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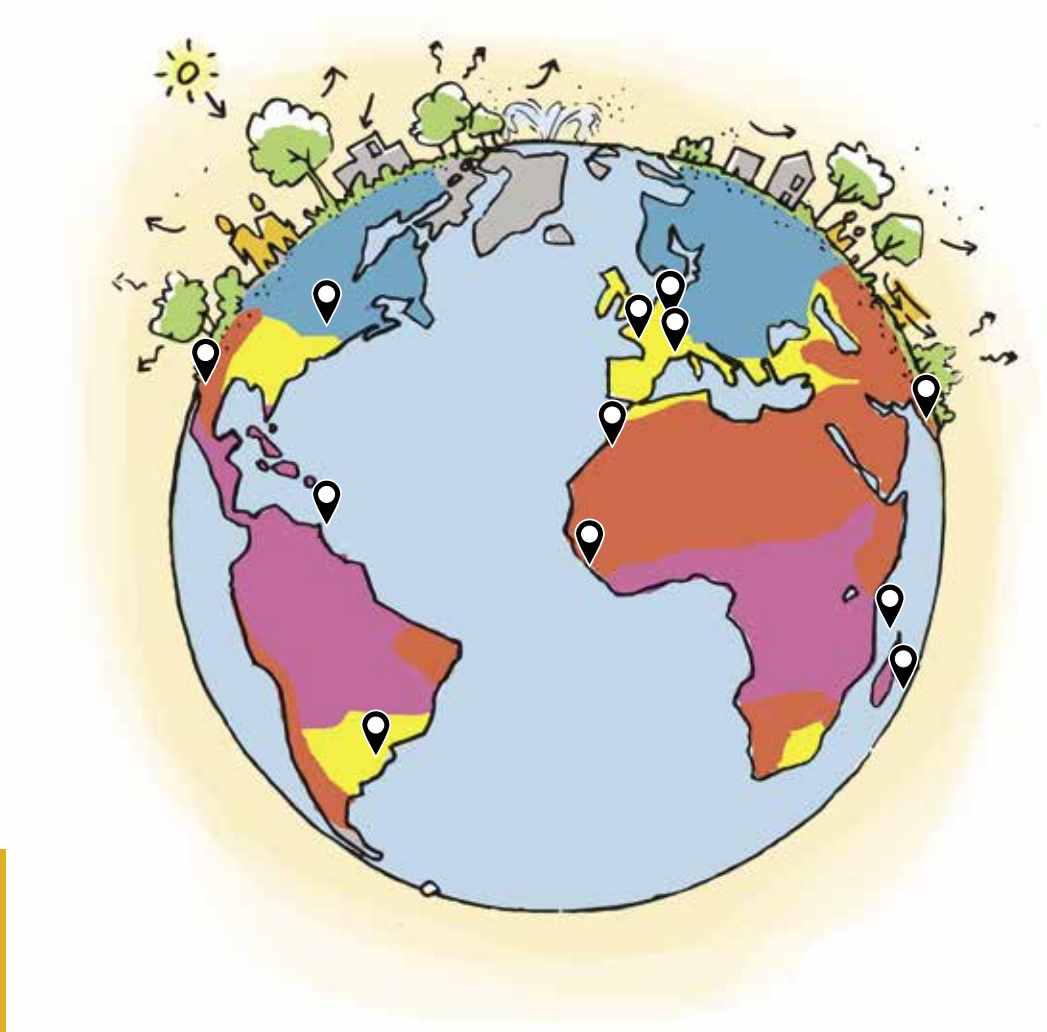

"ILS L'ONT FAIT" Collection

Urban cooling solutions

Drawing inspiration from worldwide case studies to address variability in current and future climates

AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT

This is an ADEME publication

ADEME
20, avenue du Grésillé
BP 90406 | 49004 Angers Cedex 01

Technical coordinator: ADEME: Elodie Briche

Technical advisors: ADEME: Muriel DESGEORGES, AFD: Samuel LEFÈVRE

Editors: ADEME: Olga Weil Flachat, Elodie Briche

Proofreaders: TRIBU: Marie Leroy-Thomas, Héloïse Marie
ADEME: Aurélie BERNARD, Elodie BRICHE, David CANAL, Vincent Chausserie-Laprée, Christelle CLAMAN, Pierre DEROUBAIX, Muriel DESGEORGES, Solène MARRY, Philippe MASSET, Marie-Pierre MEILLAN, Céline PHILLIPS, Johan RANSQUIN, Jérôme ROCH, Ariane ROZO, Hélène SABATHIÉ AKONOR, Daniela SANNA, Alicia TSITSIKALIS
AFD Gabriel CHARASSE, Aurélie GHUELDRE, Samuel LEFÈVRE, Benoit MAUDUIT, Matthieu MORANDO, Bertrand REYSSET, Oulfa SENNANI, Cédric VAUTIER

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CO-EDITORIAL

ADEME & AFD

In a world in which global warming has already reached +1°C on average, cities are being challenged - and will be even more challenged, according to Intergovernmental Panel on Climate Change (IPCC) projections - by numerous adverse impacts. These impacts are manifested in a slow and steady process that is pushing back coastlines on many continents, in occasionally devastating floods, and in increasingly common and acute heatwaves, all of which are detrimental to human health and well-being, urban infrastructure and development prospects of affected regions.

Against this background, in which more than half of the world's population is concentrated in urban areas and 60% of its citizens are expected to be urban dwellers by 2030, cities are emerging as crucibles of the green transition, thereby demonstrating that a new low-carbon and resilient development model is indeed feasible. They already represent a tremendously fertile ground for innovation and resources to mitigate and cope with climate change.

Hence, financing city adaptation and resilience is a priority in many parts of the world, particularly to advance energy-efficient and environmentally sustainable urban cooling initiatives.

This concurrent search for technical solutions and financing to help cities to adapt has spurred AFD and ADEME to broaden their cooperation in order to build their knowledge and share experience, as illustrated by this collection of international urban cooling solutions.

Arnaud Leroy,
Director of ADEME

Rémy Rioux,
Director of AFD

The ADEME & AFD partnership

Agence Française de Développement (AFD) and Agence de la Transition Ecologique (ADEME: French Agency for Ecological Transition) have been working hand in hand for many years, building synergies to make the ecological transition a lever for regional development and resilience.

In this regard, the Agence Française de Développement Group is determined to support the implementation of the Paris Agreement by engaging with cities in developing countries and French overseas territories. In 2020, more than €750 million in new funding was allocated to sustainable cities in developing countries, including approximately €250 million for urban resilience.

AFD has thus consistently scaled up its ambitions and the actions it takes in favour of adapting to climate change, with a fourfold increase in its funding between 2016 and 2020. The needs are immense, requiring the mobilisation of all development finance players with public development banks at the forefront. This is what motivated the Finance in Common Summit, endorsed by COP 26, which brought together all 450 public development banks worldwide for the very first time in November 2020 at the initiative of AFD and IDFC. Accounting for a total of 10% of global investments, this coalition holds out the hope of scaling up investments by bringing on board all players, including the private sector, in order to serve the needs of our cities.

In Europe and internationally, ADEME is a renowned multi-sector expert in climate change mitigation and adaptation. On all fronts of the ecological transition, it engages citizens, economic players and communities in order to empower them to evolve towards a more resource-efficient, low-carbon, fair and cohesive society. More especially, ADEME's sustainable urban development agenda revolves not only around urban planning, but also around operational development in a bid to facilitate capacity building for urban development stakeholders and the birth of pilot projects.

In terms of urban cooling, ADEME provides its technical expertise with a view to simplifying the move to action by advancing knowledge on efficiency of available solutions, providing guidelines and decision-making tools, and sharing feedback.

The partnership between ADEME and AFD thus provides a collective dynamic, allowing cities to share and build their know-how, better equipping them to fulfil their role in meeting the urgent challenges of climate change.

INTRODUCTION

Increasingly, climate change is taking centre stage in the transformation and management of regions, particularly urban regions.

Overall, amid the rising temperatures and increased incidence of extreme weather events, such as **heatwaves*** (in terms of intensity, duration and frequency), combined with the urban heat island effect, cities, urban infrastructure and communities are now extremely **vulnerable***.

As they attract an ever-growing concentration of people, cities are striving to counteract urban overheating, in order to stabilise or upgrade living conditions while cutting down their ecological footprint. In recent years, several international studies have been carried out and many urban cooling solutions tested.

This publication completes ADEME's literature on urban cooling by featuring case studies drawn internationally from outstanding development projects in a geographically and climatically diverse range of regions around the globe.

Bouéni secondary school, Mayotte, France
©LEU Réunion

Although the solutions showcased here do not claim to depict an exhaustive picture and have room for improvement, this collection equips urban planning, development and construction stakeholders with functional solutions tailored to cater to varying climate conditions and offering proven urban cooling potential.

The case studies cover projects of varying sizes - from building to city - and different time frames - from short to long term. Each project is described in detail with regard to the lessons learned for other regions and the resulting co-benefits.

This collection thus equips urban designers and planners with valuable insights into how urban cooling solutions can be rolled out in response to current and future climatic types, and how to set up strategies allowing their regions to adapt to the effects of climate change.

For.further reference

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CHAPTER 1

Cooling cities to cope with climate change

This first part introduces the reader to this international collection of case studies in urban cooling. It reiterates the definition of the concept of urban overheating, the contributions of cooling solutions to climate change adaptation, as well as the time and space scales considered in compiling the case studies.

Tetouan, Morocco
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Issues and challenges

Definitions

An urban heat island (UHI)* is the temperature difference observed between an urban area and a nearby rural area. These temperature differences are more pronounced at night, and are strongly correlated with density, urban geometry, as well as the materials used for buildings and public spaces. UHI is mainly a night-time phenomenon owing to the fact that cities typically receive less night-time cooling than the adjoining countryside, where the greenery is more luxuriant. For instance, this is reflected in an annual average night-time temperature difference of around 2 to 3 °C between Paris and its surrounding rural and wooded areas (Météo-France, 2013). UHI is a typical urban climate phenomenon that may occur in every city worldwide.

Urban overheating* encompasses both UHI and the thermal discomfort experienced by city dwellers on hot days. Urban overheating can indeed be experienced by day and by night and at all levels from the city to the individual (ADEME, 2017). As such, urban overheating may adversely affect the health of city dwellers, especially the vulnerable such as children, the elderly, *etc.*

Urban cooling, a major lever for urban adaptation to climate change

Cooling is a major lever for cities in the context of climate change, particularly with the increasing incidence of heatwaves (ADEME, 2020). Local authorities around the world have increasingly embarked on development projects related to the ecological transition of cities.

However, climate change mitigation and adaptation are only sketchily reflected in planning documents and operational development projects worldwide. Local authorities are pondering the urban overheating phenomenon and rolling out cooling solutions, some of which contribute to adapting to with climate change. Indeed, the case studies featured in this publication demonstrate that green solutions being rolled out are **Nature-based Solutions (NbS) for adaptation*.**

Local communities are constantly adapting to climate change by minimising their vulnerability. Land development is a key driver for adapting to **climate risks*** such as flooding, which may change with the climate in future. For instance, the development of riverbanks can simultaneously mitigate the risk of flooding, while facilitating urban cooling now and in the future.

However, some solutions are hastily deployed to alleviate the climate emergency and are not always carefully designed in terms of sustainability and consistency with climatic timescales. For instance, the massive use of vegetation can be contradictory in some cases with the increased incidence of drought and the scarcity of water resources.

The aim of this publication is to showcase a variety of solutions: green, blue, and gray, taking into account the changing climatic types around the globe as well as the time and space scales of projects and regions undergoing transformation.

Understanding the Köppen-Geiger climate classification

The Köppen-Geiger climate classification* adopted in this collection is a simplified portrayal of the main "climatic landscapes" (Hufty, 2001), representing the world's five major vegetation covers. Owing to the fact that it is regularly updated, this is now a universally accepted depiction of climate types.

It primarily revolves around a combination of two climate-related factors that shape the distribution of vegetation, namely: air temperature and amount of water available (Beltrando & Chéméry, 1995).

It is used to draw up a climate typology divided into 5 major thermal zones identified by capital letters:
A - Tropical without cold season (equatorial forest, savannas),
B - Arid and semi-arid (deserts, steppes),
C - Temperate: mid-latitude climates with cold winters,
D - Continental: mid-latitude climates with very harsh winters,
E - Polar with climates without an actual warm season (tundra) or permanent frost,
(Beltrando & Chéméry, 1995).

Zones C and D are subdivided based on the thermal characteristics of the hotter or cooler summer. Indeed, the aim is to show that with this classification, a distinction can be made between dry summer Mediterranean-type climates (Cs) and rainy summer subtropical climates (Cw).

According to this classification, a climate can be identified by a two- or three-letter code: the first being the type of climate, the second being the rainfall regime and the third being the temperature changes.

In this collection, the classification allows an overview of urban cooling solutions in the different climate zones worldwide. However, it does not capture the unique features, such as topography, winds, *etc.* of the surrounding local climate for each urban development project presented here.

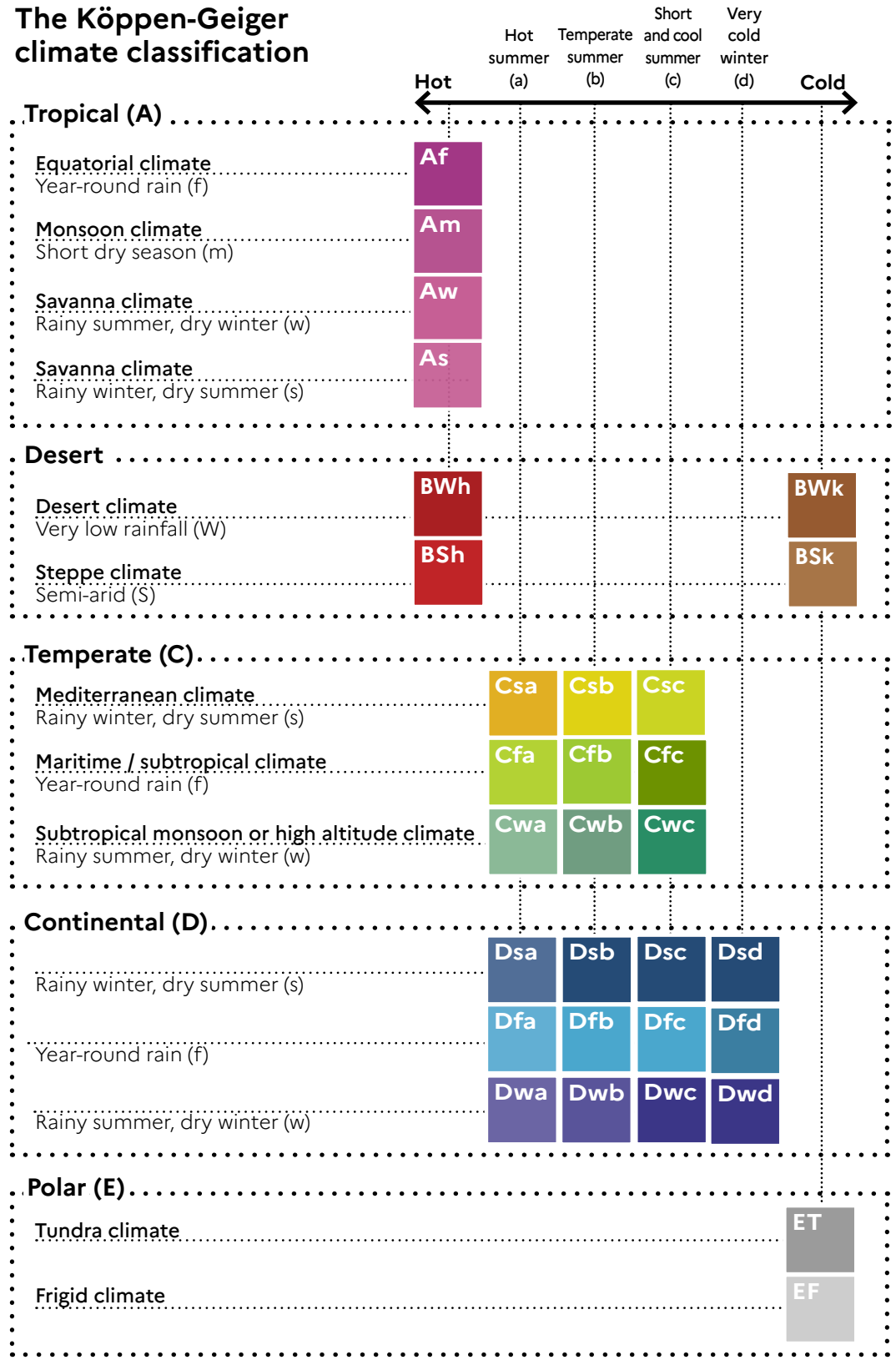
The table proposes a classification of the main climates (Hufty, 2001)

tm: minimum temperature
tM: maximum temperature

The Hufty classification

Thermal zones		Rainfall: Year round	In summer	In winter	Insuffi-cient
Hot	tm > 18 °C	Af	Aw	As	B
Temperate	tM > 10 °C -3 °C < tm < 18 °C	Cf	Cw	Cs	B
Continental	tM > 10 °C tm < -3 °C	Df	Dw	Ds	
Cold	0 °C > tM > 10 °C	ET			
Frigid	tM < 0 °C	EF			

The Köppen-Geiger climate classification



The current climate

The Köppen-Geiger climate classification of all the world's regions was devised for the current and future climate. (Beck *et al.*, 2018.)

The current climate map is derived from a set of high-resolution (10 km) and topographically-adjusted climate maps. The future climate map on the next page is drawn from a set of climate models depicting the **RCP 8.5*** (the worst case) scenario.

Tropical

- Af — Equatorial
- Am — Monsoon
- Aw As — Savanna

Temperate

- Csa Csb Csc — Mediterranean
- Cfa Cfb Cfc — Maritime
- Cwa Cwb Cwc — Subtropical

Polar

- ET — Tundra
- EF — Frigid

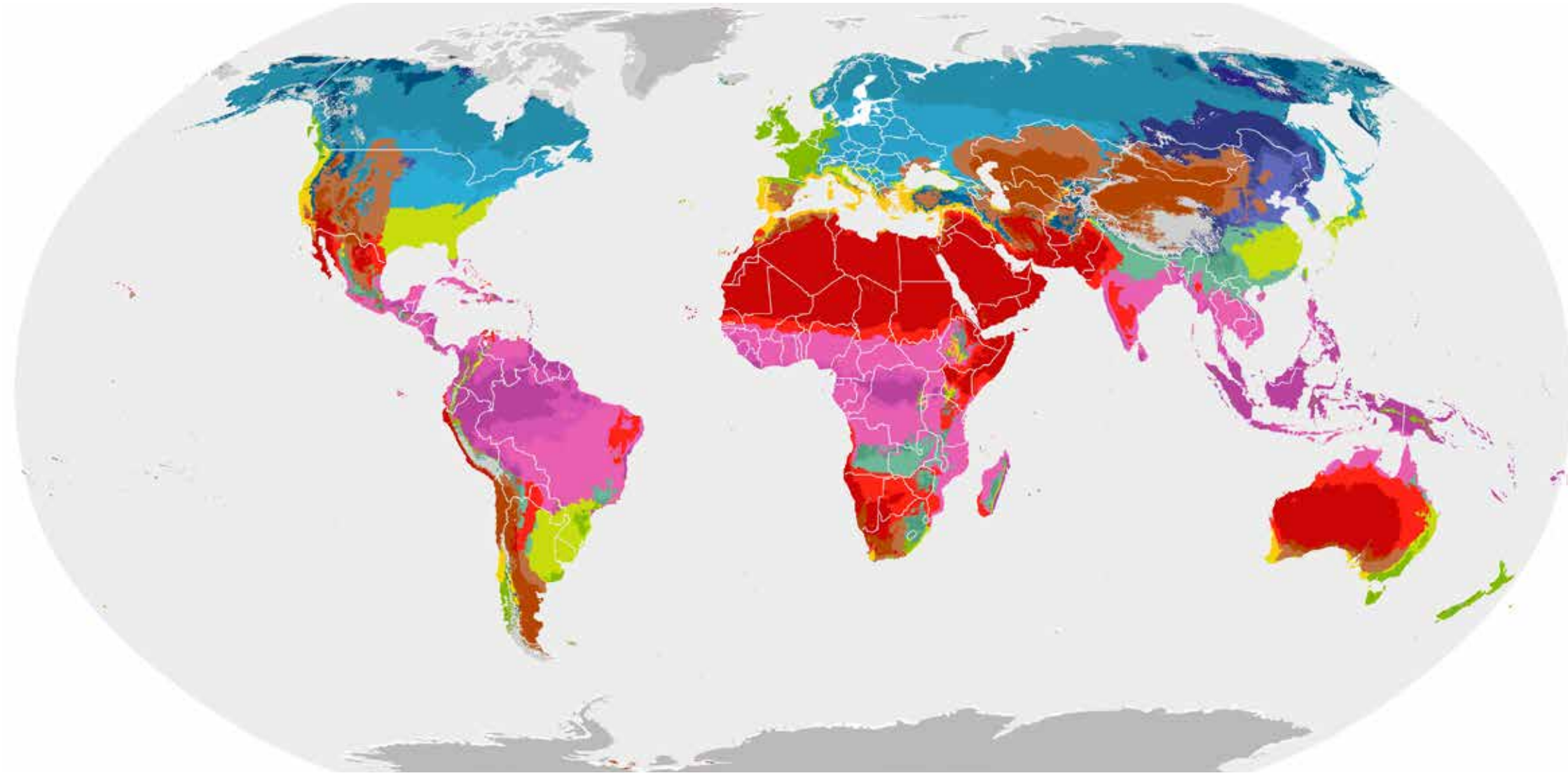
Desert

- BWh BWk — Desert
- BSh BSk — Steppe

Continental

- Dsa Dsb Dsc Dsd — Dry summer
- Dfa Dfb Dfc Dfd — Year-round rain
- Dwa Dwb Dwc Dwd — Dry winter

1980 - 2016



The future climate

Rising temperatures have become a clearly-established trend in climate change, with an increase of 2.5 to 5.5°C in the average temperature of the Earth's surface by 2100, according to the **IPCC's***, worst-case scenario, RCP 8.5. A spatial shift of climate types towards warmer climate types is being experienced:

- In Africa with a northward shift of the BSh and BWh climate types;
- In the northern hemisphere, the Dfb climate type is stretching northwards and eastwards;
- In the Mediterranean, the boundaries of the so-called Mediterranean climates are creeping northwards and further inland: in southern Spain, the desert climate has emerged;
- In France, the variability of climate types is amplified by the drier temperate climate types on the western front.
- In the Arctic, the arctic climate is shrinking on the margins of the continent, thus making way for the polar tundra climate.

Globally, more arid zones are emerging, as well as warmer climates.

Tropical
- Af — Equatorial
- Am — Monsoon
- Aw As — Savanna

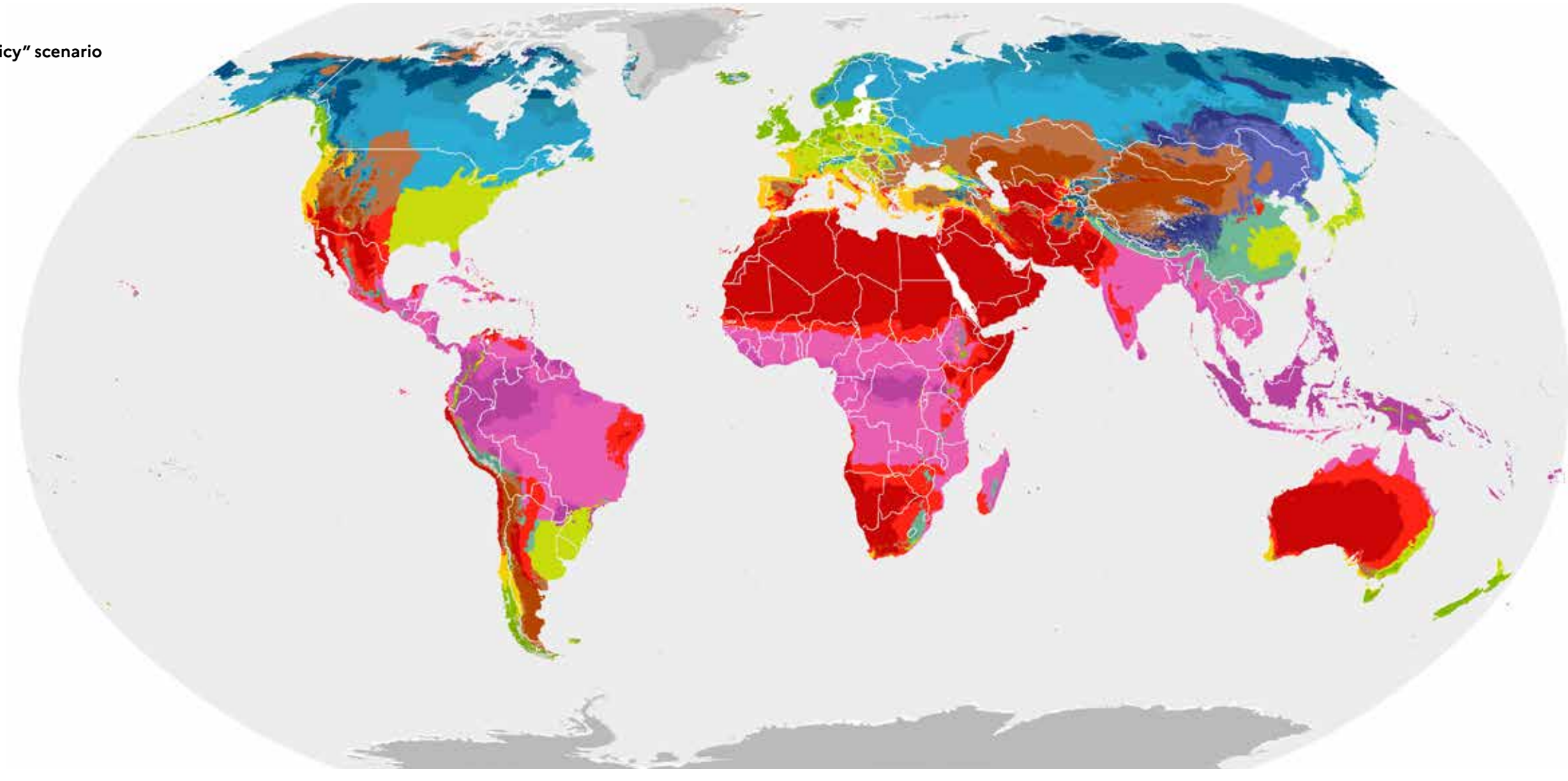
Desert
- BWh BWk — Desert
- BSh BSk — Steppe

Temperate
- Csa Csb Csc — Mediterranean
- Cfa Cfb Cfc — Maritime
- Cwa Cwb Cwc — Subtropical

Continental
- Dsa Dsb Dsc Dsd — Dry summer
- Dfa Dfb Dfc Dfd — Year-round rain
- Dwa Dwb Dwc Dwd — Dry winter

Polar
- ET — Tundra
- EF — Frigid

2071 - 2100
"No climate policy" scenario
RCP 8.5



Nantes
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Urban cooling project time and space scales

This publication features sixteen case studies of urban cooling solutions rolled out at various time and space scales and under varying climate conditions.

