WP 2 – BE and SLOD: SoA, Risks and human behavior

T.2.2 - SoA on SLOD (heat wave and pollution) in BE and their effect on health and wellbeing of its users. Methods for data collection and analysis (on medium/long term datasets). Correlation between pollution and climate data (e.g. wind, rain, fog). Current mitigation solution analysis. Identification of BE features and users' (inappropriate) behaviors modifying SLOD effects/risk levels. Development of indicators and relative weights for selected SLOD risk levels assessment

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Abstract

Heat waves, defined as an interval of abnormally hot and humid weather, have been a prominent killer in recent years. In the same way poor air quality in the built environment is becoming a serious public health concern at the global scale mainly in industrialized build environment areas. As discussed in the previous deliverables particulate matter pollution and persistent/intense heat waves are also intimately linked to human health. European Commission is asking each Member States to contrast the actual trend by implementing available mitigation measures. EU policy follows a twin-track approach: by setting legal limits for concentrations of air pollutants and by establishing agreements and standards to reduce emissions and energy intensity at source, i.e. national emission reduction commitments and sector-specific sources.
The purpose of this document is to identify the available air pollution and heat wave reduction and mitigation strategies for resilient BE. Based on a qualitative literature review, the following deliverable analysed case studies and solution options focusing on impact, similarities and level of implementation.

Keywords

Slow-Onset Disasters, Built Environment; Pollution; Urban Heat Island; mitigation techniques, literature review

Approvals

Role	Name	Partner

Coordinator	Enrico Quagliarini	UNIVPM
Task leader	Graziano Salvalai	POLIMI

Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	18.03.2020	Abstract modifications and conclusion integrations according to UNIVPM suggestion	Graziano Salvalai	POLIMI
1.0	15.04.2020	Minor revision and proofreading	Enrico Quagliarini Michele Lucesoli	UNIVPM UNIVPM

Summary

1. Introduction

Nowadays, 55% of the world's population lives in urban areas (United Nations 2018). In Italy more than 70% of the total population lives in cities, mainly in the Po Valley, where is located almost half of the country's population (Bigi and Ghermandi 2014). As the urban population continues to grow, the challenges of life in densely populated cities are intensifying as well. As identified in the first Deliverable D.2.1., the two prominent, severe and complex environmental challenges impacting humans and ecosystems are represented by the urban heat island (UHI), characterized by higher temperatures within the city than in the rural surroundings (Estoque et al. 2017), and the air pollutions concentration. Italy and in particularly the Po Valley region is one of the most air-polluted European territories (European Environment Agency et al. 2017). In fact, the high level of dioxide emission due to the high industrialization together with particular meteorological and morphological characteristics of the area, favour the persistence of pollutants in the air mainly during the winter season. The two phenomena are strictly related and cause several negative effects on energy production and supply stress, on the health of people, particularly of elderly, poor, disabled and very young citizens.

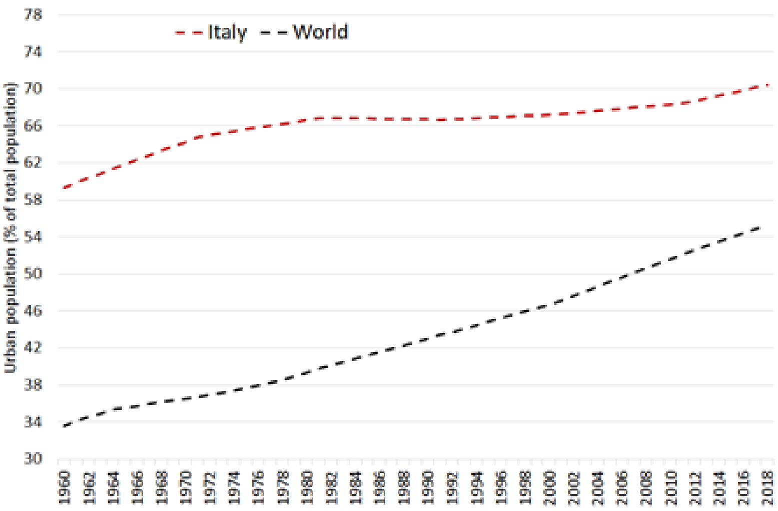


Figure 1 - Trends of the urban world's population between 1960 and 2018 (extracted from the United Nations Population Division. World Urbanization Prospects: 2018 Revision, https://data.worldbank.org)

A recent report by the Urban Climate Change Research Network (Rosenzweig et al. 2018) shows that mean annual temperatures in 39 cities have increased at a rate of 0.12 to 0.45 °C per decade over the 1961 to 2010 time period. According to the World Health Organization (WHO) survey of more than 4300 cities worldwide, only 20% of the urban population lives in areas that comply with WHO air quality guideline levels for PM2.5. Average particulate air pollution levels in many developing cities can be 4-15 times higher than WHO air quality guideline levels. Dense urban areas increase the risk of the two above mentioned SLODs for several reasons: reduced evaporation, transpiration and shading due to limited green areas, increased surfaces temperatures with high thermal capacity, increased the air stagnation decreasing the wind speed etc.. Facing urban heat waves and air pollution, spatial planning and urban governance play a particular role in adaptation and mitigation of adverse effects (Bicknell et al. 2012). The term "mitigation" is defined as the action or a sum of actions to reduce how harmful, unpleasant, or bad an event can be.

