	Low
Other non-sealed urban areas	Woodland (other)	3.1	-	4.3	1.28	2.89	Medium
	Grass (other)	2.9	-	-	-	2.94	Very low
	Shrubland (other)	3.0	-	-	-	3.00	Very low
Mixed (Green-Blue)	Mixed (Green-Blue)	1.5	-	3.3	0.4	1.74	Low

Table S8. The projected influence of future climate change on the choice of GBGI in various climate zones.

Climate zone	Previous/Current climate	Future climate	Present GBGI	Future GBGI
Continent	Dfa	Dfb	Street trees Permeable paving	Wetland
	Dfb	BSk	Botanical garden	Green wall Street trees
Dry	BSk	BSh	Balcony	Green wall, street trees
	BSk	BWk	Wetland	Woodland
Temperate (Europe)	Cfb	Cfa	Green roofs, Green walls, Woodland Reservoir City farm Riparian woodland	Parks Pocket parks Green walls Green roofs Lakes Grass
	Dfb	Cfa	Green roof Balcony Road verge Playground	Parks Pocket parks Green walls Green roofs Lakes Grass
Temperate (China)	Cwa	Am	Park Green wall Green roof Rain garden	Lakes Road verge
	Dwa	Cwa	Woodland Lake Green roof Road verge Pergola Roof garden	Green roof Adopted space wetland

Table 9. Summary of key stages and action points for implementing, replicating, and upscaling GBGI to mitigate urban heat.

Stages	Action points
Stakeholder engagement[a]	● Engage stakeholders early on, and from various sectors such as urban planning, public health, environmental agencies, and community organisations to identify and frame the heat risk problem and understand their concerns and priorities. ● Foster collaboration and participatory decision-making processes to ensure diverse perspectives are considered. ● Conduct workshops, interviews, and surveys to gather input and feedback from stakeholders. ● Involve residents, local businesses, and community groups to increase awareness and support.
Feasibility study of GBGI[b]	● Conduct a preliminary cost-benefit analysis to assess the feasibility and potential effectiveness of different GBGI measures. ● Consider factors such as implementation costs, maintenance requirements, technical feasibility, and expected benefits in terms of heat reduction and other co-benefits. ● Identify suitable locations for implementation based on the analysis of UHI intensity and vulnerability maps/zones. ● Explore funding options and potential partnerships to support implementation.
Assess co-benefits and dis-benefits of the GBGI[c]	● Consider the multiple co-benefits associated with GBGI, such as improved air quality, reduced stormwater runoff, enhanced biodiversity, and increased recreational opportunities. ● Assess potential dis-benefits, such as increased maintenance requirements, potential conflicts with existing infrastructure, allergic reactions, and displacement of vulnerable populations due to gentrification. ● Conduct a comprehensive cost-benefit analysis to evaluate the overall value and trade-offs of implementing GBGI.

Design GBGI measures[d]	● Select suitable GBGI measures based on the local context, including the climate, topography, available space, and community preferences. ● Incorporate GBGI elements such as trees, green roofs, green walls, and permeable surfaces to maximise shade, evapotranspiration, and cooling effects. ● Consider the use of native and drought-tolerant plant species for long-term sustainability and reduced water demand. ● Ensure proper placement and spacing of vegetation to optimise shading and air movement.
Policy and planning[e]	● Integrate GBGI strategies into urban planning and policy frameworks, such as comprehensive plans, zoning ordinances, and building codes. ● Develop heat mitigation plans that prioritise the implementation of GBGI measures in high-risk areas. ● Provide incentives, regulations, and guidelines to encourage the adoption of GBGI in private and public developments. ● Collaborate with relevant organisations to ensure coordination and alignment of policies, goals, and levelling up of sustainability agenda (e.g., SDGs, European Green Deal, Paris Climate Agreement).
Implementation[f]	● Establish partnerships and collaborations between governmental agencies, private sector organisations, and community groups for effective implementation. ● Allocate sufficient resources, including funding, staff, and technical expertise, for the installation and maintenance of the selected GBGI measures. ● Ensure proper construction practices and quality control to maximise the performance and longevity of implemented measures. ● Incorporate community engagement and education programs to foster stewardship and long-term support for the solutions in place.

Monitoring[g]	● Utilise relevant or a combination of in-situ measurements, remote sensing, and modelling methods to monitor the performance and effectiveness of GBGI used against heatwaves. ● Deploy and use weather stations, sensors, and satellite imagery to evaluate the efficacy of the GBGI measures. ● Collect data on temperature, humidity, air quality, and vegetation health to evaluate the impact of implemented measures. ● Employ modelling tools to simulate the cooling effects and assess potential future scenarios.
Evaluation[h]	● Conduct a comprehensive evaluation of the implemented GBGI measures to assess their effectiveness and cost-effectiveness. ● Compare the heat risk before and after implementation using temperature data, health indicators, and energy consumption. ● Analyse the economic, social, and environmental benefits achieved through the implementation of GBGI. ● Incorporate feedback from stakeholders and learn from the implementation process to inform future improvements.
Upscaling and replication[i]	● Develop strategies for upscaling and replicating successful GBGI measures in different neighbourhoods and cities. ● Share successful case studies and best practices to encourage replication in other areas and facilitate upscaling of GBGI measures. ● Adapt the GBGI approach to suit local contexts, considering factors like climate, social dynamics, and available resources. ● Develop training programs and capacity-building initiatives to support the replication and upscaling of GBGI measures. ● Foster knowledge exchange among cities and regions.

[a]Sherman and Ford[233]; O'Brien et al.[234]; [b]Coutts et al.[235]; [c]Curt et al.[236]; Ommer et al.[237]; [d]Dumitru et al.[238]; Kumar et al.[239]; [e]Davies et al.[240]; [e]European Green Deal[241]; [f]Di Pirro et al.[242]; Topal et al.[243]; [g]Augusto et al.[244]; [h]Frantzeskaki[245]; [i]Cortinovis et al.[246].

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