Project implementation time scales

The case studies shared in this collection encompass projects with different implementation time scales.

The "short-term" time scale applies to projects with cooling solutions that can be implemented within short time frames, in a fairly easy and even inexpensive manner. This is known as a "*Quick, Light, Cheap*" solution. The deadlines here are a matter of days or weeks. This is the case for the use of high-albedo coatings, planting of vegetation on a small scale or installation of solar protection on a building.

See Ahmadabad Montreal Los Angeles fact sheets

The "medium-term" time scale applies to more complex solutions that require more time to design, install and commission. This is the case for development of lakes, unsealing of the soil in public spaces or formation of community action groups to promote grassroots initiatives. Here, the deadlines are counted in months.

See Nantes Dakar Pointe-à-Pitre fact sheets

Finally, the "long-term" time scale applies to projects that require several years to be implemented. These include major urban development projects, such as **"Urban Development Zones (ZACs)"** in France, promotion of local traditions or development of mature trees in the city.

See La Possession Tetouan Zenata fact sheets

Time and space scales of the city and the climate

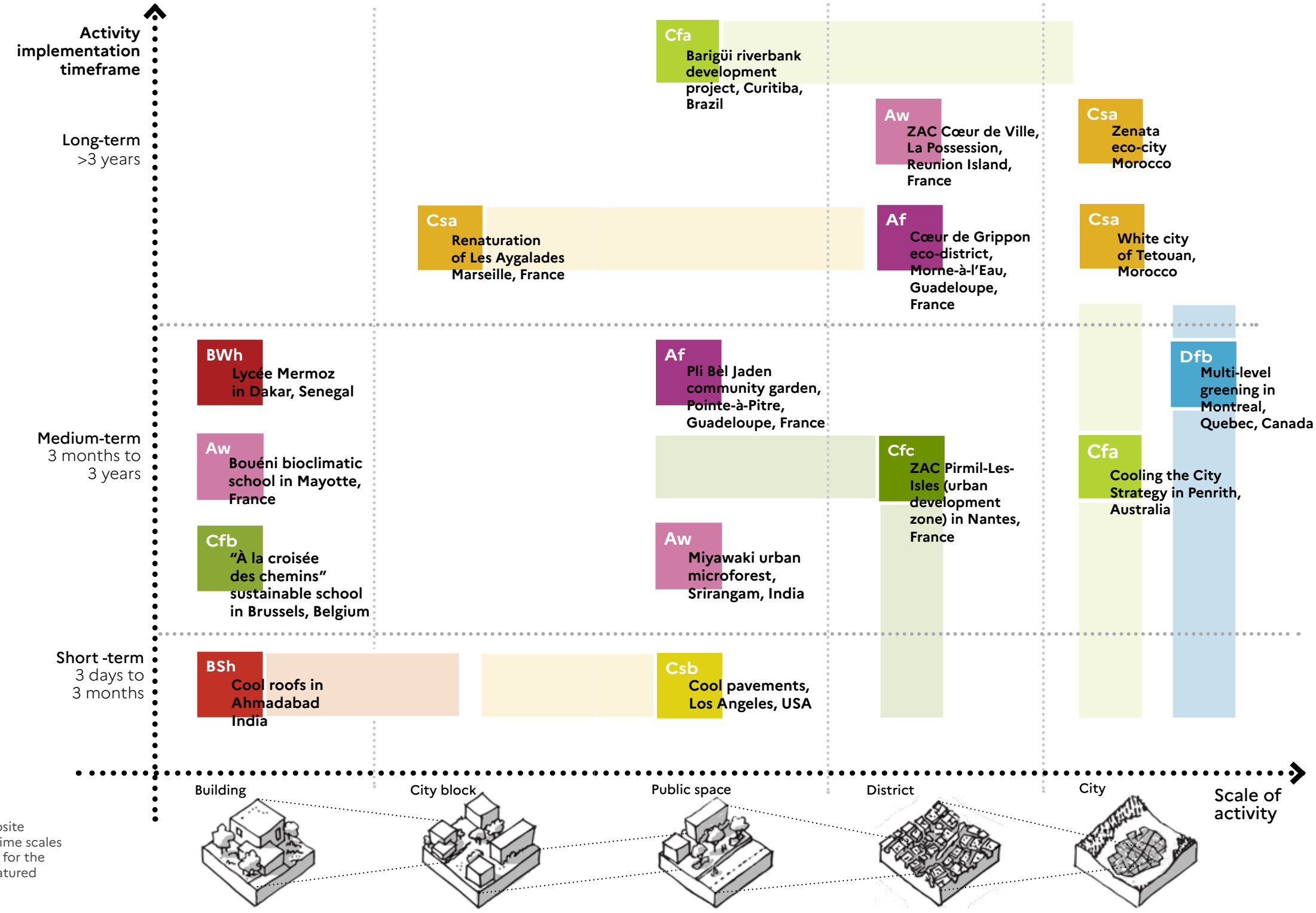
The case studies feature projects of varying sizes and time scales. Accordingly, the development projects presented implement urban cooling solutions on the scale of the city, districts, **public spaces***, city **blocks*** and buildings.
For instance, greening projects are implemented on the facades and roofs of buildings and extended to greening of streets and development of large-scale green infrastructure.

See Penrith Montreal fact sheets

Cooling solutions are also conditioned by the climate zones in which they are implemented.

The diagram below illustrates the space and time scales and climate types for the sixteen case studies presented in this collection.

Implementation scales and timeframes, and climate types in the case studies



The diagram opposite shows the space/time scales and climate types for the 16 case studies featured in this collection.

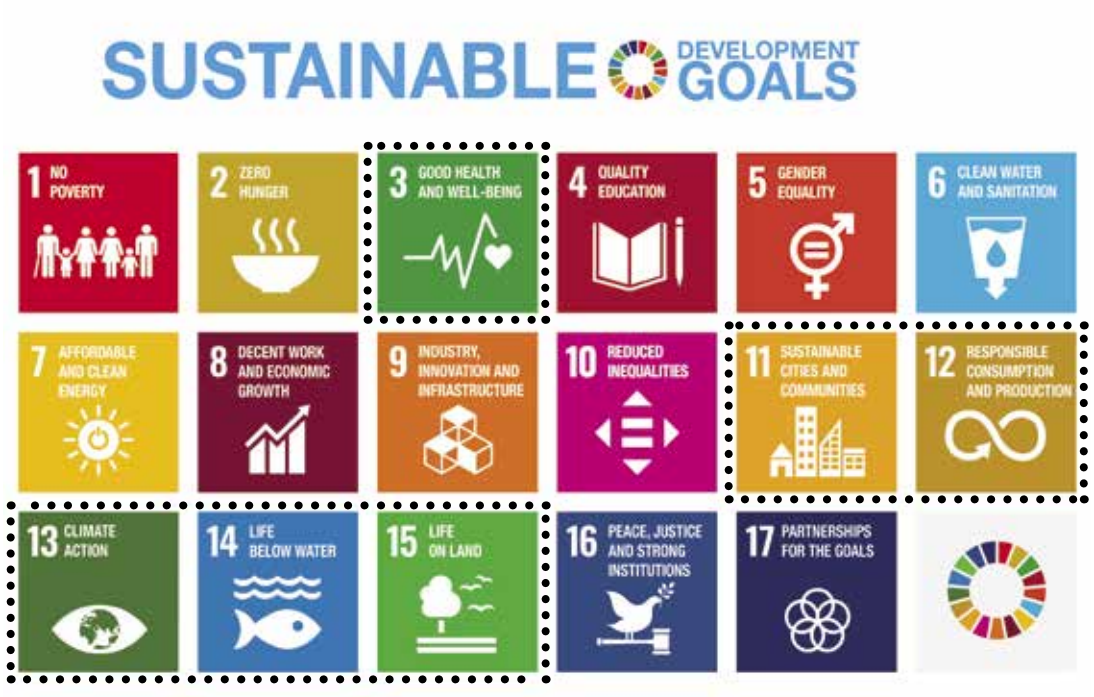
Co-benefits of urban cooling solutions

The aim of incorporating urban cooling solutions into development projects is to make our cities more restrained in their use of resources and better adapted to climate change.

This collection identifies the co-benefits or "positive externalities" of each operation for urban cooling. Indeed, the cooling solutions implemented in the case studies reported present a host of benefits for the urban system as a whole, including biodiversity, climate change mitigation, stronger social bonds and improved risk management.

The **Sustainable Development Goals (SDGs)*** set out by the UN's Agenda 2030 are targets for harmonious global development. As goals dealing with development, **well-being***, biodiversity protection, social and economic justice etc., they represent several co-benefits of the cooling solutions featured in this collection.

The six SDGs outlined below are highlighted in the case studies when discussing the co-benefits.



The solutions adopted in the case studies featured present several co-benefits in the field of sustainable development. The six main co-benefits are highlighted here:

Good health and well-being

Urban dwellers experience improved and healthier living conditions from the qualitative enhancements produced in the fight against overheating.

Climate action

Urban developments by cities to adapt to the effects of climate change can sometimes work in favour of carbon neutrality and improve mitigation.

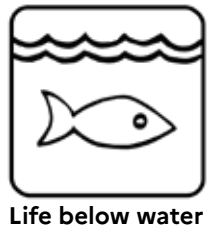
Responsible consumption and production

Sustainable soil management and development of urban and/or educational agriculture are catalysts for environmentally-responsible consumption and production.

Sustainable cities and communities

Some of the developments presented in the collection encourage the empowerment of local communities, development of community engagement processes and consolidation of social bonds.
Rational use of resources, adaptation to and mitigation of the effects of climate change, and resilience to disasters are also targets to be met.

Life on land



Life below water

Consideration of biodiversity issues in some of the development projects presented in this collection allow action to be taken to protect life on land and below water.

CHAPTER 2

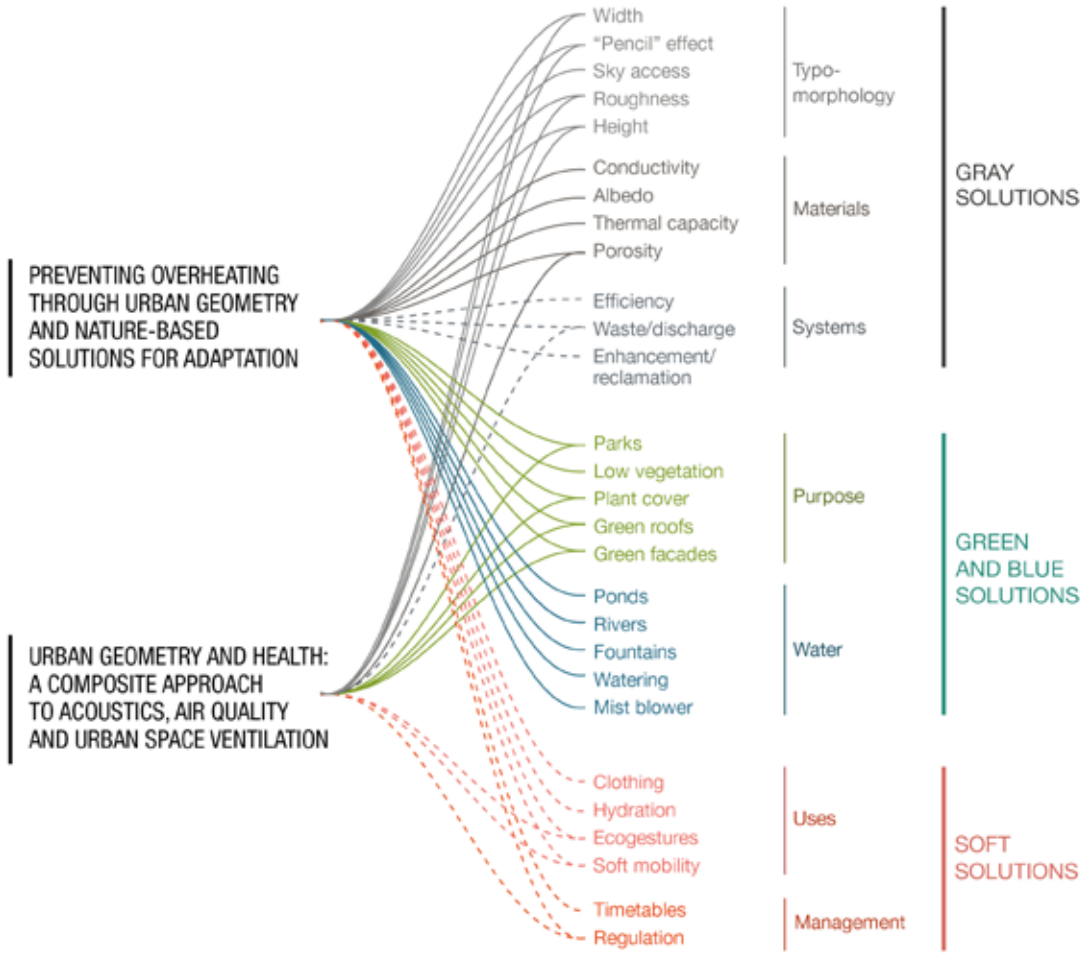
Urban cooling solutions

ZAC Cœur de Ville
La Possession,
Réunion Island
© LEU Réunion

Classification of solutions

According to the European Environment Agency (EEA), the vast array of current cooling solutions can be classified as follows (2013 classification):
- Green and blue solutions;
- Gray solutions;
- Soft solutions: these support changes to human behavioural patterns, customs and practices in the city (not developed here).

These solutions call for careful consideration on how their utilisation can optimised worldwide, particularly with respect to climate diversity. Their effectiveness is largely dependent on the climatic, geographical and topographical contexts in which they are implemented. Some cooling systems recognised as effective in temperate zones are not suitable for warmer and drier climates.



Classification of solutions to thermal comfort and health issues in urban spaces. The figure provides a graphic depiction of today's known urban cooling solutions, broken down into gray, green and blue solutions, as well as soft solutions.
Source: Franck Boutté Consultants

Classification of solutions

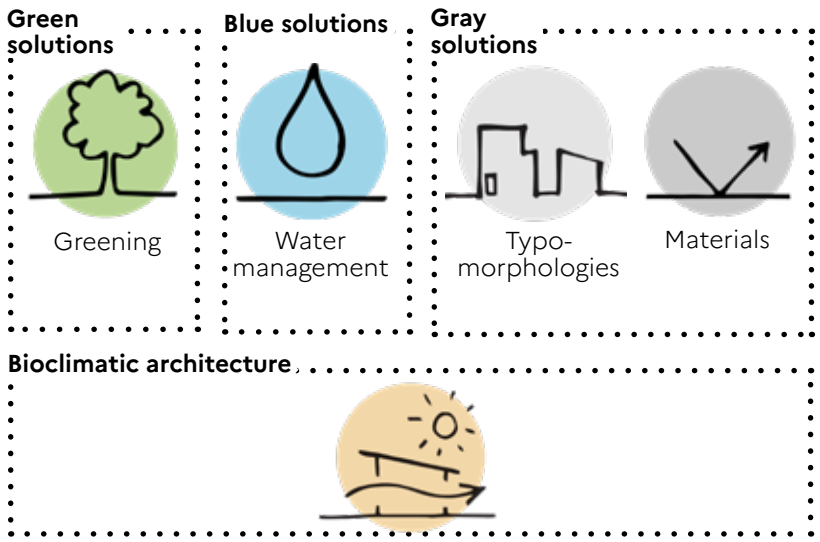
The most common example is greening, whose cooling potential, based on the evapotranspiration phenomenon, is maximised by the presence of water. This solution is not suitable for arid climates, as it would require a costly artificial water supply. The adaptation of cooling solutions to each region is also determined by future climate conditions. Global warming and the increased frequency and intensity of extreme weather events, such as summer heatwaves and droughts will make this cooling solution obsolete in many regions.

To ensure urban cooling and adapt cities to the effects of climate change, projects must incorporate both current climate conditions and future climate projections.

Some cooling solutions, such as greening, are based on services provided by ecosystems. In this respect, they combine protection, management and restoration of ecosystems. By responding both to the challenges of adapting to climate change and protecting biodiversity, these solutions have been labelled as Nature-based Solutions for (NbS) for adaptation. Their distinctive feature is that they offer other co-benefits, including well-being, carbon sequestration, *etc.*

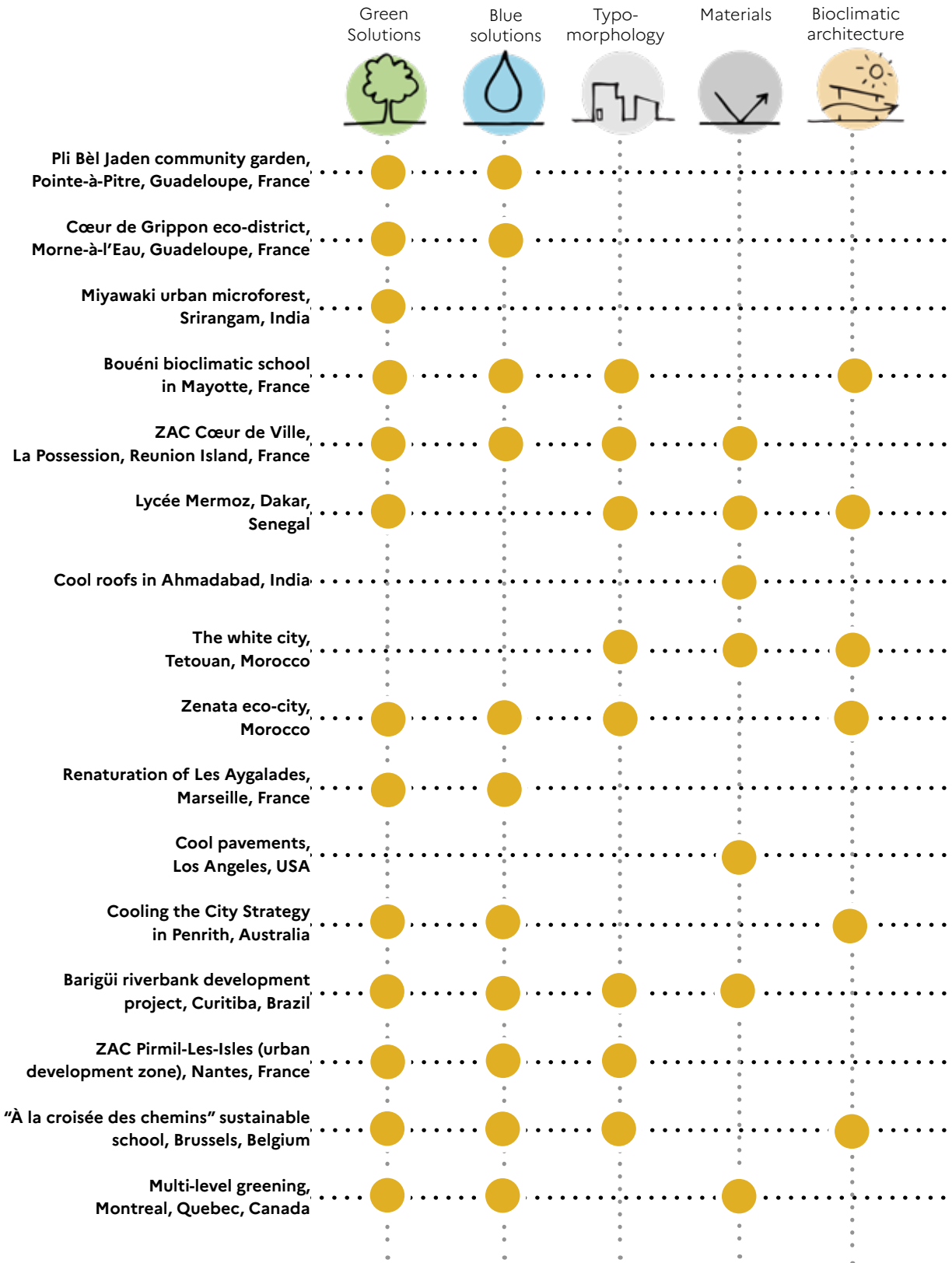
This collection features case studies of urban developments for cooling based on three types of such solutions: green solutions for greening, blue solutions for urban water management, gray solutions for action on materials and the **typo-morphological*** study of cities.

Here, **bioclimatic architecture*** is considered as a solution that cuts across all three types, invoking green, blue and gray solutions.



On left, the categories of cooling solutions used in this collection.

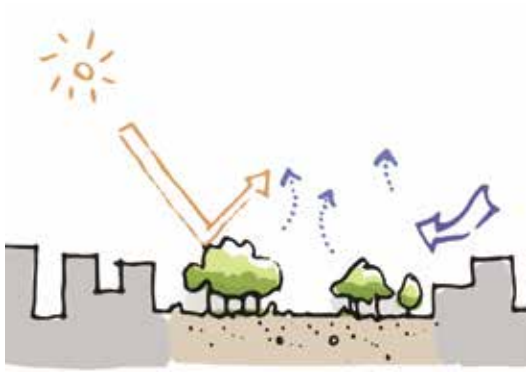
On right page, the different solutions used in each case study.



Green solutions

Cooling potential

Greening is a cooling solution regularly applied in urban development projects. It is driven by the combined effect of two phenomena: **evapotranspiration*** and shading.



Physical phenomena involved: evapotranspiration, shading, absorption of solar radiation.
©TRIBU/ADEME

Evapotranspiration is a physical phenomenon whereby liquid water in plants changes its state and evaporates on contact with the air through leaves and the soil. This change of state induces a drop in the ambient temperature. A mature tree can evaporate up to 450 litres per day (Johnston and Newton, 2004). The shading provided by plants creates cooler spaces for urban dwellers, since the canopy captures between 60% and 98% of solar energy (Giguère, 2009). Coupled with the cooling created by evapotranspiration, it has a beneficial effect on thermal comfort and lowers the ambient temperature.

Combining different vegetation strata maximises the cooling potential and diversifies the co-benefits for biodiversity. For instance, a combination of three vegetation strata can be considered, namely a herb layer, a shrub layer and a tree layer, which will act in synergy to provide cooling.

Strengths and points of caution

Urban space greening is a very valuable solution since, apart from its ornamental effect on the city, it equally presents numerous co-benefits. Among these are improved well-being of urban dwellers (Reeves-Latour, 2017) and better health (Beaudoin and Levasseur, 2017), protected biodiversity (Clergeau, 2018), carbon sequestration and minimised pollution with filtration of roughly 85% of polluting particles in the atmosphere (Johnston and Newton, 2004).

All of these co-benefits give prominence to greening in urban development projects.

However, there is need to remain cautious as to the appropriateness of its application in different climate contexts. The type of climate, both current and future, has a significant impact on the ability of plants to grow and become resilient. Moreover, the plants most resilient to drought outbreaks are paradoxically the least effective in fighting against urban overheating, since they transpire very little. By way of illustration, this is the case for succulents, which are particularly resilient to hot and dry climates because they store water and transpire very little. It is therefore necessary to determine the species planted in order to guarantee their survival and proper growth during the years ahead. Lastly, the state of the soil is a key success factor for any greening project, as it does not always allow the plants to absorb the nutrients necessary for their growth.

Green solutions featured in the publication

There are various urban greening methods to counteract the heat island effect.

©City of Montreal

Planting trees alone, in rows, in the form of urban (micro) forests, in public parks and private gardens...
See
Montreal **Penrith** **Nantes** **Brussels** **Srirangam** **fact sheets**

©Atelier Odyssée

Urban agriculture helps to provide cooling by introducing greenery, as well as through renaturation and unsealing of the soil.
See
Pointe-à-Pitre **La Possession** **Brussels** **fact sheets**

© Danica Kus

Soil revegetation is a means of combating soil sealing, thereby facilitating evapotranspiration.
See
Nantes **Pointe-à-Pitre** **Montreal** **Brussels** **fact sheets**

For further reference

ARBOCLIMAT is a forecasting and decision-making tool for urban tree planting programmes designed by ADEME and the Hauts-de-France region. It is used to evaluate ecosystem services, namely the benefits from each species, and the carbon impact of greening projects. The ultimate selection of species is informed by their cooling and UHI-control potential, resilience to the effects of climate change, air pollution control and biodiversity value.

Very soon, this tool will be converted to *open source* format and a community of stakeholders created in order to further expand the range of species available and functionalities of the tool.

Lastly, it is worth noting that ARBOCLIMAT complements the Sesame tool operated by CEREMA (French Centre for Research on Risk, Environment, Mobility and Land Use). Whereas the former offers a holistic insight into the project, the latter broadens the range of species available.
ADEME (2018) The tree in the urban environment

Blue solutions

Cooling potential

Urban water management, or urban hydrology, is a set of solutions with high cooling potential. The natural water cycle is altered by anthropogenic (human-induced) activities, particularly by urbanisation and soil sealing. It is therefore necessary to reintroduce this cycle in our urban spaces, to allow the evaporation that is responsible for producing the cooling effect.

Physical phenomena involved: evaporation, winds, absorption of solar radiation.
©TRIBU/ADEME

In contact with solar radiation, the liquid water in waterways, lakes, fountains and soils transforms into vapour. The energy consumed during this transformation process lowers the ambient temperature (Volker *et al.*, 2013). The cooling effect is experienced at the waterfronts, hence the rationale for developing or rehabilitating riverbanks or sea shores in order to allow urban dwellers to use these cooled spaces (ASTEE, 2020).

The cooling generated by (re)introducing water into the city is sometimes a secondary objective of urban projects. For instance, flood risk management schemes are likely to have a side benefit on cooling.

Strengths and points of caution

Like greening, bringing water into the city yields numerous co-benefits for the quality of urban spaces. Additionally, blue solutions interact with green and gray solutions in meaningful ways: availability of water boosts evapotranspiration of plants, watering of road surfaces is an ancestral Japanese method of cooling (Solcerova *et al*, 2018), while the cooling potential of natural ventilation is maximised by the presence of lakes. However, using blue solutions for urban cooling is largely contingent upon the hydro-climatic conditions of each region. Although the cooling potential of water is high in "dry climate" cities, its use is quite costly in terms of resources. The use of external water supply must be minimised, while the development of existing water resources is optimised. Other decisive factors are the natural presence of waterways and the nearness of coastlines. Lastly, it is important to note the health risks posed by stagnant water, which can be a vector for diseases and pest species, such as the tiger mosquito (GRAIE, 2013).

Blue solutions featured in the publication

Among the of cooling solutions derived from urban water management in cities, this publication presents:

©Agence BASE

Rehabilitation of riverbanks and waterfronts
See Nantes Curitiba Zenata Morne-à-l'Eau Marseille fact sheets

Opening up and clearing up naturally-open waterways
See Marseille fact sheet

©LEU Réunion

Soil unsealing projects: removal of pavements, laying of permeable pavements, construction of ditches, etc.
See Nantes Brussels Pointe-à-Pitre fact sheets

©Klaas Verdru

Bioclimatic use of water to improve thermal comfort: fountains, water games, etc.
See Brussels Tetouan fact sheets

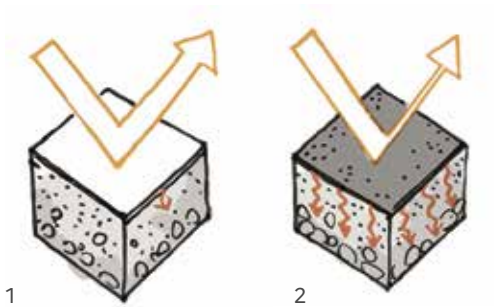
For further reference

The TACCT (Regional trajectories for adaptation to climate change) approach developed by ADEME supports regions in implementing their climate change adaptation strategy. It provides a methodology guide and a tool for each step, from diagnosis of the region's vulnerabilities to monitoring of measures taken. It helps to choose cooling solutions adapted to each region and to sequence them over time to prepare for future climate change.

Gray solutions
Typo-morphologies and materials

Cooling potential

Gray solutions for urban cooling include acting on the materials used to construct roads and buildings, as well as dealing with typo-morphology issues (analysis of urban forms, the road network, building volumes and layouts... (ADEUS, 2014)).
The materials used in cities are largely to blame for the UHI phenomenon. In many modern cities, road surfaces are black and asphalt, while roofs are covered with dark materials (Gilbert *et al.*, 2017). The way the materials respond depends on their thermal properties and color. Where their **emissivity*** is high, they can help to drive up ambient temperatures dramatically, especially at night (Akbari *et al.*, 2009). In order to ensure cooling, it is therefore necessary to analyse the properties of building materials facing the sun. **Albedo*** is the very first key indicator. It is the fraction of solar energy reflected back to space when it lands on a surface. A higher albedo corresponds to a more reflective surface that absorbs less solar radiation and emits less heat.



1 2
Cool surface (1) reflects solar radiation (high albedo), asphalt (2) absorbs solar radiation (low albedo).
©TRIBU/ADEME

The configuration of built and unbuilt urban spaces and study of the typo-morphology both have an impact on urban temperatures. The density of built spaces and their layout on the road network may obstruct free air flow, thus creating **canyon effects*** and overheated streets. By taking a multi-level approach connecting the various levels of planning of the region, the city, the district and each city block, it is possible to contribute towards urban cooling (Akbari, 1999). It is therefore necessary to study the layout of the road network in order to encourage natural urban ventilation, while protecting the streets from excessive sunshine.

Physical phenomena involved: shading, solar radiation trapping, winds
©TRIBU/ADEME

Points of caution

Acting on the city's typo-morphology and on the materials used for its construction can be challenging. In highly urbanised countries, the city of tomorrow is already largely in place and is therefore quite difficult to change. However, it is possible to work on coatings, claddings and surfaces to improve the thermal properties of the materials used.

Indeed, it is possible to implement gray solutions for cooling in all types of climate, although their effectiveness may vary slightly depending on the environment. For instance, ventilation facilitated by urban geometry is largely conditioned by the presence of natural breeze, clusters of greenery and lakes. Meanwhile, cool and high-albedo coatings, claddings and surfacing are effective in hot and very sunny cities.

Lastly, urban development that alters the typo-morphologies and materials of the city is not without effect on its appearance. More particularly, changing the colour of urban surfaces can have a profound impact on the city's aesthetics, and the visual comfort of its residents. Non-horizontal surfaces can reflect solar radiation onto other surfaces of the city, thereby only shifting the problem elsewhere. A paramount issue is to determine how the spaces covered with cool coatings, claddings and surfacing are actually used. Large urban car parks that are not used all the time, such as those of shopping areas, stadiums, or convention centres should be prime targets (Chester *et al*, 2015). However, cool coatings, cladding or surfacing in public spaces with heavy foot traffic can induce unwanted effects. In addition to the glare earlier mentioned, it can impair thermal comfort by increasing the body temperature of passers-by. Pedestrians will actually absorb the radiation reflected by the ground. (Middel and Turner, 2020).

Gray solutions featured in the publication

Materials and surface coatings/coverings for urban cooling can be used in many ways:

©L Backer/ Shutterstock.com

High-albedo white roofs or "cool roofs"
See Ahmadabad Penrith fact sheets

Los Angeles ©LA City

High-albedo coatings on roads or "cool pavements"
See Los Angeles fact sheet

Use of high **thermal inertia*** materials in buildings
See Dakar Tetouan fact sheets

Secondary school in Dakar ©Daniel Rousselot

Using typo-morphology for cooling purposes also requires several channels:
- Working on the **airflow patterns*** and the floor space to ease air flow across the entire city block
See La Possession Zenata Brussels Bouéni fact sheets
- Working on the road network layout to provide protection from excessive sunlight
See Dakar Tetouan La Possession Zenata fact sheets

For further reference

The MESH-2C (*Morphology, Environment, Sustainability and Human comfort – City Climate*) project is a logical sequel to the MESH project (APR MODEVAL URBA 2019/2020), which culminated in the development of multi-criteria optimisation methodologies for city blocks during the design phase, and is currently furthering its ambitions by opting to focus more specifically on how urban environments can become more climate resilient.

Bioclimatic architecture

Cross-functional solution

Cooling potential

Bioclimatic architecture is a cross-functional solution used to achieve summer comfort through the interplay of green, blue and gray solutions on the scale of the entire building and nearby urban spaces. Often inspired by the climatic approaches applied in local architecture, it leverages local climate conditions to improve thermal comfort (Supic, 1994). Indeed, it uses morphologically-driven gray solutions to promote natural ventilation of indoor and outdoor spaces, while expelling masses of hot air and creating shading (e.g., access balconies allow for such dual action of ventilation and shading).

Using green solutions for urban space greening, and blue solutions to bring water into buildings and their surroundings also enhances cooling. Traditional bioclimatic solutions are said to be **passive*** in that they are low on energy and non-renewable resources, thus promoting "responsible" cooling. They help to avoid or minimise the need for air conditioning.

Points of caution

Bioclimatic architecture principles are particularly appealing in that they combine the cooling potential of each type of solution. They are often drawn from ancient traditions tailored for local climates. However, passive solutions call for a measure of caution by building occupants, who must take action to ensure that such solutions remain effective during the building's service life.

Although appropriate during hot weather, bioclimatic cooling architecture can lead to energy overconsumption during winter in colder climates (Amritanshu and Sharma, 2020). Local architecture is best suited to the type of climate in which it has developed, and it is highly unlikely to be exported to other regions.

Finally, most bioclimatic shading systems for buildings only offer a one-off enhancement of thermal comfort. Where they come with greening, they also have the advantage of cooling the air by inducing the evapotranspiration phenomenon.

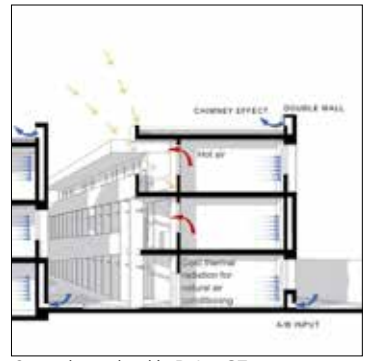
Solutions featured in the publication

Many bioclimatic solutions can be implemented in buildings. Among those presented in this publication are:

Secondary school in Bouéni ©LEU Réunion

Protection of buildings from the sun through fixed or mobile shading systems: shutters, pergolas, sunbreakers, "green" shading features...

See
Dakar **Tetouan** **Brussels** **Bouéni** **La Possession** **fact sheets**



Secondary school in Dakar ©Terreneuve

Dispersion of hot air masses and free flow of fresh air using access balconies, buffer zones at the entrance of buildings, "green" patios, fountains, ceiling heights, openings at top of walls, shutters, wooden lattices, stilts...

See
Dakar **Tetouan** **Bouéni** **fact sheets**

School in Brussels ©Simon Schmitte

Minimising heat loss through insulation systems: double walls, triple glazing, high thermal inertia materials...

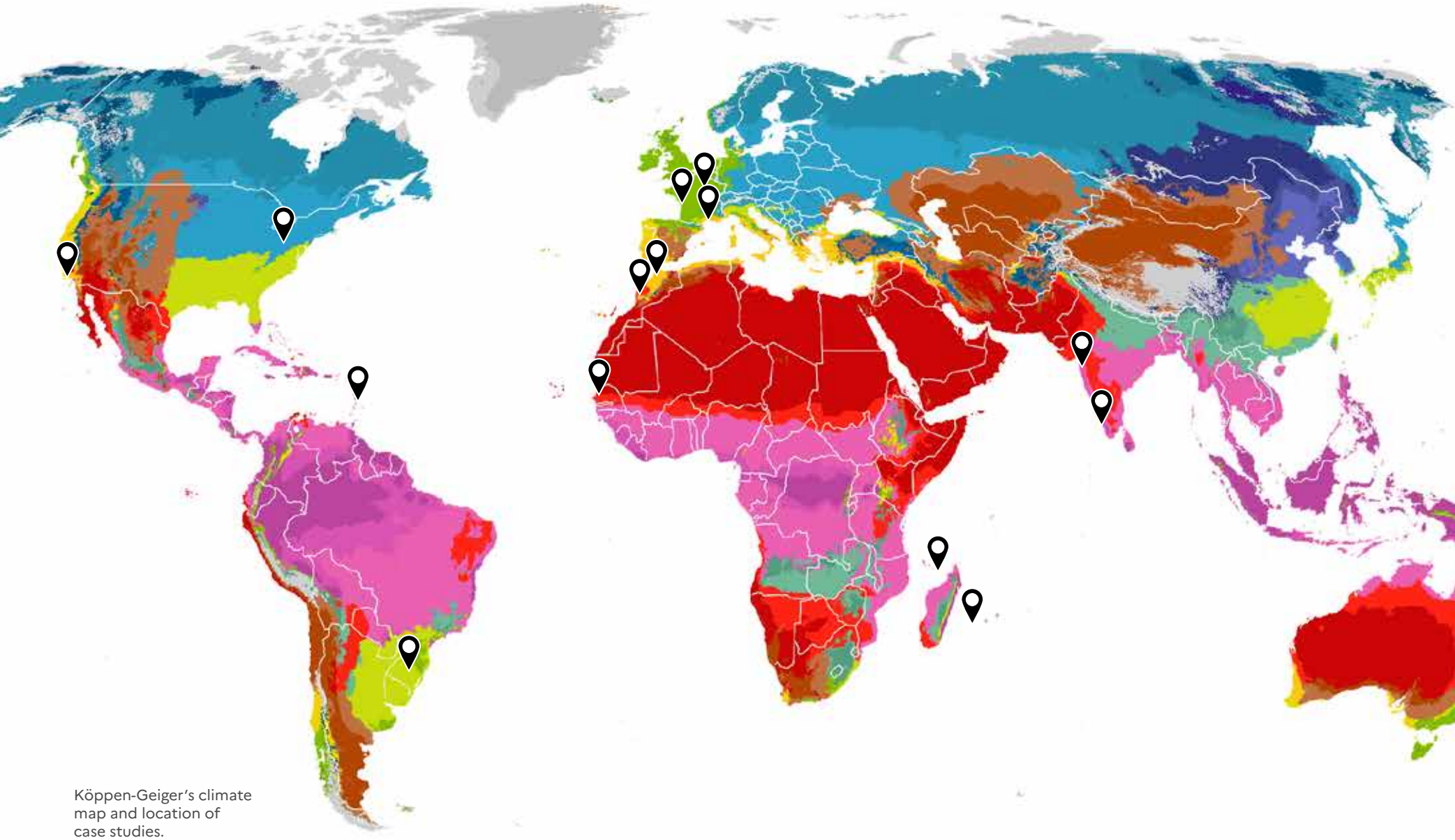
See
Dakar **Tetouan** **Brussels** **Bouéni** **fact sheets**

For further reference

(ADEME, 2019) (The building in the tropical environment. A network for sustainable design)
Testimonials from leading experts from countries with tropical climates worldwide, seeking to advance the principles of climate-friendly architectural design and rethink how to incorporate bioclimatic principles of local architecture into current architectural standards.

CHAPTER 3

16 Case Studies in the current climate...

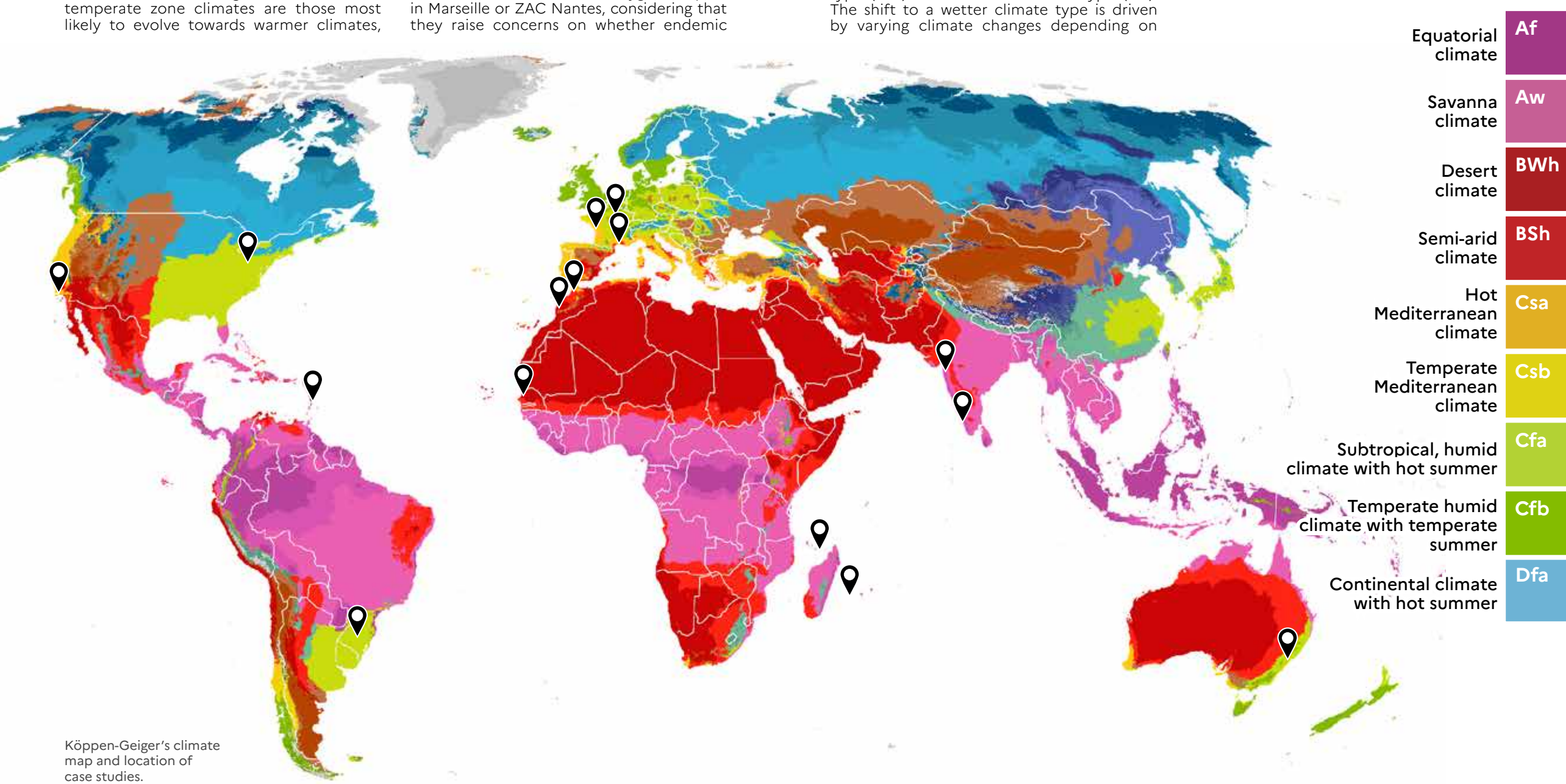


Köppen-Geiger's climate map and location of case studies.

...and future climates

For these 16 case studies, with the "no climate policy" scenario (RCP 8.5), the current climate type (2018) could evolve to a warmer climate type by 2100, with generally warmer and drier summers in 8 cases:
(Montreal, Marseille, Zenata, Nantes, Brussels, Curitiba and Los Angeles). Indeed, the temperate zone climates are those most likely to evolve towards warmer climates, with drier summers. This is partly ascribable to the growing number of summer heatwaves and droughts in the future as predicted by the IPCC (2021). More specifically, it is such extreme climates that could jeopardise some cooling solutions, particularly plant-based ones like those in Les Aygalades park in Marseille or ZAC Nantes, considering that they raise concerns on whether endemic species will adapt not only to changing temperatures but also to a potential scarcity of water resources during summer.

For Ahmadabad's cools roofs in India, the change under way is from a semi-arid climate type (BSh) to a savanna climate type (Aw). The shift to a wetter climate type is driven by varying climate changes depending on the regional patterns of different climate variables such as rainfall simulated by the full array of climate models.



Köppen-Geiger's climate map and location of case studies.

16 urban cooling case studies

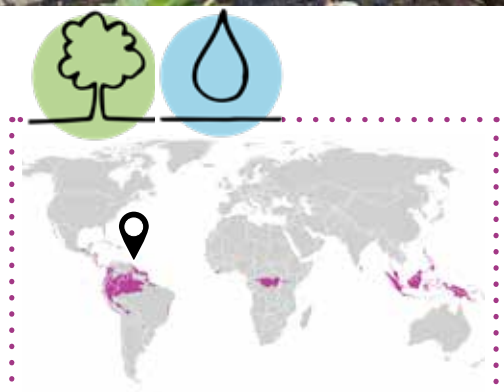
For each current climate type, specific fact sheets are provided:

Af	**Equatorial climate**	• Pli Bèl Jaden community garden in Pointe-à-Pitre, Guadeloupe, France (p39) • Cœur de Grippon eco-district in Morne-à-l'Eau, Guadeloupe, France (p43)
Aw	**Savanna climate**	• Miyawaki urban microforest in Srirangam, India (p47) • Bouéni bioclimatic school in Mayotte, France (p51) • ZAC Cœur de Ville (urban development zone) in La Possession, Reunion Island, France (p55)
BWh	**Desert climate**	• Lycée Mermoz in Dakar, Senegal (p59)
BSh	**Semi-arid climate**	• Cool roofs in Ahmadabad, India (p63)
Csa	**Hot Mediterranean climate**	• White city of Tetouan, Morocco (p67) • Zenata eco-city, Morocco (p71) • Renaturation of Les Aygalades, Marseille, France (p75)
Csb	**Temperate Mediterranean climate**	• Cool pavements in Los Angeles, USA (p79)
Cfa	**Subtropical, humid climate with hot summer**	• Cooling the City Strategy in Penrith, Australia (p83)
Cfb	**Temperate humid climate with temperate summer**	• Barigüi riverbank development project, Curitiba, Brazil (p87) • ZAC Pirmil-Les-Isles (urban development zone) in Nantes, France (p91) • "À la croisée des chemins" sustainable school in Brussels (p95)
Dfb	**Continental climate with temperate summer**	• Multi-level greening in Montreal, Quebec, Canada (p99)

Pli Bèl Jaden community garden

Pointe-à-Pitre
Guadeloupe
France

©Atelier Odyssée

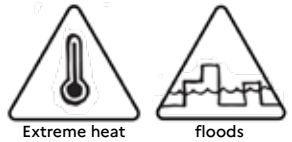


The current climate
Equatorial (Af)

Scale
Public space

Timing
Medium-term

Risks



The future climate
Equatorial (Af)
+2.9 °C to +3.3 °C by 2100
(RCP 8.5, IPCC)

Pli Bèl Jaden exemplifies a community-driven initiative with multiple co-benefits. It is a perfect embodiment of how to showcase the tangible and intangible heritage of a region, foster social bonding, protect biodiversity through urban space renaturation, manage rainwater sustainably and cool the ambient temperature.

The garden sits on a plot of land with a temporary occupancy permit issued by its owners. Urban planning and land management can become serious impediments to long-term sustainability of urban agriculture projects.

Pli Bèl Jaden community garden, Pointe-à-Pitre, Guadeloupe

Background

With a population of 16,000, Pointe-à-Pitre is a coastal municipality in Guadeloupe located at the junction between Grande-Terre and Basse-Terre. Formed of a group of islands, Guadeloupe is prone to many risks that may be few and far between but can inflict heavy casualties (cyclones, volcanic eruptions, earthquakes, coastal floods...). The cities of Guadeloupe are particularly vulnerable to urban flooding due to torrential rains and undersized drainage systems (DEAL Guadeloupe), as well as to overheating exacerbated by heat island effects.

+ 200 to 300
additional hot days per year expected in Guadeloupe by 2100 (Météo-France)

The Pli Bèl Jaden community garden is located in the Chemin Neuf Carénage Darboussier priority district. Launched and managed by the Atelier Odyssée association, it exemplifies a community-driven initiative to improve the living environment by focusing on food and education, while contributing positively to urban cooling.

©Atelier Odyssée

Cooling actions

This garden is an integral part of a project to beautify the district. Originally, the Pli Bèl Jaden project was aimed at revitalising a 250 m² wasteland that had been abandoned by the inhabitants. By creating green spaces, the association has contributed to unsealing the soil of a public space. Renaturing the soil and planting numerous plant species helps to bring down the ambient temperature and enhance thermal comfort through shading from the grass and shrub cover, and evapotranspiration from the plants and soils. The creation of green spaces in the city's open spaces makes it possible to combine densification and cool blocks.

©Atelier Odyssée

Description

Urban and educational agriculture

Pli Bèl Jaden is composed of several unique layout: the large vegetable garden, shared gardens and green spaces. This diversified layout allows for a variety of activities on the site, ranging from organic market gardening to recreational activities and pleasure gardening. Pli Bèl Jaden is modelled on the Creole garden, a small space traditional in the Caribbean, created for food and decorative purposes. Crops are diversified, including fruits and vegetables, aromatic plants, ornamental plants, medicinal plants... This helps to promote a rich, home-grown and organic diet for the residents. This crop diversity is also a boon to urban cooling and biodiversity. Indeed, it makes it possible to leverage the interaction of the herb, shrub and tree layers. Rainfall in Guadeloupe is high (1600 mm/year, Source: Météo France), which therefore facilitates evapotranspiration without need for substantial water supply from external sources.

Renaturing an unused space

Pli Bèl Jaden garden is located on wasteland. This is one of the main attractions of the project. This renaturation approach to revive urban wastelands is a perfect opportunity to incorporate cooling solutions in every unused space. It is a means of controlling urban sprawl, and a densification model that leaves plenty of room for the well-being and thermal comfort of residents.

Additionally, unsealing the soil on the plot of land allows for easier absorption of the runoff during heavy rainfall in Pointe-à-Pitre. Apart from cooling, it also helps to minimise the runoff and migration of pollutants to the water table.

Valuable lessons for other regions

Community gardens: maintenance and governance

Creating community gardens in urban areas is a highly promising approach to developing **nature in the city***, protecting biodiversity and cooling the environment. However, there are a few points of caution to be considered to ensure smooth functioning and sustainability. Where food production is the ultimate goal, the first consideration is to have a proper knowledge of the existing environment: soil fertility, exposure to air pollutants, environmental and health risks from potential pollution... Attention must also be paid to the issue of space management. Local public authorities need to encourage associations to take ownership of projects conducted in public spaces, in order to build mutually-beneficial synergies for the entire region. Lastly, securing the co-benefits of improved cooling, nutrition, health, biodiversity and environmental protection will require an understanding of the practices of the gardeners engaged in developing these spaces.

Activation of public spaces and social bonding

Pli Bèl Jaden is the "Nature in the city" facet of the Pli Bèl Lari project led by the Atelier Odyssée association. Its main goal was to beautify the district and create bonds between residents. Controlling urban heat islands and protecting biodiversity have emerged both as desirable co-benefits and catalysts for activating the space. Thermal comfort of public spaces is indeed a key determinant of whether or not they will be adopted.

Pli Bèl Jaden community garden, Pointe-à-Pitre, Guadeloupe

Co-benefits

Good health and well-being

High-quality public spaces
The Pli Bèl Lari embellishment project, particularly the creation of the Pli Bèl Jaden gardens, has helped to develop cool and friendly spaces that are conducive to a multiplicity of activities. The growing number of green spaces in the district is improving the well-being of residents.

Sustainable cities and communities

Stronger social bonds
Pli Bèl Jaden is a community garden that encourages residents of the district to participate in its development, management and in the numerous events hosted by the Atelier Odyssée association. The growing number of green spaces in the neighbourhood strengthens the community by building strong social bonds (Westphal, 2003).

Responsible consumption and production

Urban and educational agriculture
Crops harvested from the Pli Bèl Jaden vegetable plot are shared with the local population, thus giving them access to a balanced and organic diet. The garden also serves as a platform for Atelier Odyssée's environmental and nutritional awareness activities.

FOR FURTHER REFERENCE:

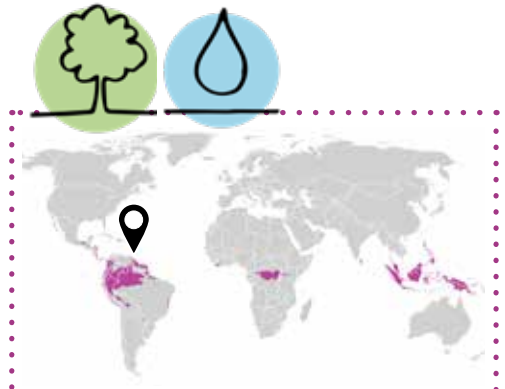
- Sustainable urban planning in French overseas territories — AEU2 technical booklets Successful sustainable planning and development. (2016)
- Fact sheet "Greening: action for urban cooling" (2020)

OTHER SIMILAR STORIES:

- The Prêcheur neighbourhood farm in Martinique (Aw, Savanna climate) is a good example of urban agriculture geared towards building social bonds and promoting professional integration
- Almost half of the surface area of Madagascar's capital city, Antananarivo, is used for crops (CIRAD, 2019). This largely contributes to food resilience in this city of nearly three million inhabitants

Rehabilitation of Canal des Rotours in Cœur de Grippon eco-district

Morne-à-l'Eau Guadeloupe France



The current climate
Equatorial (Af)

Scale
District

Timing
Long-term

Risks

The future climate
Equatorial (Af)
+2.9 °C to +3.3 °C by 2100
(RCP 8.5, IPCC)

Morne à l'Eau's approach to planning and developing the Cœur de Grippon **eco-district*** successfully balances economic development and tourism goals with the city's adaptation to the effects of climate change. By steering the city towards its canal and greening its public spaces, the cooling initiatives fit seamlessly into a process to improve the living environment for Morne-à-l'Eau's people. The forward-looking approach taken by the city for its climate adaptation actions is also very interesting. However, it is worth noting that developing the Cœur de Grippon eco-district has been hampered by various factors, including a lack of comprehensive data on the region and the fact that existing operational tools are not adapted to French overseas island territories. The is a pioneering project in Guadeloupe, and therefore the inapplicability of financial tools for the experiments conducted is yet another hindrance (BatiTrend, 2017).

Rehabilitation of Canal des Rotours in the Cœur de Grippon eco-district, Guadeloupe, France

Background

Morne-à-l'Eau is a municipality of 16,000 inhabitants on Grande-Terre Island, in Guadeloupe. It owes its name to the large amounts of water on its territory. Apart from its extensive hydrographic network, with Canal des Rotours being the largest watercourse, it is also home to the Plaine de Grippon underground water table, the largest reserve of high-quality water on the island. The ecosystems of maritime marshes and mangrove swamps also form permanent features on the Morne-à-l'Eau landscape, while one-third of the city's territory is covered by wetlands. Finally, Morne-à-l'Eau offers approximately 2,000 hectares of coastal space.

The inescapable presence of water entails considerable urban flooding hazards, in addition to the seismic and cyclonic hazards inherent to Grande-Terre. The existence of significant climatic hazards has long been acknowledged by the Municipality, which has already instilled a solid risk culture in its development projects. Over the past decade, Morne-à-l'Eau has been actively engaged in adapting its territory to the effects of climate change. Cœur-de-Grippon eco-district is a dual-purpose project, namely: to revitalise the city and its tourist and residential appeal on the one hand, and adapt to climate change on the other hand.

Cooling actions

Cœur de Grippon eco-district's adaptation agenda begins with flood risk management. Prominence is also given to protecting and developing the territory's outstanding biodiversity. Urban cooling therefore emerges as a co-benefit induced by sustainable greening projects and reintroduction of water. The eco-district is built around the Canal des Rotours, which stretches over 6 km in the midst of a swampy forest ecosystem. Cleaning up and renaturing the watercourse, and rehabilitating its banks creates cool spaces for residents. In the heart of the eco-district, wetlands are preserved, developed and showcased, while the tree planting helps to expand the vegetation cover.

1/3 of Morne-à-l'Eau's territory is covered by wetlands

©vouvraysan/Shutterstock.com

Description of solutions

Rehabilitation of Canal des Rotours

Historically, Morne-à-l'Eau city was built around the Canal des Rotours, a navigation route dug partly by slaves. The Canal is therefore firmly rooted in the city's history and landscape, and its rehabilitation is a milestone in the development of the eco-district. The waterway has been cleaned up and all logjams removed, thus restoring its free flow. The canal is a vital waterway for Morne-à-l'Eau's economy and tourism.
The interface between the city and the waterway has been developed and the banks of Canal des Rotours rehabilitated. By enhancing the area's landscaping features, these developments offer the residents access to a cool and attractive walking space. Indeed, the riverbanks are cooled by evaporating water and wind forces.

Nature in the eco-district

Besides the inescapable blue belt formed by Canal des Rotours, "biodiversity spots" and green belts have also have been created on a total surface area of 10 hectares in the Cœur de Grippon eco-district. Greening is being conceived on a district-wide scale by planting a thousand avenue trees, as well as on a block-wide scale: a comprehensive greening effort goes into designing the heart of city blocks. An orchard has been planted in the district as a cool public space available to residents. This tree cover provides shade for passers-by and promotes evapotranspiration, which is particularly high in equatorial climates (Burman and Pochop, 1984). The district's wetlands and wet meadows were identified for protection and enhancement during development of the eco-district. Additionally, the Guadeloupe school board has set up a "ZHE" (an educational wetland), for educational purposes to help students of the Guadeloupe Academy.

Valuable lessons for other regions

Integrating the project into a proactive approach to urban adaptation.

Developing Cœur de Grippon eco-district and rehabilitating Canal des Rotours are integral features of a proactive policy pursued by the municipality.
The city is looking to build a model Caribbean eco-district and become a pilot for regional resilience. Adaptation to cyclonic, seismic and flood hazards is an essential component of Morne-à-l'Eau's urban projects. Indeed, a holistic approach to adaptation and resilience was taken when designing the eco-district. Cooling is a critical objective of such adaptation of urban space.

An attractive region and community engagement as project cornerstones

Morne-à-l'Eau has an ageing population and has experienced acute economic recession since the 2000s. In responding to these challenges, the Municipality is banking on sustainable urban development aimed at mitigation, adaptation, building social bonds and boosting the local economy. The feasibility of creating an eco-district to enhance the city's residential and tourist appeal was articulated in the municipality's Agenda 21 in 2011. Since then, participatory approaches have been taken to create a consistent region-wide project that caters to the needs of residents both today and in future. The initial planning of the eco-district was mainly informed by the AEU2 approach (Environmental Approach to Urban Planning), a decision-making tool and participatory diagnosis method championed by ADEME.

Rehabilitation of Canal des Rotours in the Cœur de Grippon eco-district, Guadeloupe, France

Co-benefits

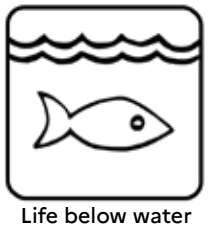

Sustainable cities and communities

High-quality public spaces
Cœur de Grippon eco-district is home to 4 km² of public spaces. These include the orchard park and the rehabilitated banks of Canal des Rotours. These developments create cool and green spaces for the residents and reinstate their bond with the water. Enhancing the city's natural and historical heritage is also of benefit to tourism and business activities.


Climate action

Flood risk management and urban sprawl control
Cœur de Grippon eco-district is being built with the goal of **sobriety***. Identifying empty spaces and wastelands with the district's residents has made it possible to develop new projects on the existing land. Developing abandoned spaces also contributes to restoration of the city's architectural heritage that is a cornerstone of its history.


Life on land


Life below water

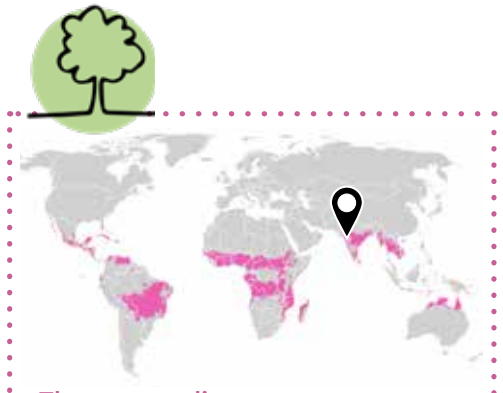
Live on land and below water
Biodiversity protection and management lie at the heart of the Cœur de Grippon eco-district project. Protecting and enhancing the municipality's flora and fauna heritage calls for a thorough diagnosis, including identification, knowledge and conservation of species.

FOR FURTHER REFERENCE:
- On the AEU2 approach (Environmental Approach to Urban Planning), ADEME has released six technical guides on the following topics: Urban atmospheres, Mobility, Business activities, Ecosystems in the regions, Climate and energy, and Building the city on itself.

OTHER SIMILAR STORIES:
- The Huveaune River in Auriol (13) (Csa) was the site of a development project that not only reduced the flood risk, but also enhanced the river's physical quality and the living environment for residents, encouraged soft mobility and promoted new activities by taking advantage of the cool riverbanks.

Miyawaki urban microforest
Srirangam
India

©Jacques LE GOFF/ADEME

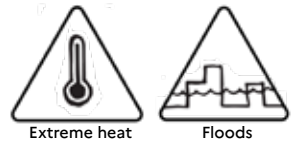


The current climate
Tropical savanna with dry winter (As)

Scale
Public space

Timing
Medium-term

Risks


Extreme heat Floods

The future climate
Tropical savanna with dry winter (As) +3.1°C annual peak temperature by 2070 (Tamil Nadu State)

The Miyawaki urban micro forest in Srirangam has the major advantage of expanding the vegetation cover of the very densely populated and built-up city. It introduces a green space that matures twice as fast as a conventional forest, thereby enhancing the well-being of city residents.

The cooling impact, carbon storage and the benefits for biodiversity have been demonstrated by a scientific study on tropical climates, but remain unknown for temperate climates. Although it may be useful to add Miyawaki forests to a portfolio of urban greening solutions, their implementation cost and the mortality of species originally planted in temperate climates tend to undermine the relevance of such solutions in tackling the challenges of adaptation and cooling.

Miyawaki urban microforest
Srirangam, India

Background

Srirangam is an Indian city in Tamil Nadu State that belongs to the Tiruchirappalli urban area. This very attractive conurbation in the south of India has a constantly growing population that currently stands at more than one million. Srirangam is renowned for its Hindu temple which makes it a popular tourist destination. These features add more pressure to an already densely populated conurbation.
During the COP 21 conference in 2015, the Indian government pledged to expand the country's vegetation cover to 33 % of the national territory in 2022. However, only 24 % of the territory was under forest cover in 2019 (Roy, 2020). Against this backdrop, Tiruchirappalli is taking action by planting trees in its urban spaces, some of which follow the Miyawaki method of creating urban micro forests that offer the advantage of planted trees growing and maturing much faster.

Cooling actions

Although the originally-declared purpose of Srirangam micro forest is to increase the vegetation cover and create a space for walking and biodiversity conservation, it is also serves a cooling objective. However, it takes several years for the forest to mature and realise its cooling potential. Therefore, most Miyawaki micro forests need to be watered heavily in the first few years of their life cycle.

The presence of trees, although not yet mature, still helps to improve thermal comfort for people through shading and unsealing of the soil. The evapotranspiration induced by the trees cools the environment and moistens the air, thus contributing to creating a sense of thermal comfort.

Project description

The Miyawaki method

10,000 trees were planted on the entire 5000 m^2 of the Srirangam urban micro forest. The micro forest was designed according to the Miyawaki method, named after its pioneer, the botanist Akira Miyawaki. This method is built on the principles of botany and phytosociology, the study of the relationships between plants and their environment. When applied under the right conditions, the trees grow faster to deliver a mature forest after 25 to 30 years versus 100 years under normal circumstances.

The process entails planting a large number of trees on a small area, such that their high concentration and the attendant interactions create the right conditions for quick growth and enhanced immunity to disease. The tree species are chosen based on diversity and being native to the region.

Change of scale

The Tiruchirappalli conurbation has clearly understood the pressing need to cool its urban area: the planting of a single micro forest space will be insufficient to lower temperatures. Accordingly, a strategy of planting about twenty similar micro forests has been adopted on the territory since 2019 and for the coming years, which is expected to create a tangible impact on the city's cooling and not just deliver occasional and micro-local thermal comfort.

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Project timing

Valuable lessons for other regions

Innovative "Quick wins" project

Although Miyawaki urban forest will only mature and deliver its full cooling potential after 30 years, it will still yield quick and considerable dividends in terms of biodiversity, vegetation cover and public space quality. Its quick growth helps to cover and replace sealed and dark heat-retaining soils. Additionally, the presence of plants, even when young, largely enhances the quality of public spaces, as well as the well-being and mental health of residents and visitors.

Points of caution: High mortality rate

One reason why Miyawaki forests grow so fast is that the tightly clustered trees compete with each other for available nutrients. The outcome of this natural competition is the death of less competitive species. In one study, 61 to 82 % trees died in Miyawaki forests after 12 years (Schirone, 2011). Most Miyawaki experiments were conducted in areas with tropical, hot and humid climates where plant species thrive at high density. This is not the case for temperate climate species. Furthermore, the very small size of Srirangam micro forest precludes the possibility of recreating biodiversity akin to that of a natural forest.

Soil quality and method cost

The high mortality rate of plants coupled with the pressing need for frequent watering make the Miyawaki method a rather resource-intensive but low-efficiency solution. Another major downside of this method is the preparatory work required on the soil. Poor or polluted soil prevents plants from maturing to their full cooling and carbon sequestration potential. Apart from the high clean-up costs, such interventions also severely disrupt the soil's ecosystems.

Planted species

The Miyawaki method recommends planting a large variety of species, about 30, in micro forests. It stresses the need to select native species adapted to the climate to ensure sound plant health. However, it seems more appropriate to anticipate changes in distribution patterns of species in order to best adapt plantations to future climate conditions (Muller, 2021).

Similarly, this method developed in a humid tropical climate needs to be adapted to other types of climate. More particularly, a lower planting density in drier climates should be considered (Ducousso *et al.*, 2021).

Miyawaki urban microforest
Srirangam, India

Co-benefits

Life on land

Biodiversity
Planting urban micro forests using the Miyawaki method can aid biodiversity protection and development. Indeed, it will increase the incidence of native flora in the area. The variety of planted tree species provides a habitat for many insects, birds and other animals, although this phenomenon is far less pronounced than in natural forests.

Sustainable cities and communities

Community engagement and empowerment
A key step in the Miyawaki method when creating an urban micro forest is planting. It is recommended to engage the local community in the planting process, especially so that residents and other local stakeholders can take ownership of the space and its environmental implications. In Srirangam, the residents, users of the nearby temple and a local women's association participate in the planting process to collectively implement a community-driven environmental initiative.

Good health and well-being

Health
Planting urban micro forests contributes to improving the environmental health of urban residents. Assuming the inconveniences associated with allergenic species are eliminated during the design phase, the urban forest helps to filter fine particles and minimise the amount of pollutants (carbon monoxide, nitrogen dioxide, ozone, suspended particles, etc.).

Climate action

Carbon sequestration
Having trees in the city, particularly micro forests, contributes to carbon sequestration (in leaves, branches, soil, etc.). Although carbon sequestration is lower than in natural forests, it can reach up to 25.1 metric tons per hectare per year (average for US urban forests) (Nowak and Crane, 2002).

FOR FURTHER REFERENCE:

- The Miyawaki method – Data & concepts, Urban forests (2020)
- Miyawaki method, why microforests are not really forests, The Conversation, B. Castagneyrol, A. Porté, C. Plomion (2021)

OTHER SIMILAR STORIES:

- The City of Paris (Maritime climate Cfb) has adopted the Miyawaki method in planting some of the 170,000 trees the Municipality is looking to have on its territory by 2026.
- The Kenya Forest Service has adopted the Miyawaki method to expand the Karura Forest in Nairobi (Warm Temperate Climate Cfb).

Bouéni bioclimatic secondary school
Mayotte
France

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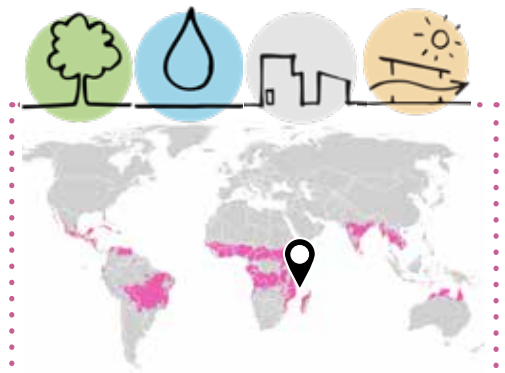
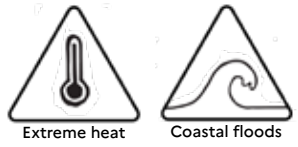


The current climate
Tropical savanna with dry winter (As)

Scale
Building

Timing
Medium-term

Risks



The future climate
Tropical savanna with dry winter (As) + 1.4 °C to +3 °C annual average temperature by 2100 (ONERC, 2012)

Bouéni secondary school was designed with aim of minimising its ecological footprint. Its light structure, absence of earthworks on the site, passive lighting and cooling devices all go a long way to minimising construction and maintenance costs. The bioclimatic approach adopted in its construction is easy to replicate in regions with similar bioclimatic and topographic conditions.

However, it is worth noting that the main goal of the school's design is the thermal comfort of its users rather than cooling ambient temperatures in the city. As such, its impact on the surrounding urban spaces is limited, though it is not known in detail, as no studies or temperature surveys have been conducted since its construction.

Bouéni bioclimatic secondary school
Mayotte, France

Background

Bouéni is a town in southern Mayotte, an island region and French overseas territory in the Indian Ocean. It has a fast-growing young population and the Mayotte academy has had a student enrollment of more than 100,000 since 2020, including approximately 30,000 secondary school students.

Climate forecasts predict rising temperatures combined with lower annual total rainfall in Mayotte (ONERC, 2012). The island is prone to high risks of coastal flooding (Jouzel *et al.*, 2012), earthquakes and cyclones. In this context, it is vital to ensure that schools continue to operate autonomously in the event of power outage.

Cooling actions

The 6000 m² site on which Bouéni secondary school was built in 2019 is highly exposed to the natural risks of urban and coastal flooding, earthquakes and cyclones. The project seeks to integrate the building into the landscape and local environment, in order to enhance its climate hazard resilience. The design is built on bioclimatic principles that leverage local microclimatic factors to deliver optimal comfort for users, while minimising the need for air conditioning.

Natural ventilation systems designed to capture local wind forces and directions are used for passive cooling of buildings and their surroundings. Protecting the outside of the building from solar radiation also shields the school from overheating and from heating up the ambient air.

Project description

Natural ventilation and protection from the sun

Bouéni secondary school's design strikes a balance between maximising the cooling potential of natural ventilation and securing the building's resilience to the well-known extreme wind and rain events in Mayotte. To this end, the school is built on a slope and with a very open design. The porosity of its facades is nearly 50%. Its construction on stilts allows air to flow freely under the building and rainwater to drain away. Louvred shutters on the facade allow the natural ventilation to be adjusted and can be manually operated so that they can still function in the event of a power cut. The shape of the building creates a low-pressure well, which allows fresh air to flow freely across the school.

The building is very open and bright, providing good lighting autonomy in the classrooms, while incorporating numerous sun protection devices on the exterior. Horizontal and vertical adjustable sunshades cover the facades, thus minimising heating of the building.

Greening and water management on the plot: cooling by evapotranspiration

Greening and renaturation of school outdoor spaces are key drivers for introducing nature-based solutions for adaptation into cities. In Bouéni, the school was built while preserving the existing noteworthy trees, including baobabs and an orchard. The school's surroundings were heavily greened, thus contributing to improving their landscape quality and combating landslides. Approximately 60% of the outdoor soils are permeable, while green ditches have also been built to properly manage rainwater on the plot. Through evapotranspiration and shading of the soils and used spaces, all of these greening features contribute towards cooling the building.

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Project owner: Rectorate, Académie de Mayotte
Project manager: LAB Réunion, 2APMR (agents/partners)
Architect: Tand'M

Valuable lessons for other regions

Project integrated into the landscape

The Bouéni secondary school building is an architectural showpiece, not only in terms of its solar and wind control features, but also in terms of aesthetics and imprint on the landscape. It is indeed perfectly integrated into its natural landscape, with its steel structure making it a light and lean building. To achieve sobriety and resilience, its designers have successfully harnessed the topographical features of the site. By adapting the building to its landscape and building on the slope, no earthworks were required.
Conservation of the site's remarkable plant species rather than replacement by new vegetation is also a hallmark of how the architectural project is adapted to its construction site.

Bioclimatic school buildings

The architectural qualities of the school buildings are a particularly valuable consideration when it comes to adaptation and the quest for resilience. These centres of learning are indeed exemplary in nature, and conducive to raising awareness of students and staff of the need to adapt to climate change. Beyond their cooling potential, creating a proper living space, preserving the orchard and planting a garden all contribute to the visual and aesthetic comfort of the site, while serving an interestingly symbolic purpose.
Bouéni secondary school is a low-cost building with low maintenance needs. Its architectural simplicity (**low tech* solutions**, minimised earthworks, simplified structural and natural ventilation principles) makes the project easy to replicate in other areas exposed to similar climate and topographical conditions.

Bouéni bioclimatic secondary school
Mayotte, France

Co-benefits


Life on land


Climate action

Biodiversity
Biodiversity lies at the heart of the school's educational approach. During the design phase, the special attention paid to permeability of more than half of the ground surfaces, as well as the greening efforts made around the school and the preservation of noteworthy trees, contributed to biodiversity preservation.

Flood risk management
The large proportion of permeable soil on the school site and the development of green ditches allows for sound water management on the plot of land with numerous side benefits. By preventing runoff and properly channelling rainwater, the soils absorb water as close as possible to where it falls. This helps to replenish the water table, thus preventing floods.

Sobriety
The resilience of the Bouéni building is also enhanced by its low environmental impact. Its architectural simplicity, light foundations and zero earthworks make it a light building with little impact on its environment. Its passive cooling system and the preference for natural lighting substantially minimise energy consumption.


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FOR FURTHER REFERENCE:
- Confort thermique dans les écoles dans les bas à la Réunion (2019) - Centre de ressources EnviroBAT Réunion

OTHER SIMILAR STORIES:
- The Saint-Pierre municipality in Reunion Island built the Aimé Césaire bioclimatic public elementary school in a climate similar to that of Bouéni (Aw Tropical savanna).
- The Célestin Freinet bioclimatic school in Dagana, Senegal, was built in a desert climate (BWh)

ZAC Cœur de Ville
La Possession
Réunion Island
France


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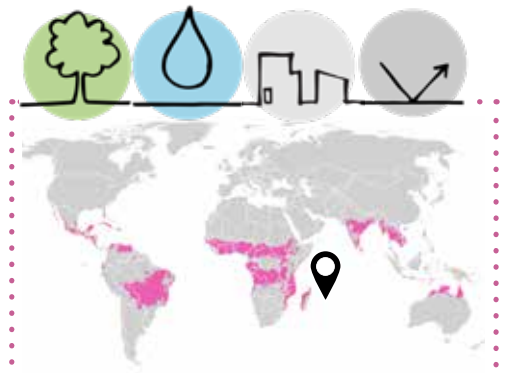
Aw



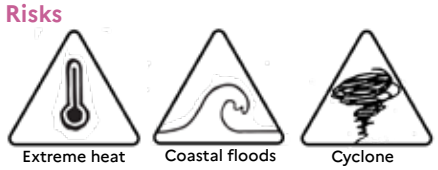
The current climate
Tropical savanna with dry winter (As)

Scale
District

Project cost
€400 M (excl. tax)

Timing
Long-term

Risks


Extreme heat | Coastal floods | Cyclone

The future climate
Tropical savanna with dry winter (As) + 1.4 °C to +3 °C annual average temperature by 2100 (ONERC, 2012)

The ZAC Cœur de Ville eco-district project is outstanding in several respects. Its thorough diagnosis, followed by a bioclimatic design and a relevant programming of the district's spaces contribute towards achieving the desired goals of sustainability, economic dynamism and stronger social bonds.

Incorporating Nature-based Solutions (NbS) for adaptation generates an adapted and resilient region, particularly by cooling the ambient air.

ZAC Cœur de Ville (urban development zone) in La Possession Reunion Island, France

Background

Located in the north-west of Reunion Island in the city of La Possession, ZAC Cœur de Ville is a 33-hectare development project. Over the last decade, the municipality of 32,000 inhabitants has experienced demographic growth of almost twice that of the rest of the island. La Possession's eco-district welcomed its first residents in 2019, and is expected to grow to 5,000 residents by 2026.

The fact that Reunion is an island calls for more adaptation and anticipation than elsewhere. More particularly, development projects must anticipate the issue of the carbon footprint from electricity generated on the island. Indeed, Reunion Island's current energy mix is currently composed of primary fossil fuels (oil and coal) at 67%, with only 32% renewable energies. Energy sobriety is one of the key principles of the Cœur de Ville eco-district development project.

AFD awarded a €14 million loan to SEMADER (Société d'Economie Mixte d'Aménagement, de Développement et d'Equipement de la Réunion) in 2013 to finance two development concessions, including ZAC Cœur de Ville in La Possession.

Cooling actions

The eco-district built on ZAC La Possession incorporates sustainability criteria at each stage of its development and into all components of the development project. On the issue of combating urban heat islands, the solution applied by the developers is versatile. The multiplicity of levers and scales of action helps to maximise the project's cooling potential.

On the municipal scale, the developers are looking to maintain a "garden city" identity, where cooling is delivered through greenery by way of shading and evapotranspiration. An in-depth study of airflow patterns was used to provide natural ventilation, thereby ensuring block-scale cooling. Lastly, buildings are passively cooled using bioclimatic principles, including facilitation of natural ventilation and protection from the sun's rays using sunshading devices.

Project description

Cœur de Ville, a permeable eco-garden-district

ZAC La Possession benefits from cooling provided by shading, plant transpiration and evaporated water, all the more so as these are largely prevalent in the district. More than 80,000 plants of 100 different species have been planted to realise the vision of creating a "garden city". Most of the plants are endemic species, adapted to current local climate conditions. The greenery on nearly a third of the surface area of the public spaces is planted directly in the soil, and residents are encouraged to green their own gardens.

The district's surfaces have been designed to maximise soil permeability. Outside the greened areas, 50% of the soil is permeable. Landscaped ditches have been created to store rainwater as close as possible to where it falls and channel it naturally to proper outlets. This avoids the need for pipes and also promotes evapotranspiration.

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Aligning roads and buildings to leverage wind and screen the sun

Passive methods of optimising urban geometries and alignment of streets and buildings used in the ZAC Cœur de Ville project maximise cooling while minimising energy consumption. When adapted to existing conditions, these solutions minimise overheating by leveraging cool winds to ventilate indoor and outdoor spaces, and by screening the sun. This was achieved by introducing alignment rules that incorporate solar protection and by designing the road network to minimise exposure of buildings to the sun. Building alignment was also simulated in a physical wind tunnel to ascertain the optimal wind porosity of their facades.

At building scale, the recommendations encourage including solar protection on the facades, architecture geared towards green hearts of city blocks, as well as minimised width between building facades in order to allow for natural and efficient ventilation of interior spaces. These measures help to minimise the use of resource-intensive air conditioning.

Valuable lessons for other regions

Social and generational diversity in eco-districts

From the inception of the project, ZAC La Possession made a commitment to promote social diversity in the district. New and high-quality eco-districts often come with higher land prices and rents, as well as a gentrification phenomenon. By guaranteeing that 60% of the housing will be low-cost or subsidised housing, the city has pledged to fight the gentrification effect. The existence of schools, an EHPAD (elderly care facility) and a health centre is also a contributing factor to generational diversity.

The eco-district label

The ZAC Cœur de Ville project is pursuing numerous sustainability objectives, which have earned it the "Eco-district stage 2: construction phase" label. This French label recognises the sustainable approach of urban projects by acknowledging their efforts to not only mitigate and adapt to the effects of climate change, but also address the risks specific to the region. It is a guarantee that the project is exemplary on several counts, which are embodied in La Possession, namely: preservation of biodiversity, soils and natural environments, quality of the living environment, development initiatives to promote well-being and social harmony, functional diversity and proximity, *etc.*

Public space quality and short-distance cities

The functional diversity and density of ZAC Cœur de Ville encourage soft mobility. The many facilities available within walking distance are contributing factors in improving the quality of life for residents.

Conservation of endemic species

The ZAC project has taken care to work with existing resources. A diagnosis of the existing plant heritage was carried out, and 150 prominent trees were identified and have all been preserved, including old banyan trees.

Conducting these diagnoses early enough in the design process of such development operations helps to adapt the entire project to the existing natural heritage, thereby preserving the biodiversity and cooling capacities of mature trees. Young trees planted during such operations take several decades to reach a satisfactory canopy size for them to provide the shade and evapotranspiration needed for effective cooling. Mature plants are therefore vital assets for urban spaces that must be protected during development.

ZAC Cœur de Ville (urban development zone) in La Possession Reunion Island, France

Co-benefits


Sustainable cities and communities


Responsible consumption and production


Life on land


Climate action

Community engagement
A good number of the facilities at ZAC Cœur de Ville were designed following consultations with the future residents and neighbouring communities. Public information meetings were held, as well as participatory workshops that yielded collective projects in public spaces and shared gardens.

Responsible consumption and production
There are ten shared gardens and a community vegetable garden in the eco-district. These facilities offer the opportunity for a community of residents to engage their neighbourhood by joining forces to produce vegetables on a small scale on plots of land. This also contributes towards raising public awareness of biodiversity issues.

Biodiversity
The special attention paid to greening the district is of benefit to biodiversity. The greenery in many public spaces has been planted on open ground (nearly a third of the surfaces), giving priority to endemic species while banning invasive species. More than one hundred plant species make up this "garden city", thus contributing to enhancing the ecological sustainability of La Possession.

Climate change mitigation
The functional diversity and the density of the district facilitate daily activities over short distances, and encourage the use of soft modes of transport. Additionally, the passive solutions used to cool the district and its buildings are a contributing factor in controlling energy consumption. This consideration is vital in an island setting like Reunion, where the carbon footprint from electricity generation is high.

FOR FURTHER REFERENCE:
- Over-ventilation and summer comfort, Keys for action, ADEME (2018)
- Natural ventilation in practice, Practical methodology for the development of natural ventilation in construction as applied in Reunion Island, ADEME

OTHER SIMILAR STORIES:
- ZAC Hibiscus de Cayenne eco-district in French Guiana (Equatorial climate Af)
- Also see Cœur de Grippon eco-district in Morne à l'Eau, Guadeloupe, fact sheet (Equatorial climate Af)

Lycée Mermoz in Dakar Senegal


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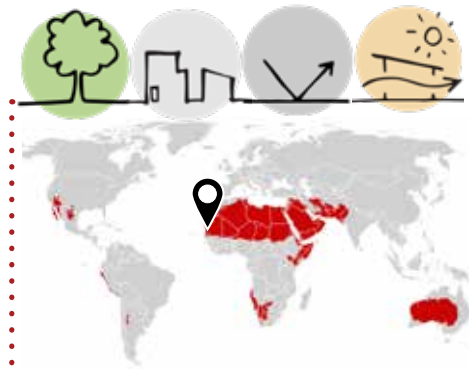
BWh

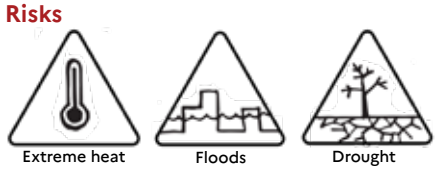


The current climate
Hot desert climate (BWh)

Scale
Building

Timing
Medium-term

Risks



The future climate
Hot desert climate (BWh)
+ 1.7 to +2.2C° by 2070
(RCP 8.5, IPCC)

The school's bioclimatic design offers thermal comfort to users, both inside and outside the buildings. By opting for passive, traditional and low-tech solutions, the school becomes a cool block. Greening the site with endemic species is a solution adapted to the city of Dakar's current climate.

Today, the school is only accessible to French nationals and students of the school, thus preventing the majority of the population from appreciating its cooling. For instance, opening it to the general public outside classroom hours may benefit residents of the area.

Lycée Mermoz in Dakar, Senegal

BWh

Background

The Jean Mermoz French Lycée is located in the Senegalese capital, Dakar. This city of more than one million inhabitants is currently under heavy demographic pressure, with more than 25 % of the Senegalese population concentrated there.

Urban overheating is a well-known issue, since Dakar's hot desert climate is compounded by high urban density. Indeed, the environment is conducive to the development of UHI effects with multiple heat sources concentrated in the same space. Dakar receives large amounts of sunshine, but although the hot season is lengthy, it is less intense than in the rest of the country. The Senegalese capital enjoys a mild and less dry microclimate, dominated by maritime trade winds. Such natural ventilation is a valuable asset to be considered during urban cooling development projects.

Cooling actions

Built in 2011 by the architects Terreneuve, Dakar's French Lycée is a very interesting example of contemporary bioclimatic architecture in a hot desert climate. The building has more than 17,000 m² of built area and is located on a 40,000 m² site, namely on a vast scale that impacts not only the **microclimate*** in its immediate environment but also its occupants.

The architectural approach was intended to be contextual, adapting the building and its construction process to the climatic, topographical and socio-economic conditions of Dakar. The buildings were constructed by local teams, and their visual appearance blends modern architecture anchored in Senegalese tradition. The colours were carefully chosen Lycée to reflect the local building earth, thus easing the project's integration into its environment. Adapted to Dakar's hot climate, the Lycée is equipped with numerous passive cooling solutions built on traditional techniques: shaded and ventilated access balconies, patios, blinds, etc. These passive devices have helped to limit the use of air conditioning to two months per year since 2012. Greening was also carried out on outdoor spaces, particularly by planting climbing plants on the pergolas to shade the pathways between the buildings.

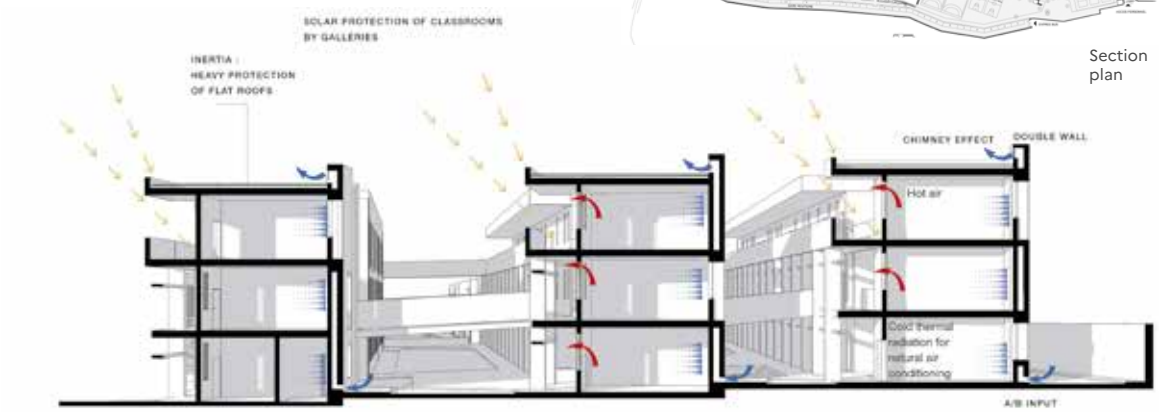
Project description

Buildings protected from the sun

The architecture of Lycée Mermoz creates shaded and cool spaces within the school using features offering protection from solar radiation for its walls, roofs and outdoor spaces.

Ground plan

Section plan



©Terreneuve

The buildings are located close enough to each other to create shading and wind effects. Building facades are also equipped with a double exterior wall. This acts as a sun shield while allowing natural lighting into the building. Protective roofs with reinforced inertia minimise overheating by storing heat during the day and releasing it at night. Outdoors, green courtyards and pergolas provide shade, thereby improving the thermal comfort of the courtyard and patios.

Passive ventilation solutions

Natural ventilation was also preferred within the school premises. The alignment of the buildings and their linear arrangement accommodate the free flow of trade winds, thus maximising their cooling potential. The pathways between each building were designed as protected walkways, drawing on tropical local architecture, thus allowing air to flow freely.

The double-walled structure coupled with the window and louvre systems interconnecting the rooms allow air to flow freely.

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Valuable lessons for other regions

Building adapted to its urban landscape

Lycée Mermoz was built in Dakar with a view to matching the buildings with their region. The construction was carried out by a Senegalese company, which opted for construction processes consistent with local resources. Similarly, importation of construction materials from abroad was minimised, thereby limiting the carbon footprint. However, the regional rooting of the school was hampered by the configuration of the construction site. There are few spatial references to the rest of the city, as only two contact points connect it to the rest of the district.

Cooling schools

Although they are not public spaces as such, schools are built as true living spaces. Accordingly, bioclimatic architecture processes should be used during their construction, in order to ensure greater thermal and visual comfort.
The French Lycée in Dakar is a unique building that exemplifies the application of traditional local bioclimatic principles in a contemporary setting. However, its cooling impact on the rest of the city is low and it would be useful to consider opening up such cool spaces to the general public by creating the opportunity for new activities to develop within the school premises.

Co-benefits

Climate action

Flood risk management
Urban water management systems are generally undersized for the heavy rainfall events that typically occur in Dakar between June and October. The French Lycée's design applies bioclimatic principles for proper rainwater management with the aim of easing water infiltration into the plot, the ultimate goal being to avoid runoff and replenish the soils and water tables. Temporary storage tanks on roof terraces and drainage tanks at the foot of walls allow large quantities of water to be discharged over time, always with a view to avoid saturating the soils or drainage systems.

Sustainable cities and communities

Community education and awareness
By virtue of its outstanding architecture, Lycée Mermoz is an emblematic and inspiring building. It is thus a showcase of best practice in how local traditional architectural solutions can be incorporated into contemporary architecture. As a place open to the public, the school also serves as a platform for raising the community and student awareness about climate change. Exhibitions on local bioclimatic architecture have been organised on the school campus and the school sponsors an innovative eco-brick project initiated by the students.

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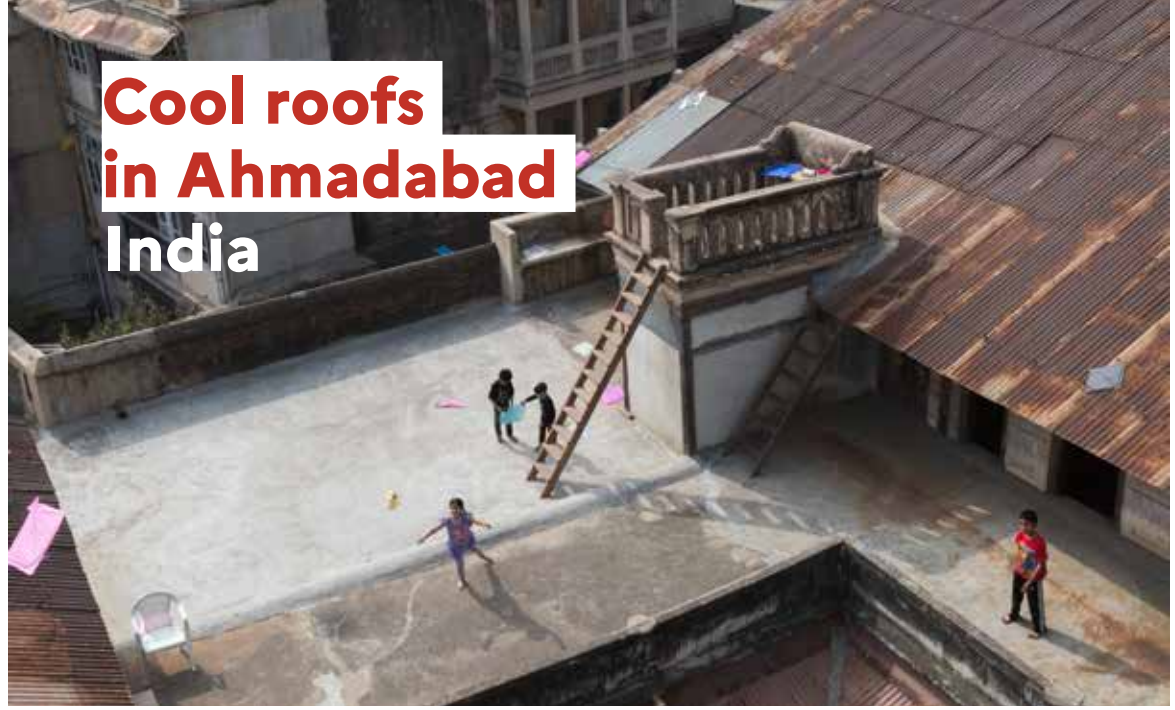
FOR FURTHER REFERENCE:
- PNEEB/Typha – CRAterre (2017): Bioclimatic architecture and the energy efficiency of buildings in Senegal

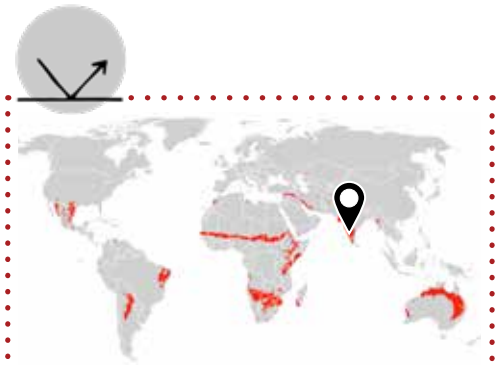
OTHER SIMILAR STORIES:
- The Lycée Théodore Monod extension project in Nouakchott applies bioclimatic principles in a desert climate (BWh) similar to Dakar.

Cool roofs in Ahmadabad India



Parikh Mahendra N/Shutterstock.com

BSh

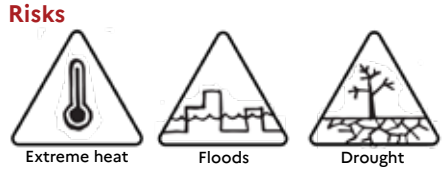


The current climate
Semi-arid steppe (BSh)

Scale
Building, city block

Timing
Short-term

Risks



The future climate
Tropical savanna with dry winter (As) +5 °C by 2100 (RCP 8.5) according to the Gujarat State (Gujarat SAPCC) climate action plan

The cools roofs found in Ahmadabad are quick to install. Depending on the technique used (acrylic, lime, jute...) they are also cheap to install and maintain. The cooling action on these roofs is suitable for a densely-populated city like Ahmadabad. The municipality's heat plan factors in the vulnerabilities of its residents and prioritises the most vulnerable. By adopting a robust risk management approach, it is able to take account of the health issues at stake in combating urban overheating.

The cool roofs must be combined with greening initiatives and a holistic study on urban typo-morphology to naturally discharge the hot air masses and facilitate comprehensive cooling of the city.

Cool roofs in Ahmadabad, India

Background

Ahmadabad is the largest city in India's Gujarat region, with a population of 7.2 million in 2017, including 25% living in informal settlements or slums. It is ranked among the top 20 fastest growing cities in the world (Forbes, 2010). In May 2010, the entire region was struck by a heatwave of unprecedented intensity. The air temperatures observed that year soared to a record of 46.8°, and the health crisis triggered by this phenomenon left a lasting impact on the city and its adaptation policies. The region is also prone to earthquakes. The last major earthquake in 2001 also helped create a strong risk culture in Ahmadabad.

Cooling actions

Having conducted a thorough diagnosis of the region's heat-related social and health vulnerabilities, Ahmadabad municipality launched its sixth Heat Action Plan in 2019. The diagnosis highlighted two vulnerability factors, namely extremely high informal-housing density and working conditions of residents, many of whom work outdoors and in small, poorly ventilated and overheated kitchens, occupied mostly by women who suffer the consequences directly.

In Ahmadabad, more than 700,000 people live in informal and dilapidated settlements known as "slums". These dwellings are particularly exposed to heat. They are often built with materials such as sheet metal that trap heat and subsequently release it into the atmosphere, thus contributing to heat island effects. Additionally, slum dwellers are often left with few adaptation options because they have little control over their housing. The Ahmadabad Heat Action Plan has therefore initially targeted these slums to install cool roofs.

Project description

Cool roofs

In 2016, the Kigali Amendment to the Montreal Protocol identified cool roofs as a key strategy for urban cooling. Different technical solutions can be used to create these cool roofs, the common principle being to coat roofs with high-albedo and strongly-emissive coloured materials and paints. These coatings reflect the solar radiation towards the sky instead of heating the roof and the ambient air. In the process, the thermal comfort and well-being of building occupants is not only enhanced, but the city is also cooled by several degrees when such roofs are adopted on a large scale. Under the Ahmadabad Heat Plan, more than 500 white roofs have been fitted on slum rooftops, residential buildings and municipal buildings. Cool roofs are usually whitewashed with lime, a light-coloured material with insulating properties. Roofs can also be painted with acrylic resin. White porcelain is also a traditional roof whitening solution used in Gujarat.

Finally, Ahmadabad municipality is promoting a low-tech roof cooling technique based on water evaporation. By moistening jute fibre laid on the roof, the house benefits from lower temperatures through evaporation. This is a very cheap technique that also serves to recycle used jute bags.

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Communication and public awareness

The Heat Action Plan incorporates a public outreach communication approach. An early warning system is sent out via the media three days before a heatwave. Illuminated billboards across the city also serve as a means of communicating with residents. Another key measure taken by the municipality is raising residents' awareness on how to behave in the event of a heatwave. The municipality proposes to extend the opening hours of parks and air-conditioned buildings, such as libraries and shopping malls, to provide cool spaces for the residents most exposed to heat.

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BSh

Valuable lessons for other regions

Key success factors of Ahmadabad's Heat Action Plan

Ahmadabad's cool roofs are not able to cool the ambient air by themselves. They are part of the municipality's Heat Action Plan, which is a more holistic approach. The diagnosis carried out prior to drawing up the plan is quite elaborate. Building on the city's spatial morphology and socio-economic surveys, it provides insights into the most vulnerable areas in terms of heat islands. Ahmadabad's risk culture is a valuable asset. Developed within decision-making circles and gradually passed on to residents through awareness-raising initiatives, it helps to build a collective awareness of heat-related risks.

Limitations of cool roof systems, the critical mass

However, cool roofs are not a perfect solution to UHI. Although they are an effective solution in reducing indoor temperatures of buildings, thus producing thermal comfort, their cooling impact on the ambient air is limited. To see a real cooling effect, a critical mass of cool roofs must be achieved (Akbari &Matthews, 2012). Cool roofs alone cannot effectively combat heat islands. They must be combined with greening initiatives and introduction of water into the city.

Points of caution

The effectiveness of cool roof systems depends on the context and the local climate. The higher the temperatures and the stronger the light radiation, the more the roof coverings will cool the atmosphere. Conversely, in more temperate climates where the cities are shadier or further from the equator, the cooling effect from the roofing will be lower (Oleson *et al.*, 2010).

In Ahmadabad the roofs covered by the action plan are mostly flat or slightly sloped. Sloping cool roofs are more likely to cause visual discomfort. The reflected light can also be reflected back to another building or part of the city and heat up the ambient air.

Cool roofs in Ahmadabad, India

Co-benefits

Good health and well-being

Climate action

Health and well-being
By lowering the indoor temperature in buildings, cool roofs largely improve thermal comfort in homes and apartment buildings. Ahmadabad's Hospital in particular features cool roof systems, which have lowered heat-related discomfort, illnesses, and deaths (Mavalankar, 2011).

Climate change mitigation and energy saving
Cool roofs help to save resources in several ways. By naturally cooling indoor air, they minimise the need for air conditioning (Akbari and Matthews, 2010). This is particularly critical as electricity bills are often high in poor housing due to poor insulation, and low quality ventilation and air conditioning systems.
The coatings used for cool roofs also help to prolong the life cycle of roofing systems. Moreover, they reduce their porosity and keep them watertight for much longer. Cool roofs are cheap to maintain, since this mostly entails regular cleaning to keep the colour bright.

FOR FURTHER REFERENCE:
- Climate Change and Health Preparedness in India: protecting local communities in Ahmadabad from extreme heat, Indian Institute on Public Health (2011)
- The UNEP (United Nations Environment Programme) Cool Coalition provides details of various cool roof projects worldwide.

OTHER SIMILAR STORIES:
- Cool roofs are popular in India, despite varying climate types across the country. They can be found in Delhi and Hyderabad (semi-arid climate BSh), Jodhpur (desert climate BWk), Bhopal (Mediterranean climate Csb) or Surat (tropical savanna climate Aw).
- Cool Roof France is a French start-up that designs and installs cool roofs on public buildings (schools, shopping centres, hospitals, etc.).

White city of Tetouan
Morocco

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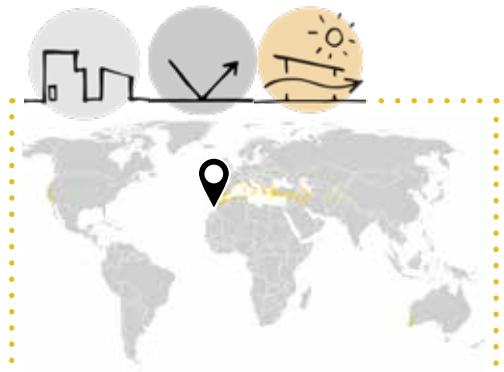

The current climate
Mediterranean (Csa)

Scale
City

Timing
Long-term

Risks

Extreme heat

Drought

The future climate
Semi-arid steppe (BSh)
+1.3 °C by 2050 (RCP 8.5, IPCC)

The Tetouan medina exemplifies well-preserved ancient local architecture, partly thanks to its classification as a World Heritage Site by UNESCO in 1997. It features an inspiring array of bioclimatic principles for improving thermal comfort and urban cooling in hot Mediterranean climates.

Nonetheless, the issue of how relevant it is to reproduce traditional local cooling solutions remains. Actually, it is rather a matter of building on the local climate adaptation approach, and minimising the use of fossil fuels by replacing them with climate-based energy sources. A modern bioclimatic architecture informed by traditional local principles would therefore combine climate change adaptation and mitigation solutions.

Csa

Background

The city of Tetouan is located in northern Morocco in the western Rif mountains and has a population of 402,000. Built on the south-facing slope of a rocky plateau, it is highly exposed to sunlight. Its old town is a medina ("city" in Arabic) classified as a UNESCO World Heritage Site, with a traditional Mediterranean layout exemplifying the local architecture. The district's traditional architecture is rooted in the land, shaped by local necessities, building functions and cultural influences. More especially, the architecture of Tetouan's medina is deeply steeped in Andalusian culture.

Cooling actions

The urbanisation of the Tetouan medina traditionally pays heed to thermal comfort, while catering to the demand for sustainability. The medina's bioclimatic architecture and layout apply various cooling solutions simultaneously. They all seek to improve thermal comfort through shading, natural ventilation, building insulation and evaporation.

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The medina is a space offering considerable functional diversity, where housing, craftspeople, shops and public spaces interact in a confined space. Preference is given to soft mobility, thus minimising the number and intensity of anthropogenic heat sources.

Description of solutions

The medina's urban geometry

The Tetouan medina's urban typo-morphology can accommodate the creation of cool pavements, squares and souks. It is a dense city with compact and inward-looking houses. As such, its buildings are blocked off from the street and turned towards the courtyards (patios) and inner gardens (riads), thus helping to retain cooling. The street pattern or road network is composed of narrow alleyways aligned in various directions in relation to solar radiation. This helps to preserve the cooling within the urban network.

The medina's bioclimatic architecture

The medina's traditional buildings are historically cool, owing to the bioclimatic principles governing their architecture. Due to the proper insulation and high thermal inertia of their exterior, the buildings offer greater thermal comfort with lower energy consumption for cooling. Such thermal inertia is made possible by solid construction and use of high-density materials such as earth and stone. The thickness of the exterior walls prevents loss of cooling and entry of heat. Buildings have bright-coloured lime coatings and high albedo that reflects solar radiation.

All houses are arranged in a similar manner. A patio or garden serves as a thermal regulator, and allows air to flow freely indoors. The existence of fountains and some greenery makes them cool spaces owing to the dual effect of natural ventilation and evapotranspiration. Inside the buildings, the moucharabiés (wooden lattices) provide both shading and natural ventilation. Warm air in the rooms is released through high ceilings and high windows. Openings are minimised to protect the building from solar radiation and retain cooling.

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Valuable lessons for other regions

Bioclimatic architecture in hot climates

Examples of traditional local architecture, such as the Tetouan medina illustrate which bioclimatic principles are the most suitable for different types of climate. In this instance with a hot and relatively dry climate, the city's **compactness***, use of heavy materials with high thermal inertia, search for shading and creation of skylights and air wells by means of patios, the height of vaulted ceilings and the opening of ventilation holes to release hot air are all effective solutions for boosting thermal comfort.

Local architecture and replicability of solutions

By definition, traditional local architecture is rooted in the history and culture of the region in which it is applied. As such, it is adapted to its type of climate. Often the legacy of ancient traditions, it is particularly inspiring by virtue of its sobriety and use of local materials.

Tetouan's medina is therefore an inspiring model for regions with a hot and dry climate similar to that of the Western Rif. It is adaptable to its environment, needs no water-intensive cooling solutions and is geared towards generating natural cooling through shading by screening from the sun. It is an example of adaptation to the challenges and opportunities arising from local climatic conditions. However, the heavy impact of socio-cultural influences on local architecture can also be a barrier to replication of cooling solutions. This is the case in using wooden lattices, for instance, in place of glazed windows.

The advantage of drawing on local architecture in contemporary urban planning therefore lies in reviving its techniques and understanding thermal phenomena. By gaining a detailed understanding of local microclimatic functions, it is possible to optimise the construction of buildings and districts in order to retain cooling. Moreover, buildings with passive cooling require active residents, since the cooling solutions have to be adjusted throughout the year and the day.

Co-benefits


Sustainable cities and communities


Good health and well-being


Climate action

High-quality public spaces
The medina comprises several districts with diversified functions and activities. Its functional and utilitarian diversity, ranging from business to leisure and housing, makes it an appealing and qualitative space. Its characteristic coolness contributes to this urban attribute.

Health and well-being
The medina's buildings, inner gardens and even the streets are cool spaces that guarantee thermal comfort for people at any time of the day. Such access to cool spaces improves the well-being of residents and health conditions for the most vulnerable.

Climate change mitigation
Local architecture is traditionally built on a sobriety model. Its passive cooling opportunities avoid the use of costly, polluting and heat-emitting air conditioning solutions. Its building materials (earth and stone) have low environmental impact, while the medina's spatial density makes it a land-saving space.

FOR FURTHER REFERENCE:
- Architectures CREE et ADEME (2015)
- Matériaux de construction : retour aux (bio)ressources—Panorama et perspectives d'utilisation des matériaux biosourcés dans le monde

OTHER SIMILAR STORIES:
- Santorini in Greece (Csa, dry Mediterranean climate), is a showpience of Cycladic vernacular architecture featuring white coatings/cladding, flat roofs, narrow streets and troglodytic structures that keep the city cool.

Zenata eco-city
Morocco


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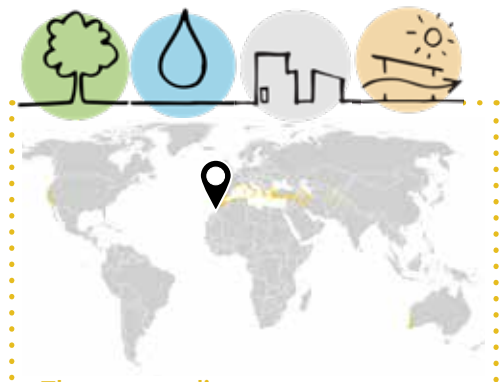
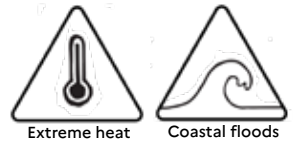


The current climate
Mediterranean (Csa)

Scale
City

Timing
Long-term

Risks


Extreme heat

Coastal floods

The future climate
Semi-arid steppe (BSh)
+1.3 °C by 2050 (RCP 8.5, IPCC)

From its design phase, the Zenata eco-city project adopted a cross-cutting approach, putting the emphasis on green spaces and developing ecological continuity across its territory. Natural ventilation was devised from a study of airflow patterns, which provided detailed insights into its cooling potential. The functional diversity of the future city and the public transport connections with the region of Greater Casablanca guarantee the attractiveness of the project.

However, since the eco-city project is not yet complete, it is difficult to have the necessary hindsight to assess the actual efficiency of the cooling solutions as well as the goals pursued by the developers. There is also a need to keep track of the ecosystems undergoing renaturation. The deteriorated dune ridge and the numerous species being planted, which are adapted to the current climate for the time being, should be closely monitored in order ascertain the project's adaptation to the effects of climate change.

Csa

Zenata eco-city, Morocco

Background

Zenata is Africa's pioneer eco-city. Currently under construction on the northern coast of the Greater Casablanca conurbation, Zenata has become a benchmark for the development of new environmentally-friendly cities in Africa. It is part of a programme to build 15 new cities across Morocco with a view to providing housing, facilities and services to the country's middle classes.
To successfully implement this eco-city project, the Caisse des Dépôts et Gestion group founded SAZ, the Société d'Aménagement de Zenata (Zenata development corporation). SAZ was awarded a €0.3 million grant by Agence Française de Développment (AFD), a €150 million loan and another grant of €4 million in the form of EU delegated funds. The total project budget is expected to be approximately €1.9 billion.

Cooling actions

The Zenata project was designed as an eco-city with the aim of tackling challenges in a systemic manner, building on economic, social and environmental considerations, while paying heed to future climate hazards. The risks of flooding and heat island formation are well-known, and several public facilities in the city are geared towards adaptation. Zenata is looking to becoming a model for incorporation of green and blue solutions, as many green spaces with unsealed soils have been created, while the waterfront has been opened up to the city. Natural ventilation of the entire city is being provided through gray solutions leveraging on urban geometries. These solutions capitalise on Zenata's nearness to the sea, the mountains to the east and the dominance of cool northerly winds in summer to naturally cool the city.

Project description

Zenata bioclimatic city

Bioclimatic studies were carried out during the eco-city's design phase, and its road network design is therefore informed by bioclimatic and aeraulic (airflow) principles. The topography of the site is conducive to cool winds with an average annual speed of 3 metres per second. This relatively low speed allows for proper ventilation of the site, generating cooling of -2 to -3 °C in summer.

To maximise the cooling potential of the winds, greenery and water masses were created upstream of the neighbourhoods. This ventilation model was tested in a wind tunnel in order to guarantee optimal comfort. Wind can also become a challenge if the urban geometry allows for too many Venturi effects that accelerate the air masses. The bioclimatic master plan drawn up before the city was built was transposed into the regulatory documents.

The eco-city also seeks to meet bioclimatic and energy-efficiency standards. These requirements were transposed into the technical specifications sent to the developers. In addition to aiming for low CO_2 emissions, indoor thermal comfort is secured through insulation, sunbreakers and natural ventilation.

Water and vegetation

The Zenata project also incorporates green and blue spaces. 470 hectares of gardens and public spaces are greened, giving priority to endemic species during planting. Mediterranean plants thrive on little water and therefore offer less cooling potential.

The urban hydrology strategy in Zenata is geared towards retaining water and allowing it to percolate down into the soil of the plot. This is achieved by creating open ditches that store water before its infiltration into the soil, by replenishing the water table and creating wetlands. The city has opted to turn towards its coastline by rehabilitating its waterfront to make it accessible, and creating a cool and attractive public space for residents. The dune ridge is also being renatured after informal settlements disrupted the smooth running of the site.

Zenata's green spaces account for
470 ha or 1/3 of its territory
This represents 15m² of green spaces per capita
WHO recommends 10m²/inhabitant

Project timing

- **2004** – New cities programme launched in Morocco
- **2013** – Eco-city project kicks off in Zenata
- **2019** – Business hub opened
- **2021-2026** – Resettlement process launched for families living in slums
- **2030** – Construction completed and eco-city delivered

Valuable lessons for other regions

Key success factors: an attractive and economically viable city connected to its region

Zenata's priority is its attractiveness to the population of Greater Casablanca. The developer is therefore proposing an urban project with high functional diversity, thus reflecting the traditional model of the Moroccan medina. The project seeks to build a fully-fledged eco-city, which will allow people to live, study and work at the same time. This consistent quest for social and functional diversity should ultimately culminate in the construction of a university, shopping centre, health centre, logistics centre, collective housing, public spaces, etc. Paying heed to eco-mobility, efforts have been made to encourage active mobility such as walking or cycling, thereby cutting down CO_2 emissions.

Social considerations

The Zenata project entails the need to resettle 36,000 slum dwellers within the site of the new city. The development company conducted a census, as well as a support, dialogue and consultation process to organise this resettlement programme. New low-cost housing was proposed, as well as the provision of plots of land for the inhabitants to build new homes.

Systemic approach to development

The systemic approach adopted by Zenata is quite noteworthy. The methodology of the "Zenata eco-city model" highlights the existing interactions between the different development components of the eco-city. From greening to mobility, from employment to public spaces, all steps of the development process undergo the scrutiny of the eco-design method.

Co-benefits

Life on land

Biodiversity
Zenata's urban design is conducive to biodiversity. Green spaces cover one third of the territory and are designed for continuity, while several blue networks are featured in the project, with the creation of landscaped parks.

Good health and well-being

Health and well-being
The aerodynamic design of Zenata's urban geometries promotes ventilation and proper wind flow with salutary effects on air quality. Additionally, it is a high-density city where functional diversity is given centre stage, thereby promoting active and low-carbon modes of mobility.

Climate action

Flood risk management
Zenata eco-city's design incorporates the occurrence of 100-year floods and the risk of submergence, which is exacerbated by the dune erosion phenomenon. Ditches and water reservoirs have been built in the different districts, in order to absorb water and direct the residual runoff towards the sea. A plan has been developed for the protection and renaturation of the dune ridge.

Climate change mitigation
The Zenata eco-city model allows for the project to be articulated around the concept of urban resilience against changing temperatures. Additionally, the project will incorporate a profound reflection on sobriety, on the energy mix to be adopted and on the energy efficiency of the buildings.

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FOR FURTHER REFERENCE:

- Claude De Miras, & Catherine Paquette Vassali. (2021). New cities: what their obvious difficulties in the South reveal. Reflection on the Moroccan case. African Cities Journal, 02(03)

Renaturation of Les Aygalades
Marseille
France

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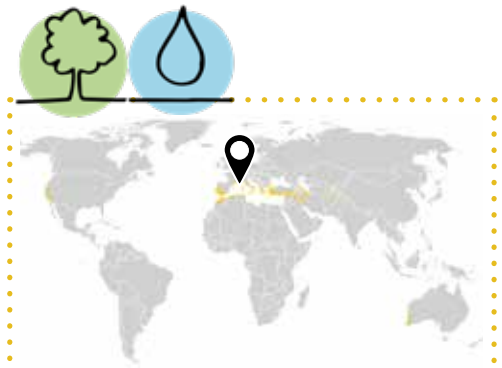


The current climate
Hot Mediterranean (Csa)

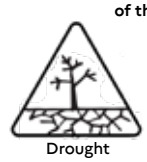
Scales
City block, public space, district

Timing
Long-term

Project cost
€38.5 M
including €2.5 M for restoration of the waterway

Risks

Extreme heat



Drought

The future climate
Semi-arid steppe (BSh)
+1.3 °C by 2050 (RCP 8.5, IPCC)

The waterfall nestled in the heart of the Jardin des Aygalades, within the Cité des Arts de la Rue (15th district of Marseille) is part of an ecological restoration project led by the Gammares association. The aim is to look after the stream that was used as a sewer, to revive the waterfall and to rehabilitate the banks with the garden comprising a footpath along the banks, a garden of aromatic plants and a viewpoint overlooking the waterfall.

The Parc des Aygalades and Parc de Bougainville (14th district) are part of a Euroméditerranée large-scale **urban project*** in the city of Marseille aimed at renaturing the Les Aygalades riverbanks. The developers are making it the centrepiece of the rehabilitation project in the surrounding districts. It is therefore contributing towards greater inclusivity by accommodating new cultural events in the northern districts.

Csa

Renaturation of Les Aygalades in Marseille

Background

Marseille is a French city with a population of approximately 870,000. Located on the Mediterranean coast and surrounded by small mountains and massifs, it is known for its hot and dry Mediterranean climate. With 2,858 hours of sunshine, it is the sunniest city in France. Marseille is intersected by several coastal rivers with relatively low flows. These waterways are highly channelled from their source and their flood-water is quite heavy when it rains. The city has been marked by the extreme events of 1978 and 2003, which resulted in severe flooding of the hyper-centre (Chalvet and Claeys, 2011). The extreme rainfall of October 4, 2021 triggered a red alert for rain and flooding in the Bouches du Rhône department. In Marseille, the equivalent of more than two months' rainfall was recorded in a few hours. The renaturation of the Les Aygalades coastal river from upstream to downstream will not only contribute to a better understanding of the risk of flooding, but will also create cooling islands in the city.

Cooling actions

The renaturation of the Les Aygalades coastal river under the Euroméditerranée 2 project includes the future development of two urban parks, namely the 10-hectare Les Aygalades Park (to be completed in 2028) and the 4-hectare Bougainville Park (to be completed in 2024). Construction work began in 2021.
Euroméditerranée is a 480-hectare urban renewal project in Marseille. Since 1995, Euroméditerranée has been a laboratory for urban experiments to create a sustainable Mediterranean city. The latest stages of this operation are geared towards redefining the urban territory by structuring its spaces around urban parks: The "Bougainville" park is only the foundation stone of the future Les Aygalades park, a long green corridor of 14 hectares along its eponymous stream. This project will feature a 215 metre open stretch of river. The aim of these projects, which have been ongoing for the better part of the last 10 years, giving birth to the Gammares association in the Cité des Arts de la Rue and expected to be extended further downstream by Euroméditerranée, is not only to renature but also to open up the Les Aygalades stream, which was largely concealed underground, concreted, channelled and highly polluted. Opening it up to the general public will be an opportunity to fully harness its cooling potential. The entire green corridor envisioned for the Euroméditerranée stretch will undergo a major greening operation from north to south. Urban cooling goals therefore lie at the heart of the various initiatives taken along this coastal waterway.

Project description

Existence of water and greenery in Les Aygalades Park, Euroméditerranée

The Les Aygalades rehabilitation and renaturation project involves dual action by the developers, including improving water quality and opening up the stream, as well as greening the riverbanks and the park. Unsealing the soil by creating landscaped ditches, recycling surface runoff and opening up the watercourse allow for better hydraulic control in case of flooding and enhance cooling through evaporation. Rehabilitating the banks of Les Aygalades to encourage recreational activities, including walking and relaxation, contributes towards reconnecting the residents to water as an inherent feature of the city. To improve spatial quality and ultimately bring the residents to take ownership of the space, a greening strategy has been developed. Greening the riverbanks also has the advantage of stabilising them. The overall greening of the park and of the Euroméditerannée 2 district promotes evapotranspiration, shading and, ultimately, cooling. However, it is vital to note that the species planted in the park were selected for their high resilience to water stress (Aleppo pines, aloes, etc.). However, although these plants require less water intake, their cooling potential is low.

-5 to -6 °C
temperature difference at night between Les Aygalades park's interior and the rest of the city (Météo France, 2013)

Urban cooling potential of the park

The initiative carried out within the Cité des Arts de la Rue demonstrates that urban cool islands can be recreated by making them gradually accessible to residents of the district. The Etablissement Public d'Aménagement de l'Opération Euroméditerranée (EPAEM) and Météo France conducted a microclimatic study on the impact of the Euroméditerranée 2 project on urban cooling during heatwaves. This approach is still rare in urban projects and allows for a comprehensive understanding of how to secure the most effective cooling.
In particular, it helped to quantify the park's cooling potential in its environment: 54ha will be cooled, i.e. about 30% of the total area of the project. This cooling will only cover the park's immediate environment, i.e. an area of 80 to 100m around its boundaries. It will cool the ambient air by -0.3 °C to -4.0 °C (Météo France, 2013).

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Csa

Valuable lessons for other regions

Climate change adaptation as centrepiece of the Euroméditerranée project

The Euroméditerranée project's declared goal of adapting to the effects of climate change is reflected in Les Aygalades park. The plant species chosen are adapted to the water stress the city of Marseille will increasingly experience in the future.
Watering of the park's plants is still ensured using the city's water, but a project is in the pipeline to ultimately utilise the wastewater from the surrounding buildings.
Combining cooling actions with enhanced flood risk management solutions is also an exemplary adaptation strategy for regions where climate forecasts predict an increase in the frequency and intensity of extreme events.

Community engagement and ownership at the core of the initiatives

Large-scale urban projects such as Euroméditerranée 2 must rise to the challenge of engaging the community throughout the project. In this instance, consultations were held with residents with a view to capturing their expectations about the accommodation of nature in the Euroméditerranée 2 project and in the Aygalades Park, and organising awareness-raising activities about waterway pollution in Marseille. For the waterfall and Les Aygalades garden in the heart of the Cité des Arts de la Rue, "Voix d'eau" conferences, walks and a market are organised every first Sunday of the month to raise awareness among residents and visitors, and gradually open up to the general public these previously derelict spaces, used as sewers. Temporary occupancy of the wasteland and transitional projects were also developed, with meaningful input from the Cité des Arts de la Rue, thereby raising awareness among residents of the need to renature the former wasteland. Scientists also took part in these initiatives. The Institut Méditerranéen de Biodiversité et d'Ecologie (IMBE) laboratory conducted a study on the ecological status of the stream.

Co-benefits

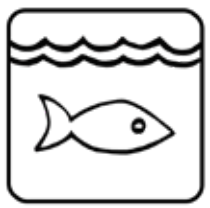

Sustainable cities and communities

High-quality public spaces
The waterfall and Les Aygalades garden promote social inclusion and community engagement. Les Aygalades urban park is destined to become one of the foremost public spaces in the city of Marseille in advancing social inclusion in the northern districts. It will become an attractive space that will eventually connect these priority districts in the city's policy with the rest of Marseille. Besides offering a cool space to the residents, it will expand the nature, sports, leisure and cultural facilities in the surrounding districts.


Climate action

Flood risk management
Les Aygalades river regularly floods during heavy rainfall. Among the aggravating factors of this flood risk are the mineral nature of the watershed downstream of the river and the large stretch of its length that is channelled and underground (Chalvet and Claeys, 2011). The development of the park and the stream are effective means of hydraulic regulation. A flood expansion zone and green ditches have improved flood management.


Life on land


Life below water

Biodiversity
Les Aygalades Park is built on industrial wasteland. The 14 hectares now covered by the park were previously a marshalling yard. Cleaning up the watercourse, renaturing the wetland and greening the space are all good for biodiversity. By combining the different scales of urban development, the park will contribute to creating a green and blue network from the Massifs de l'Étoile to the shores of the Mediterranean.

FOR FURTHER REFERENCE:
- Study of the meteorological impact of the Euromed operation during heatwaves, EPAEM and Météo France (2013)
- The fact sheet produced by Mediterranean Cities and Climate Change (MC3) emphasises the Euroméditerranée programme's relationship with climate change

OTHER SIMILAR STORIES:
- The Pen Ar Biez watercourse at Lannion (22) was the site of an urban rehabilitation project (including renaturation, remeandering, development of the banks...)

Cool pavements in Los Angeles

United States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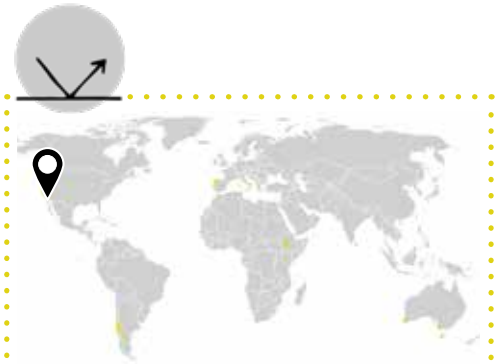
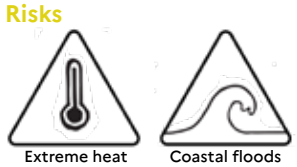


The current climate
Mediterranean (Csb)

Scales
City block, public space

Timing
Short-term

Risks


Extreme heat Coastal floods

The future climate
Semi-arid steppe (BSh)
+ 4 °C by 2100 (Source: State of California)

The main attraction of this project for the City of Los Angeles is its speed of implementation and quick measurable results. This can be considered as a "**quick win***". The city is continuing its paving efforts to quickly reach a critical mass that will enhance urban cooling.

However, it worth noting that the use of reflective pavements for roadways and public spaces is a novelty. As a result, their actual effects on the thermal comfort of users is still unknown. Research projects are currently ongoing (see Further reference box) to determine the impact of cool pavements on the thermal comfort of pedestrians.

Csb

The cool pavements of Los Angeles, USA

Background

With more than four million inhabitants, Los Angeles is the second-largest city in the United States. It has a moderate risk of extreme heat, i.e. the risk of an extreme heat event occurring in the next five years is greater than 25 %. The city of Los Angeles covers more than 1,200 km^2, and more than 15 % of its surface is occupied by paved streets. The asphalt roads used by cars are largely responsible for the UHI effects due to their dark material that traps heat. In this respect, they should be given top priority in actions to limit urban heating.

The city of Los Angeles is conducting experiments and taking proactive measures to control heat islands. In 2015, it launched the "Los Angeles Sustainable City" plan in which it committed to implementing pilot cool pavement projects. Under its "Green New Deal" in 2019, it reiterates its commitment to cool pavements and public spaces. To do so, actions are being taken: cool pavements, cool roofs, greening and construction of shading systems.

Cooling actions

The City of Los Angeles has set a target of having more than 400 km of roadways covered with cool pavements by 2028. So far, the pavement testing phases account for the lion's share of the action plan. This has made it possible to identify the numerous stresses borne by the pavements. They are highly reflective to solar radiation, thereby minimising heat on the pavement surface and in the ambient air. However, the visual comfort of users may be impacted by the brightness of the pavement. Lastly, there is a need to guarantee the sustainability of the system by adapting the friction resistance of the material to the functional purposes of the paved streets.
Cool pavements are especially effective in the climatic and topographic environment of Los Angeles. Summers, from May to October, are very dry and do not allow for action on vegetation and water. Additionally, it is a vast and sprawling city with many roadways and over 14 % of its land area covered by car parks (Chester *et al.*, 2015).

Project description

Choice of pavement

The streets of Los Angeles have undergone several experiments with different pavements, which all share the common characteristic of having a bright colour. These high-albedo pavements reflect solar energy back to the sky and their emissivity ensures that the ambient air is not heated up when the roadway surface temperature increases. They are composed of a mixture of sand, white and gray cements, polymers and white pigments.
These pavements are fairly easy to lay. Satellite imagery can be used to determine appropriate locations to lay them and no sophisticated technique is required for their installation. These cooling solutions are therefore of prime interest owing to their simplicity.

Maintenance and corrosion

The maintenance of cool pavements is a critical issue to consider. Since their high albedo is derived from their bright material, this must not be soiled by pollution. Otherwise, it will darken and no longer generate the expected cooling effect. Roadways covered with cool pavements may also be exposed to intense and repeated friction, such as superhighways, for instance. The pavement must therefore be robust to avoid the need for frequent repairs.

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A dark asphalt road surface can hit 50 to 65 °C in summer.
(Akbari & Matthews_2012)

Valuable lessons for other regions

High installation and maintenance costs for cool pavements
The technologies used for cool pavements in Los Angeles are mostly in the pilot phase. Indeed, cool pavements are yet to be manufactured on a large scale, hence their currently high cost. Depending on the purpose of the roadways on which they are laid, cool pavements undergo heavy traffic, friction and pollution. Their maintenance is critical because the grime created by such pollution lessens their cooling effect. Their regular maintenance entails ordinary cleaning, although this requires the use of labour.

The importance of human thermal comfort data
Most studies on cool pavements use computer modelling to determine the cooling potential of different pavements. These models focus on the roadway surface temperature, but fail to deal with human experience and use, or with thermal comfort. However, the few studies that have recently focused on thermal sensors in the field and on measuring the body temperature of passers-by have shown that cool pavements can produce negative effects on the thermal comfort of pedestrians. Indeed, where the surface temperature of such roadways is much lower, their high albedo will reflect the energy of solar radiation. Part of such radiation would be absorbed by the pedestrians' bodies, thereby raising their body temperature.
It is therefore necessary to consider how the spaces accommodating cool pavement streets would be used in order to make a trade-off between combating heat islands and securing thermal comfort for passers-by.

Csb

Co-benefits


Sustainable cities and communities

High-quality public spaces
Los Angeles cool pavements create higher quality public spaces wherever they are constructed. They prevent overheating of the street and high temperatures in urban spaces. Their aesthetic properties are also appealing, as their bright colour enhances night-time visibility, thus providing a sense of safety at night.


Good health and well-being

Health: air and water quality
Due to its topography, the city of Los Angeles is prone to smog, namely a cloud of air pollution that hangs over the city. When these particles come in contact with solar radiation and heat, they react and produce toxic compounds, such as ozone and nitrogen dioxide. The cooling provided by the Cool Pavements Plan is expected to reduce smog by 12% (Rosenfeld *et al.*, 1998).


Climate action

Lower energy consumption and durable equipment
By preventing overheating of street surfaces and surrounding urban facilities, cool pavements help to guarantee their durability. Urban fixtures such as pavements are less likely to wear out and deteriorate. Additionally, the cooling created helps to limit the energy consumption for air conditioning on a city-wide scale. Lastly, the improved visibility provided by the brightly coloured pavement limits the need for public lighting. (Pomerantz *et al.*, 2000)

FOR FURTHER REFERENCE:
- Middel, A., Turner, V. K., Schneider, F. A., Zhang, Y., & Stiller, M. (2020). Solar reflective pavements-A policy panacea to heat mitigation, Environmental Research Letters

OTHER SIMILAR STORIES:
- Cool pavements can be found in several cities with Mediterranean climates (Csa), such as Acharnes in Greece
- Porous or permeable pavements are another way to create cool flooring. They facilitate rainwater management at the plot level, and can be found in Montreal, for instance, in a humid continental climate (Dfb) See: Arrondissement de Mercier-Hochelaga-Maisonneuve, Montreal

Cooling the City strategy in Penrith

Australia


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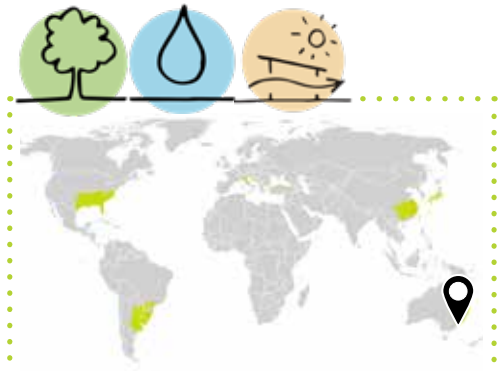
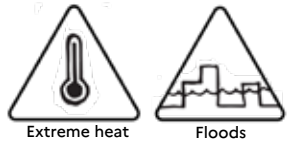


The current climate
Subtropical humid (Cfa)

Scale
City

Timing
Short to long term

Risks


Extreme heat Floods

The future climate
Subtropical humid (Cfa)
+1.5 to +3 °C average temperature (NSW Government)
+46 hot days yearly by 2090 (The Australia Institute)

The main attraction of Penrith's Cooling the City strategy is its integrated and systemic approach. Indeed, it includes the fight against urban overheating in a more global approach to adapting to the effects of climate change, and fully engages residents in the process. The latter are also invited to take action privately. Additionally, identifying city areas and populations most vulnerable to heat helps to target priority initiatives in order to relieve the areas identified, while cooling the entire city by mitigating UHIs.

However, this highly ambitious plan launched 6 years ago is yet to be assessed. Its exact cooling potential therefore remains unknown, whereas an evaluation process would have helped to chart the way forward.

Cfa

Background

Owing to its location between the city of Sydney to the east and a mountain ridge to the west, Penrith's microclimate makes it the hottest and driest city in the surrounding area. In 2020, the city experienced more than 39 days above 35 °C, with six of the heat sensors scattered around the city recording temperatures above 50 °C during the summer. Studies conducted by the Western Sydney University found many disparities in terms of overheating between different parts of the city. Two of them stood out with average temperatures almost 2 °C higher than elsewhere. The many UHI effects experienced in Sydney's western region make it an extremely overheated area (Ogge, Browne, Hughes, 2018). The City of Penrith has therefore set up a special "task force" to build a more heat-resilient city.

Cooling actions

The city of Penrith developed a "Cooling the City" strategy in 2015, with the aim of incorporating the issue of cooling into all future development policies. Among the 52 actions outlined in this plan, half of them are expected to be implemented in the short term at a low cost, while the rest will take longer. The municipality has adopted a multi-scale approach, which addresses various dimensions of development, including mobility, green spaces, road maintenance, etc.

The Nepean river and the numerous wetlands provide Penrith with plenty of water and the opportunity to apply blue and green solutions for cooling (greening, development of riverbanks...). Moreover, the highly built-up nature of the city calls for the use of gray solutions, such as laying high-albedo pavements. Initiatives to ensure education, community engagement and familiarisation of municipal services with the challenges of cooling Penrith are also incorporated in the action plan.

Project description

Identifying priority action spots

The diagnostic phase of Penrith's UHIs was paramount in designing and implementing its Cooling The City Strategy. The city decided to repeat the exercise 5 years later, to update the available data and obtain a proper understanding of the phenomenon. With this "Heat Sensor Project" study conducted by Western Sydney University, specifically-targeted actions can be taken. The cooling initiatives are mostly concentrated in identified vulnerable areas. However, like most cooling policies drafted by local governments, the Penrith Cooling the City strategy does not differentiate between actions to reduce UHI and those to manage extreme heatwave events (Pfautsch, 2020).

Content of Penrith's Cooling the City strategy

Penrith's cooling actions are built around a "water-sensitive" urban design that maximises the presence and retention of water in the city. This entails unsealing the soils, creating green ditches, ponds and fountains in the city. A related approach to greening is also deployed through a proactive policy of planting trees in the city, both in public and private spaces. Special attention has been paid to the shading potential of the canopy in the city's priority areas. Dark, low-albedo pavements in these areas were treated. The city used cool pavement techniques, covering the asphalt roads with a bright, reflective pavement to reduce heat storage. A similar approach was taken on the roofs of municipal buildings. This cool roof technique increases thermal comfort for building occupants and prevents heat storage.

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Excerpts from Penrith Cooling the City strategy

Short-term, low-cost actions
"Participate in tree planting initiatives and, where possible, plant trees in priority hotspots."

Medium- to long-term actions
"Minimise sealed surfaces where possible by replacing asphalt and concrete with porous surfaces."
"Inform residents of how the Municipality is striving to cool the city and collaborate with them on future landscape design."

Valuable lessons for other regions

An innovative project

A multi-scale approach
Penrith's Cooling The City Strategy seeks to tackle overheating both at the scale of the individual building and at the scale of the entire region. Using this multi-scale approach, cooling actions can be rolled out to all urban spaces irrespective of their specificities.

Quick wins
The Municipality's action plan sets out twenty or so inexpensive quick wins that are achievable in the short term. By so doing, a momentum can be set in motion that will benefit the entire region, while achieving the speedy buy-in of all stakeholders.

Replicability factors

The detailed understanding of the challenges facing the region and the vulnerable zones is a vital asset for the Penrith strategy. The renewed diagnosis after a five-year period is exemplary.
The education and communication efforts made by Penrith with municipal staff and residents is very critical. By persuading them of the merits of these cooling actions, the municipality not only engages stakeholder communities, but also acts in the private domain.

Cfa

Co-benefits


Life on land


Sustainable cities and communities

Biodiversity
Incorporating the Nepean river into the Cooling The City Strategy combined with efforts to green the streets, private gardens and the numerous public parks of Penrith all contribute towards creating ecological continuity that is beneficial to biodiversity development and preservation.

Community engagement
Penrith's Cooling The City Strategy gives pride of place to the engagement of private citizens. It seeks to bring them on board in the common drive to cool the city by involving them in the dialogue around the development of the city, and by encouraging them to act appropriately to adapt their homes and gardens. Building on its experience, Penrith Municipality is looking to serve as an inspiring model. Indeed, it is poised to launch a regional cooling initiative and is keen on achieving this in tandem with the state government of its region, New South Wales. It is also willing to train professionals in these cooling methods, and organises an annual conference on the topic.

High-quality public spaces
Greening the streets, rehabilitating the banks of the Nepean River and generally, paying attention to public spaces for their cooling function is beneficial for all of the city's residents. These actions carry a special urban value that yields benefits for everyone, particularly in the most densely populated districts.

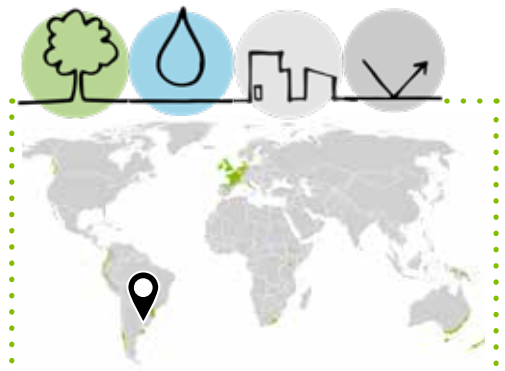
FOR FURTHER REFERENCE:
- Cooling the City Strategy (2015) and Street Park Management Plan (2017); Penrith city Council
- Benchmarking Summer Heat Across Penrith, New South Wales (2020), Pfautsch S., Wujeska-Krause A., Rouillard S.
- ARBOCLIMAT is a forecasting tool developed by ADEME for urban tree planting projects. It is used to assess the impact on climate change.

OTHER SIMILAR STORIES:
- The Climate Action Program 2014-2020 of Mexico City (maritime climate Cwb) features 69 actions geared towards adaptation. It is designed to cover all sectors of urban development, from mobility to greening and energy efficiency.

Barigüi riverbank development project

Curitiba
Brazil


© City of Curitiba



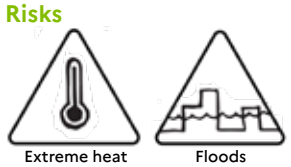
The current climate
Temperate maritime (Cfb)

Scales
Public space, district, city

Timing
Short to long term

Project cost
€72.3 M

Risks


Extreme heat

Floods

The future climate
Subtropical humid (Cfa)
+2.3 to +3.5 °C in southern Brazil by 2100 (CPTE)

The Barigüi riverbank development project incorporates flood risk control and seeks to tighten the bond with the river, for the benefit of residents and managers of the territory. In this respect, the operation sought to restore the riverbank ecosystems and flood expansion areas, thereby incorporating them into the development of linear parks. By opting for solely endemic and non-invasive species, the greening of the banks stabilises the soil, controls the water flow and limits erosion.

However, there is still some uncertainty in quantifying the cooling capacity of the riverbank developments due to the lack of studies and temperature records before and after the parks were created. The same is true for studies on the social inclusion to be derived from the various uses of the site by collecting data on how often the facility is used by different groups of people.

Cfb

Barigüi riverbank development project
Curitiba, Brazil

Background

With a population of nearly two million, Curitiba is the capital city of Paranà State, in the south-east of Brazil, and its municipality has been a benchmark since the 1970s for its proactive and ambitious biodiversity policy. The city is crossed by a network of waterways forming six main rivers. This abundant presence of water compounded by the high pressures from urbanisation and extreme rainfall events generates significant risk of urban flooding (Mendonça, 2012). A risk culture is therefore included in the city's planning policies. After years of channelling the rivers, the Municipality has now embarked on development projects aimed at boosting resilience to climate hazards and building "life with the river". The Barigüi is one of Curitiba's longest rivers. Its banks are undergoing development into four linear urban parks.

It is estimated that around 25% of Curitiba's population (more than 450,000 residents) live along the Barigüi. Since the early 2000s, informal settlements have been created in the natural spaces of its banks. This phenomenon has bred complex economic, social and environmental challenges, which further exacerbate the vulnerability of occupants of such dwellings to flood risks. The Municipality has rolled out a plan to resettle 631 families.

Cooling actions

The primary objectives of the Barigüi riverbank development project are to manage flood risks and create green public spaces, in line with a city-wide approach to biodiversity preservation. Urban cooling therefore emerges as a co-benefit, or systemic benefit, of development projects. On the public space scale, greening efforts to stabilise riverbanks thus have an impact on shading and evapotranspiration. On the city scale, the ventilation and blue network created along the river allows for fresh and moist air to flow freely from North to South. The Barigüi River project is thus a highly instructive case in that it combines urban cooling with development of public spaces that are both hospitable and accessible to the population. As a partner in this project, AFD awarded the Municipality nearly €36 million in 2011 with a State guarantee to successfully complete it.

Curitiba's total green space per capita is

64.5m²

WHO recommends 10m² per capita

Project description

Creating linear parks as cool spaces

Curitiba's topography shaped by gentle hills and numerous waterways is a tremendous opportunity for cooling operations. The Barigüi riverbank development project capitalises on the natural cooling created by the abundant waters, riverside trees and wind effects. The Barigüi River flows through the city for more than 45km, spreading its cooling effect through all the districts it passes. By developing these linear parks, access to cool spaces is guaranteed for residents.

Thermal comfort in public spaces

The park on the banks of the Barigüi is an original **urban structure***: It is a cool island accessible to all residents, who can enjoy the cool, shaded spaces with their riverside trees in whatever way they choose. The park's size and linear form make it a versatile facility that can accommodate various activities in a single space. The walking and strolling areas, as well as the cycling path running through it encourage soft mobility. The children's playgrounds, the urban fixtures open for various purposes and the outdoor sports equipment are all invitations to the general public to take full ownership of the space.

Community engagement and environmental awareness

The positive effect of rehabilitating the banks of the urban watercourse lies in its capacity to reconnect city dwellers to their natural environment. This tactile and visual reconnection with water perfectly reflects the community engagement and environmental awareness philosophy is part of a process of citizen involvement and environmental awareness carried by Curitiba for more than fifty years. A water pollution clean-up programme was launched in 2011. Among its critical components is a drive to raise awareness among Curitiba's residents, through the "Olho d'Agua" educational programme, about pollutants released into the river.

© Agence BASE

Valuable lessons for other regions

Curitiba's risk culture

The Barigüi River is prone to recurrent episodes of flooding. Two urban flooding events in 1983 and 1995 caused billions of dollars of damage, leaving a lasting impact on risk management in Curitiba. From the outset, the development of linear parks along the river incorporates this risk, since the entire area is prone to floods. The spaces closest to the riverbed are designed as submersible landscaped spaces. The urban fixtures are amphibious and anchored to the ground so that they can be submerged without damage. This approach reinforces Curitiba's shared risk culture, while ensuring that flood-prone areas are not singled out as hazardous and impassable spaces.

Promoting functional diversity in the park

The functional diversity promoted in this park development project is an effective means of combating urban sprawl. By intensifying the use of public spaces and fostering multifunctionality, the city caters to the need for urban sobriety. This reduces the need for carbon-based mobility and creates breathing spaces in the high-density city, while combating urban sprawl.

Replicability factors

The main reduces of this project is the potential it holds for the Municipality to develop flood-prone areas, which is often considered unfeasible. Curitiba's risk culture informed its choice to develop a park, thereby transforming a transient challenge into a virtually permanent opportunity. The success of this project also stems from the special attention paid to the species used to green the riverbanks. A 2008 decree prohibits planting of invasive tropical species in the city, and calls for them to be replaced with endemic species, which are better adapted to the city's realities.

Points of caution

The project involved the Municipality providing support for the 631 families living in illegal informal settlements along the river, and who had to be resettled at a cost of €1 million. For its new park project south of Barigüi, specifically in the populous and partially flood-prone district of Caximba, the Municipality included a special housing and public facilities programme, which allows for risk-prone households often in informal settlements, to be resettled permanently and to take advantage of the future park.

Cfb

Barigüi riverbank development project
Curitiba, Brazil

Co-benefits


Life on land

Biodiversity
Biodiversity preservation is a top priority of the Barigüi riverbank project. It reflects an action carried out since 2007 on the entire watershed in order to enhance water quality and ecological diversity. The rivers and their banks are vital spaces for migratory birds, local fauna and flora. Planting vegetation, preserving native wooded areas, developing the river as a living environment all contribute towards improving its ecological quality.


Sustainable cities and communities

High quality public spaces and well-being
Developing parks along Curitiba's riverbanks is a shining example of development combining adaptation to climate change and improvement of quality of urban life. The facilities installed were designed to accommodate many different functions. The urban fixtures designed for multifunctionality are an invitation to engage in a plethora of activities often unforeseen by the designers, while the pacified pathways allow for soft mobility.


Climate action

Flood risk management
Curitiba is prone to urban flood risks in the event of the Barigüi and Paraná rivers bursting their banks. Extreme rainfall episodes are recurrent there, and their intensity and frequency are increasing (Pedron *et al.*, 2016). Linear parks have been developed taking into account these flood risks, with some landscaped areas even designed to withstand submergence. During flood periods, they can serve as retention ponds, while in dry periods their submersible fixtures offers residents a space to enjoy life and relax.

OTHER SIMILAR STORIES:
- Urban linear parks are a very useful option for adaptation and flood risk management. This is the case of the Luis Buñuel Metropolitan Water Park in Zaragoza, Spain (Semi-arid climate, BSk) and the St. Charles River Linear Park in Quebec City, Canada (humid continental climate, Dfb).
- Also see Pirmil-les-Isles, Nantes (Temperate maritime climate, Cfb)

River takes centre stage in Pirmil-Les-Isles ZAC urban project

Nantes
France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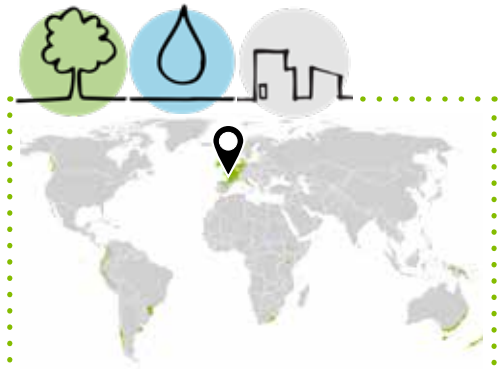
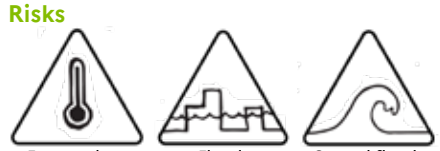


The current climate
Temperate maritime (Cfb)

Scales
Public space, district

Timing
Medium to long term

Risks


Extreme heat | Floods | Coastal floods

The future climate
Mediterranean (Csa)
+2 to +5C° by 2100
+51 hot days yearly (Météo France)

The prime asset of this major urban development project in Nantes is its global and systemic understanding of adaptation needs. It incorporates flood risk management, cooling, biodiversity protection and urban space quality. Conducting a large-scale participatory process with local professionals further emphasises this global understanding of adaptation needs.

As the district is yet to be delivered, there is no feedback on its limitations. The high cost of designing and building a ZAC is obviously a factor to be considered. There is also a need to remain alert as to how future residents will adopt the various public spaces, and to the potential for civic and community engagement they are likely to hold.

Cfb

River takes centre stage in the ZAC Pirmil-Les-Isles urban project, Nantes, France

Background

The Nantes metropolitan area has a population of approximately 650,000. Its location on the Loire estuary, less than 50 km from the ocean, lends it a temperate maritime climate with mild summers and winters. The river is an essential element of the landscape, customs and local risk culture, and lies at the heart of the ZAC Pirmil-Les-Isles development project.

This urban development zone covers 150 hectares on the southern banks of the Loire. It is located on a former industrial area which had been urbanised by backfilling an arm of the Loire. It is therefore a highly flood-prone area and the entire development project is impacted by this understanding of the extant risk. For the future district and its residents, it is a matter of "living with the river", the prime goal of the project being to blend urban quality with flood risk management. The fight against urban overheating thus stands as a secondary goal and a co-benefit of anti-flood measures.

Cooling actions

As a district being developed in a flood-prone space, the project emerges as a local pilot for urban adaptation to the effects of climate change. Urban cooling is considered one of the criteria for assessing resilience and adaptation. Living space quality and biodiversity protection are also considered key indicators.
Bringing adaptation into the project entails greening efforts (tree-lined avenues, Miyawaki micro forest, urban parks, etc.) and unsealing the soil (wetland reinforcement, renaturation of soil, etc.).

Project description

Living with the Loire: Water and Pirmil-Les-Isles

The goal of the ZAC is to adapt the district to the landscape, so that its residents can "live with the river". The river park development project gives residents the opportunity to build a bond with the Loire, including during periods of flooding. Along the 3km of the Loire's riverbanks, an urban river park is being built directly adjacent to the district. In addition to being a public space accessible for most of the year, it also serves as an expansion field for when the Loire floods. Moreover, its fixtures and entire surface are all submersible. Access to the banks of the Loire and to their cooling (outside flood periods) can therefore be opened up, while instilling a risk culture and learning to live with the rhythm of the river. A major co-benefit of this submersible park is cooling, since in addition to being a heavily vegetated park, most of its soil surface will be permeable. It will thus have a significant effect on ambient temperatures owing to evapotranspiration. The trees to be planted there will also provide shading, which will boost cooling.

Greening strategy

For Nantes Métropole Aménagement, Pirmil-Les-Isles is destined to become a "nature city". Greening initiatives have therefore been proposed at each stage of the project and on all its sites. Ultimately, apart from the river park, the district will also include shared gardens, green buildings and 50,000 new trees.

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The ZAC project site is a former industrial site with polluted soil. A nursery was set up from the outset of the project and experiments are currently ongoing to gradually renature and enrich the soil by adding local organic matter. Planting of some of the 50,000 trees has also already begun. A Miyawaki forest (see Feedback from Srirangam city, India) was planted by volunteers during an event for community engagement and discovery of the ZAC project. By planting the greenery early, the developer is sure to have trees of various ages, including already mature ones, when the project is delivered.

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Valuable lessons for other regions

Climate change adaptation as centrepiece of the project

The climate change adaptation measures developed in the Pirmil-Les-Isles urban development project are of particular interest. They are mostly nature-based solutions for adaptation, i.e. beyond their adaptation objective, they help to restore ecosystem functions and contribute to human well-being. This is the case for the greening solutions applied in the district, for instance. In addition to their ornamental function, the species are chosen to promote biodiversity and provide cooling. They are also selected to be adapted to the future climate of the Pays-de-Loire.

Keeping the site alive during the project

Major development projects in the form of a ZAC are meant for the long-term. Several initiatives for transitory occupation of the future site are currently ongoing. This is the case with the "Transfert" open-air arts and culture space, for instance. Activities to boost ownership of the site by potential future residents are being organised, such as collective planting of trees and shrubs. Such early planting also makes it possible to take immediate action for cooling and unsealing of soils, even before construction of the future buildings.

Cfb

River takes centre stage in the ZAC Pirmil-Les-Isles urban project, Nantes, France

Co-benefits

Sustainable cities and communities

High-quality public spaces
The major challenge of the ZAC Pirmil-Les-Isles project is to reconcile development of a qualitative urban space with flood risk management objectives. By building a cool and hospitable submersible river park that promotes well-being, the ZAC meets this dual objective. The special attention paid to urban design, submersible fixtures and diversity of buildings contributes to achieving this high-quality urban and landscape.

Local community engagement and empowerment
The participatory process adopted by the developers of this project is both innovative and very inspiring. More than 400 local professionals from the construction, architecture, landscaping and design industries were invited to jointly identify the innovations that would advance their industry and to imagine applications in the ZAC. These workshops dealt with various issues, such as soil renaturation or ecological construction materials.

Climate action

Flood risk management
The submersible river park project is a means of instilling a risk culture in the district and learning to live with the Loire, its floods, and its flow and tide. This space offers an opportunity to restore access to the Loire riverbanks and create an open field for flood expansion. The project also includes actions to reinforce the surrounding wetlands, thus contributing towards overall water and flood management.

FOR FURTHER REFERENCE:
See fact sheets:
- The Barigüi riverbanks, Curitiba (Brazil) for another example of developing riverbanks into a submersible park
- The Srirangam micro forest (India) for further details on planting a Miyawaki micro forest in an urban setting.

OTHER SIMILAR STORIES:
- The development of the banks of the fjord in Stockholm (Cfb) is an example of how to build a solid bond between residents and their natural aquatic environment.
- La Faute sur Mer (Cfb), a municipality that was heavily stricken by the Xynthia storm in 2010, has designed an urban park built around a large landscaped ditch to absorb rainwater and runoff.

"À la croisée des chemins" sustainable school

Brussels
Belgium

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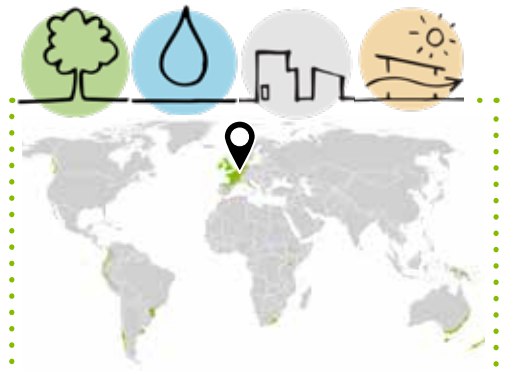

The current climate
Temperate maritime (Cfb)

Scale
Building

Timing
Medium-term

Risk

Drought

The current climate
Subtropical humid (Cfa)
+2 to +5C° by 2100
+51 hot days yearly (Météo France)

The main attraction of this project lies in how its developers were able to harness cooling solutions both inside the courtyard and in the building. The combined effect of greening, water, solar protection and geothermal energy improves the comfort of occupants. Reliance on Nature-based Solutions (NbS) for adaptation helps to blend climate change adaptation and mitigation into the common goal of ecosystem preservation and human well-being.

However, it is worth noting that due to its scale, this project has a high impact on the thermal comfort of its users, but a lower effect on the city's ambient temperatures. It is therefore necessary to think of ways and means of offering the cooling generated within the school to the greatest possible number of people. Extended opening hours are an interesting possibility.

Cfb

"À la croisée des chemins" sustainable school in Brussels, Belgium

Background

Neder-Over-Heembeek is a district in northern Brussels. The Belgian capital has a population of just over 1.2 million, and its population and infrastructure density produce higher temperatures in the city than in the rural surroundings. The temperature patterns in Brussels are largely shaped by anthropogenic factors. Although the current climate is temperate maritime, with cool humid summers, and roughly 4 days of heatwave per year, the effects of climate change will trigger increasingly hot weather by the end of the century.

In this context, the Brussels municipality has taken up the issue of adapting public buildings to the effects of climate change, particularly schools. Children are particularly fragile and vulnerable to high temperatures. School facilities must provide environments conducive to their learning, comfort and well-being.

Cooling actions

"À la croisée des chemins" elementary school in Neder-Over-Heembeek accommodates 900 kindergarten and primary students. The building and its courtyard have been designed to provide comfort and well-being to users, children and staff of the school. Actions to facilitate cooling of the ambient air and improvement of thermal comfort have been taken, which are adapted to the climatic, typo-morphological and architectural landscape of Brussels. These include introducing more water, planting vegetation, and applying techniques to promote natural air flow within a high-density built-up area.

Project description

Architectural design of buildings for education and adaptation

The "À la croisée des chemins" school building meets a passive standard. Geothermal energy is used to guarantee indoor thermal comfort by providing heat and cooling through 30 wells dug 100m deep into the ground. The south-facing windows are equipped with triple glazing, which allows natural light to enter with neither heat loss nor heat gain. Sunshades are also installed to protect indoor spaces from solar radiation. The roofs of the building are greened and equipped with rainwater collection tanks. The building is thus adapted to the current and future overheating of the city. It equally helps to maintain thermal comfort and provide cooling in a sober manner.

"À la croisée des chemins" school has also managed to marry the school's educational purpose with its architectural and landscaping design. Ecology, bonding with nature and sustainable development take centre stage in a proactive educational approach, where students stand at the heart of their learning experience. The vegetable garden, harvesting rainwater and using it in the courtyard, the educational river and the small woods are all architectural features that encourage students to experiment, act and live together.

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Outdoor recreation spaces: landscape design taking full advantage of water and greenery

A balance was sought between the compactness of the building and the green spaces of the playground. The latter is an integral part of the building and serves adaptation, cooling and thermal comfort objectives. More than half of its surface area is permeable, and the absorption of rainwater and runoff by the soil is conducive to cooling by evaporation. The presence of water in the courtyard is further enhanced by the presence of an educational river. It raises the children's awareness of the natural water cycle, cools the ambient air and improves outdoor thermal comfort. The courtyard also offers a pond and a small wetland, an educational vegetable garden, a chicken coop and a small forest, which all provide shading, evapotranspiration and biodiversity protection. These Nature-based Solutions (NbS) for adaptation are essential to urban cooling approaches aimed at adapting cities to the effects of climate change.

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Client: City of Brussels – Department of Urban Planning
Architects: B2Ai

Valuable lessons for other regions

Three pillars of sustainable development in all steps of the school's life cycle

From its design phase, "À la croisée des chemins" school has incorporated the three pillars of sustainable development, namely economic, social and environmental viability. The circular economy was employed during the construction phase, social innovation highlighted in laying out the teaching and student interaction spaces, and the building's operation in terms of energy and waste meets sobriety criteria.

The schoolyard: A key component in an urban setting

Schools in general and schoolyards in particular can play a determining role in urban quality, which in turn partly depends on thermal comfort (Nikolopoulou, 2001). The "À la croisée des chemins" schoolyard is exemplary in that it offers its users a space that combines visual and aesthetic comfort (presence of water and plants, building different from surroundings...), thermal comfort (cool space) and various urban functionalities (educational urban agriculture, games, teaching...).

Cfb

"À la croisée des chemins" sustainable school in Brussels, Belgium

Co-benefits

Life on land

Responsible consumption and production

Climate action

Biodiversity
Both environmental and educational objectives have led to the design of numerous facilities that promote biodiversity in the school: green roofs, woods, pond, wetland, vegetable garden, etc.

Urban and educational agriculture
Some of the outdoor recreational areas of "A la croisée des chemins" school are used for educational agriculture. Teachers and students cultivate a vegetable garden with an educational objective of observing and conserving biodiversity, studying healthy food and nutrition.

Climate change mitigation
The building has been designed in a spirit of sobriety, both in its construction and operation. The waste generated by the project has been quite low, and since it was commissioned, the building has allowed for strict monitoring of its water and energy consumption. This helps to raise its users' awareness of their daily impact. Recovery of rainwater to supply the educational river and the chicken coop is also aligned with this approach. Lastly, the passive operation of the building helps to limit energy consumption linked to improving thermal comfort.

FOR FURTHER REFERENCE:

- The RECRE research project (Renaturation of schoolyards for ecological resilience) from the ODEVAL-URBA 2019 Call for Research Project aims to understand, recognise, protect and develop the ecosystem assets of schoolyards

OTHER SIMILAR STORIES:

- The "Cours OASIS" project in the City of Paris (Cfb) to adapt schoolyards to the effects of climate change
- The Pays du Cordais school (Tarn, France) (Cfb), a bioclimatic school project implemented in consultation with residents, pupils and parents.
- Numerous schoolyard greening projects in France and abroad

Multi-level greening in Montreal

Canada

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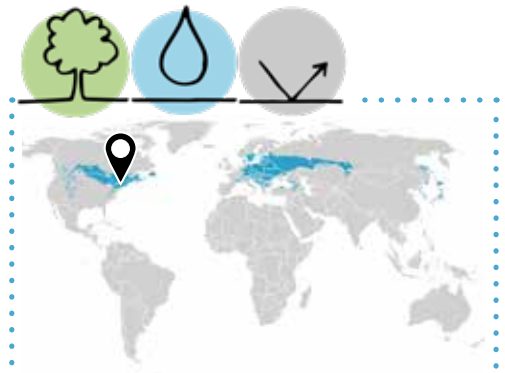

Temperate
Cold continental (Dfb)

Scale
City

Timing
Short to long term

Risks

Extreme heat

Floods

The future climate
Continental with hot summer (Dfa)
+2 to + 4°C by 2100 (RCP 8.5, IPCC)

The City of Montreal adopted an inspiring approach for its greening policies. In addition to implementing them at all levels, from small private gardens to the entire city, the city is successfully balancing activities between its various plans and strategies. The facilitation of community-driven greening and soil-unsealing initiatives forms part of this approach.

One drawback of these projects is their high cost, estimated at about €105 million by SOVERDI (Société de Verdissement du Grand Montreal). Additionally, the very high quantitative planting objectives imply having access to a local nursery with an extremely large size and budget.

Dfb

Multi-level greening in Montreal, Canada

Background

Montreal is Canada's second-largest city. With its two million inhabitants and cold continental climate, it is an interesting example of a city impacted by anthropogenic factors of temperature increase. Montreal is an archipelago where water is omnipresent, making it a flood-prone city.

It is exceptionally green, owing partly to its natural topography. It is home to a network of twenty-five large parks, including twelve natural parks and thirteen urban parks. More than 14,000 district parks have also been developed across the city. Over the years, Montreal has developed a proactive greening policy, as well as a longstanding policy of facilitating community-driven initiatives in its alleyways.

Cooling actions

Although combating heat islands and urban overheating is not a cornerstone of Montreal's greening policies, it is actually embedded in a global development vision of adaptation to the effects of climate change. The quality of living environments is also taken into account.

The greening approach deployed by the city of Montreal is unique in that it is rooted in a multi-level and multi-stakeholder model of action. The plans named "A tree for my neighbourhood" and "One child, One tree" are aimed at individuals and entail planting a tree on a micro-local scale, in both public and private spaces. The "Green Alleys" plan is suitable for block-scale action, while the community gardens plan can engage an entire district. Finally, the Canopy Action Plan initiated in 2012 seeks to extend greenery on a Greater Montreal scale and understand how it spreads over the whole city.

Project description

A global vision of city-scale greening: the Canopy Action Plan

The City of Montreal's Canopy Action Plan has been operational since 2012. Its prerequisite was the development of a canopy index, to set a benchmark to facilitate the study on how green spaces are developed in the city. At the time of its inception, this index was 20.3%, meaning that just over 20% of the territory had tree cover. The goal of the Canopy Action Plan is to reach 25% by 2022.

To this end, two key actions have been implemented, namely planting of 300,000 new trees on the one hand, and conservation of the existing canopy. Older trees have a higher cooling potential and higher benefits for biodiversity (compared with younger trees). It is therefore vital to incorporate the limitation of felling into the city greening plans. Meanwhile, the planting of the 300,000 young trees was carefully planned. This operation covers both the public and the private domains, and high-definition aerial photos were used to identify areas with a lack of plant cover beforehand. They were also used to make additional arrangements aimed at accommodating the new planting operations, such as removal of pavements on certain spaces, for instance.

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Designing greening to micro scales: Green Alleys and green car parks

The macroscopic approach proposed by the Canopy Action Plan is complemented by actions on a more micro scale. The most important and oldest of these is the Green Alleys plan. Since the 1990s, the city of Montreal has been experimenting with the development of 317 alleys (69 linear kilometres). This development is built on community-driven initiatives. Residents must first form "alley committees" before deciding together on how to develop these shared spaces. Thereafter, the City of Montreal provides technical, logistical and financial support (pavement removal, planting of greenery, beautification, etc.). This plan has been in existence for 30 years, so the trees planted at the beginning of the experiment are now mature and provide shading and cooling to Montreal's city blocks.

The city's parking lots and parking spaces are also being greened. Recognized as major heat island aggravation zones (Chester *et al.*, 2015), an effort is currently ongoing to "deasphalt" them, green them to provide cooling and shading, and create bio-retention basins for rainwater around them.

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Valuable lessons for other regions

Multi-level approach to greening plans

The advantage of adopting a multi-level approach to urban greening lies in stakeholder mobilization, both private (businesses and individuals) and public (Société de Verdissement du Grand Montreal, municipal services, etc.). It makes it possible to reach a critical mass that is actually beneficial for the quality of living environments, biodiversity and urban overheating control.
The example of the "Plan Ruelles Vertes" is a reflection of this philosophy, since its first and foremost aim is to extend the program to the largest possible audience and democratize it. It provides a strong impetus for development of best practices across Greater Montreal.

Living space quality takes centre stage

The fight against urban overheating facilitated by the greening of Montreal is an offshoot of a global policy to enhance the quality of living spaces. Its adaptation measures stem from an approach to improving urban quality in its many dimensions: comfort, functions, mobility, safety, security, landscape...

Next step, create a common adaptation narrative

Among the numerous greening plans rolled out by the city of Montreal, some have existed for more than thirty years, and it is now time to rethink their future. Today, community engagement tends to be essential in ensuring more effective monitoring of initiatives and creating a common narrative around adaptation.
This can be done by broader networking of the targeted spaces, starting with the green alleys, but also proceeding to car parks and parking spaces. Such networking would help to align the greening process with the living environment improvement process. Engaging the community in this conversation would be the first step towards democratising measures aimed at urban adaptation to the effects of climate change.

Dfb

Co-benefits

Sustainable cities and communities

Community engagement
The various greening plans of the city of Montreal are policies that promote community engagement and community building. Indeed, they encourage residents to meet and form committees to develop their local shared public spaces as they see fit (Barbosa *et al.*, 2007).

High-quality public spaces
The notion of urban quality and living environments is emphasised in the city's greening plans. Montreal's residents can therefore enjoy numerous and varied green spaces, which largely contribute to the well-being of urban dwellers (Reeves-Latour, 2017).

Life on land

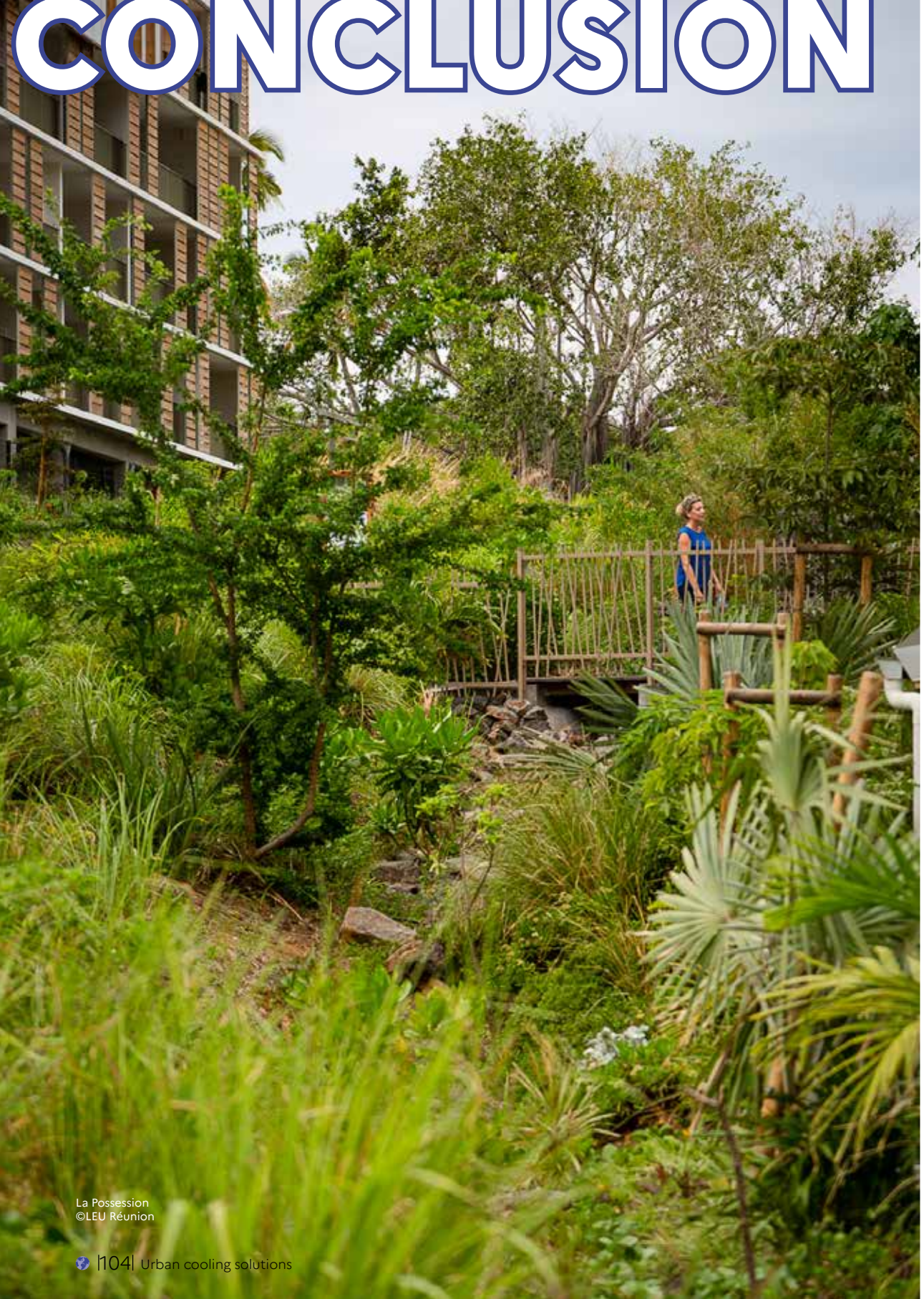
Biodiversity
Planting new plants each year through an ambitious action plan enhances biodiversity. The city of Montreal oversees the selection of planted species to ensure diversity in terms of type, species, age, local character and overall resilience of the plant population.

FOR FURTHER REFERENCE:
- ARBOCLIMAT is a forecasting tool
- developed by ADEME for urban tree
- planting projects. It is used to assess the impact on climate change.
- REEVES -LATOUR (2017), The representation of well-being in the context of urban greening: the case of the Green Alleys of Montreal.

OTHER SIMILAR STORIES:
- The Lyon Metropolitan area's Canopy Plan (Cfb) is the operational component of its Tree Charter.
- The Orleans Metropolitan area's Urban Tree Charter reflects the city's greening policy (Cfb).

The French Lycée in Dakar
©Daniel Rousselot

CONCLUSION



La Possession
©LEU Réunion

The case studies in this collection are packed with valuable insights and presented according to the varying types of climate around the globe. Some of them offer a response to the challenge of urban adaptation to and mitigation of climate change and its mitigation, and all of them help to advance several sustainable development goals, including health and well-being, life below water, etc.

To best adapt regions, urban cooling solutions must be incorporated into a global planning strategy that will include a preliminary phase to diagnose the impact of climate change on the region: climate diagnosis, assessment of climate risks, regional and urban vulnerabilities, resources... This applies in particular to the case studies in Ahmadabad (India), Morne-à-l'Eau (Guadeloupe), Penrith (Australia), Curitiba (Brazil), Los Angeles (United States), Marseille (France) and Montreal (Canada), which stem from planning documents with clearly defined objectives for mitigation and adaptation to climate change.

In the future, urban cooling solutions must be climate change adaptation solutions that reflect the types of climate that can be expected by 2050 and 2100. They must also be systematically in tune with climate change mitigation by consuming as few resources as possible and limiting greenhouse gas emissions. To this end, a space and time study is required on how these solutions should best be implemented to make them permanent, sustainable and effective in a future climate.

In a sustainable urban planning approach, planning tools are essential for the regionalisation of carbon neutrality and climate change adaptation strategies. For them to fully play this role, regions must take up the challenge of aligning them with the timeframes of the various climate forecasts.

GLOSSARY

Albedo
Proportion of incident solar radiation reflected by a surface or a body in relation to the incident radiation (Beltrando and Chéméry, 1995).

Airflow patterns
Aeraulics is the study of airflow and its application. By analogy with the patterns of a fabric, the airflow pattern refers to the network and meshing of identifiable airflows in a city. The study of the airflow pattern provides an understanding of the city's airflow and hence the cooling potential of natural ventilation.

Bioclimatic architecture
A style of architecture that leverages local climatic and microclimatic conditions in order to ensure the greatest possible comfort for occupants of buildings, as well as minimal consumption of energy resources. This encompasses the development of passive cooling, heating, ventilation and shading solutions. Bioclimatic architecture may also refer to local traditional architecture, taking into account the characteristics of a given region.

Canyon effect
This is experienced in narrow streets bordered by tall buildings. Light rays and air are trapped, thus increasing the ambient temperature.

City block
The city block is the smallest spatial unit in urban geography. It is a portion of land that accommodates buildings and is bordered by roadways. Most often of a simple geometry, it may be square or rectangular when bordered by four lanes, and triangular when bordered by three lanes. In French, the term "îlot" (block) is used by geographers, urban planners and architects, while the term "pâté de maisons" (block of houses) is more commonly used. In English-speaking countries, the term "block" is used. http://geoconfluences.ens-lyon.fr/glossaire/ilot-urbain-Cœur-dilot

Climate risk
The IPCC concept of climate risk is based on the definition and understanding of risk and its components as used by the Disaster Risk Reduction community https://www.adaptationcommunity.net/wp-content/uploads/2019/03/CRM-Infosheet.pdf

Compactness
Compactness is a characteristic of urban morphology. It is the ratio between the volume and the surface occupied by the building. A compact building allows for urban density, but is also likely to obstruct free air flows thus contributing to overheating.

Eco-district label
Sponsored by the Ministry for Territorial Cohesion and Relations with Local Government and the Ministry for the Ecological Transition, this label certifies sustainable development projects. Eco-districts must incorporate all issues and principles of sustainable regions, defined according to 20 sustainability commitments categorised into 4 areas: Approach and process, Living environment and uses, Regional development, and Environment and climate.

Emissivity
The ratio of the energy flux emitted by any body to the energy flux emitted by a black body of identical shape and temperature, which flux is calculated by integrating the entire emitting surface (Beltrando and Chéméry, 1995).

Evapotranspiration
Quantity of water evaporated into the atmosphere, either by evaporation of liquid water (free water or soil) or by transpiration of biomass (Beltrando and Chéméry, 1995). Water removes air-sensitive heat by turning into vapour, thereby transforming it into latent heat and lowering the ambient temperature.

Heatwaves
For further information on definitions of heatwaves, go to ex. https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/temperature/heatwave.

IPCC, the Intergovernmental Panel on Climate Change was formed in 1988 to provide comprehensive assessments of the state of scientific, technical and socio-economic knowledge about climate change.

Köppen-Geiger climate classification
This climate classification is based on temperature and rainfall. A two- or three-letter code is used to accurately characterise each climate type globally.

Low-tech
Low tech objects, systems and techniques refer to a mode of integration of technology in production. This technology must be useful and meet basic needs, accessible and applicable by individuals, easy to produce and repair locally, and sustainable.

Microclimate
Climate of a small atmospheric layer adjacent to any surface: soil, tree trunk, meadow, slope...
The notion of microclimate is sometimes inaccurately extended to a small area (city, valley...). In this instance, it is better to speak of local climate or topoclimate (Beltrando and Chéméry, 1995).

Nature-based Solution (NbS) for adaptation
Nature-based Solutions for Adaptation are used to adapt urban spaces by combining actions to protect, manage and restore nature in order to ensure human well-being and biodiversity conservation. ("ARTISAN" research project)

Nature in the city – Renaturation
Nature in the city is an approach to development that connects nature to **urbanity***. It helps to improve the quality of urban spaces and the living environment, and also contributes towards biodiversity protection and development.

Passive solutions
They seek to improve the thermal properties of a building in order to guarantee comfort while limiting energy consumption. This is especially the case for insulation, installation of sunshades, etc.

Public space
https://www.fncaue.com/glossaire/espace-public/
Public space is the part of the unbuilt public domain allocated for public use, a place open to the general public, vital for social interaction and structuring a city. It includes the urban landscape and facades* that form the interface between the public and the private domains. It must be differentiated from public buildings*. By extension, certain spaces used for a public purpose but with public or private status (stations, public facilities) are considered as public spaces.

Quick win
Quick wins are inexpensive solutions that are simple and quick to implement, and deliver tangible results immediately.

RCP or Representative Concentration Pathways
They refer to the scenarios with four greenhouse gas concentration pathways (RCP) selected by IPCC experts:
- RCP 8.5: No climate change policy (the worst-case scenario);
- RCP 6.0 and RCP 4.5: Mid-case scenarios with mitigation policies;
- RCP 2.6: Emission reduction policy likely to limit global warming to 2°C.

Risk
Risk is the combination of two elements: the probability of occurrence of a dangerous event, and its severity, or the severity of its consequences.

Sobriety – Urban sobriety
Sobriety is an approach to reducing and eliminating unnecessary consumption: materials, time, resources... Urban sobriety applies this approach in building the city by thinking about circularity, recycling, multi-functionality, intensification of spaces, innovation in urban organisations, pacification of modes of mobility and reduction of their number, *etc.* It seeks to limit the pressure on ecosystems, particularly due to urban sprawl.

Sustainable development goals (SDGs)
There are 16 sustainable development goals. Formulated by the UN as part of its Agenda 2030, they designate "the path towards achieving a better and sustainable future for all" (United Nations). These include the preservation of life on land and below water, good health and well-being, zero hunger and no poverty...

Thermal inertia
The physical capacity of an element to retain, store and then release heat. Urban paved surfaces (bitumen, concrete, asphalt) have a high inertia, meaning they store the heat of the sun during the day and only release it at night. This is one of the causes of the UHI effect. In the case of buildings, a good indoor inertia helps to retain cooling during the day in summer when it is combined with night ventilation (Cooling cities: varied solutions, Ademe, 2021).

Typo-morphology
The analysis of the typo-morphology of an urban space refers to the study of the built and unbuilt urban forms, the volumes and siting of buildings, the road network...

Urbanity
Urbanity is an urban quality achieved through social and functional diversity. It is created and fostered by density, encounters between residents, possible functions of the city...

Urban heat island (UHI)
A local climate phenomenon characterised by higher temperatures in the city compared to the surrounding countryside, or to a regional average. It is caused by the accumulation of phenomena related to urban morphology, heavily built-up surfaces and anthropogenic heat input.

Urban object
An urban object is an item of the urban system that interacts and is interdependent with other urban objects.

Urban overheating
All phenomena related to decline of the thermal experience in the city during periods of high heat, by day and by night, from the pedestrian level to the urban level. Urban overheating refers both to the urban heat island effect and to the discomfort of pedestrians in urban spaces (solar radiation and paved surfaces, lack of ventilation, *etc*).

Urban project
An urban project refers to the definition and implementation of development projects in a given urban area. It leads to the construction of infrastructure at different scales, from the building to the city, the block, the public space, the district...

Vulnerability
The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (IPCC Glossary 2014).

Well-being
Well-being is a difficult indicator to understand since it does not depend solely on objective criteria. It refers to a state of satisfaction of the needs of the body and mind, as well as a level of comfort. Good health is a state of physical, mental and social well-being.

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Urban cooling solutions

Drawing inspiration from worldwide case studies to address variability in current and future climates

Abstract: This collection features international urban cooling case studies from development projects with insightful information on how they are implemented in different geographical and climatic areas of the World. It presents key and illustrative information on solutions (green, blue or gray) tailored to the current and future climatic conditions of each region described in the fact sheets.

By providing feedback on urban development projects of various sizes - from the building to the city - and on time scales ranging from short to long term, this collection gives city designers and developers valuable insights into how urban cooling solutions can be rolled out from one climate type to another, and equally enables them to reflect on how to adapt their region to the effects of climate change.

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