Major project	Project	Description	Heat island	Air pollution
Horizon2020	BRIGAID	BRIGAID is a 4-year project (2016-2020) under EU Horizon2020 aimed to effectively bridge the gap between innovators and end-users in resilience to floods, droughts and extreme weather. https://brigaid.eu/	✓	
	ICARUS	The ICARUS project's main objective is to develop integrated tools and strategies for urban impact assessment in support of air quality and climate change governance. The project will develop policies and measures for the short term (until ca. 2030) and visions of green cities for the long-term perspective (2050 and beyond). https://icarus2020.eu/		✓
	iSCAPE	iSCAPE (Improving the smart control of air pollution in Europe) was a European research and innovation project active from 2016 to 2019. It worked on the development of sustainable and passive air pollution remediation strategies, policy intervention and behavioural change initiatives. https://www.iscapeproject.eu/		✓
	URBAN GreenUP	URBAN GreenUP is an EU-funded project (2017-2022) which aims at developing a methodology for Renaturing Urban Plans to mitigate the effects of climate change, improve air quality and water management and increase the sustainability of our cities through innovative nature-based solutions. https://www.urbangreenup.eu/	✓	✓
	CLAiRCity	ClairCity is an EU innovative project (2016-2020) working directly with citizens and local authorities in six countries around Europe. The project has been examining the collectivity behaviour and practices to better understand air pollution and carbon emissions. http://www.claircity.eu/		✓
	HEAT-SHIELD	HEAT-SHIELD is a research programme funded by the EU (2016-2020) which aims in addressing the negative effect of climate change, like increasing workplace temperature, on its working population. The program studies the heat exposure issue and its prevention in different sector, providing adaptation strategies. https://www.heat-shield.eu/	✓	
	SAFER**UP!**	The SAFERUP project is designed as a network, to train top level researchers and professionals with high expertise in the field of recycled, smart and durable pavement, vulnerable users and road safety, pedestrian accessibility and protection, lca tools, behaviour simulator. The goal is to provide cities with a more liveable environment and safer, more accessible and sustainable spaces for mobility. https://site.unibo.it/saferup/en	✓	✓
	CLIMATE-FIT-CITY	The aims of Climate-fit.city will translate the best available scientific urban climate data into relevant information for public and private end-users operating in cities across a range of different sectors. https://climate-fit.city/		
LIFE	PREPAIR	Po Regions Engaged to Policies of AIR is a 7years (2017-2024) project that aims at implementing the measures foreseen in the regional plans and in the Po valley agreement to be taken with the aim of reducing emissions over the next years. http://www.lifeprepair.eu/		✓
	AIRUSE	The overall goal of the AIRUSE project was to develop and demonstrate cost-effective measures for ensuring better air quality in urban areas. http://airuse.eu		✓

Table 1. List of the European funded projects

Mitigation strategies can be adopted by single citizen, spatial planning and urban governance are crucial in making progress towards adequate social and physical infrastructure. Due to the complexity of cities, integrated approaches to adaptation and mitigation considering people and built environment are urgently needed (Ruth and Coelho 2007). At the EU level several initiatives have been funded within the H2020 research programme to contrast the two investigated SLODs (Table 1). Some of them are working on developing specific technology for risk mitigation others are studying mechanisms to increase the resilience of the built environment. The purpose of the present study is to support the identification of solution options contrasting the negative effect of the heat wave and air pollution focusing on specific products, technologies and specific design approaches, strategies and user behaviours. The document highlights also how some strategy like the intensification of the green infrastructure has multiple benefits for urban citizens such as human health and well-being (Kim and Miller 2019) and urban thermal comfort (Hami et al. 2019). The overall work is based on the concept that is hard to find a single "optimal strategy" for urban heat island and air pollution mitigation, it is more likely to design a portfolio of different options able to intensify the complete effects. The designers and planners have to adopt a real holistic taking into account multiple factors at a different levels of detail.

The mitigation measures are categorized into two main areas: the first strictly related to the quality of the built environment and the second related to the anthropogenic factors. In the first category has been listed urban morphology, physical-material and energy efficiency while in the second the factors related to the impact of the users' behaviour (Figure 3). For each of these categories a literature study has been carried out highlighting the main finding of experimental and real data analysis. The morphological factors are influencing the urban layout of the BE and especially the form of buildings, dimension and distances, the presence of green is changing the outdoor temperature condition and the way in which people can feel discomfort. Physical-material factors are related to the characteristics of the building's envelope and it is divided in vertical and horizontal surfaces. Finally, energy efficiency measures consider how the building use impact on the environment. Figure 3 presents the complete set of measures analysed in the document.

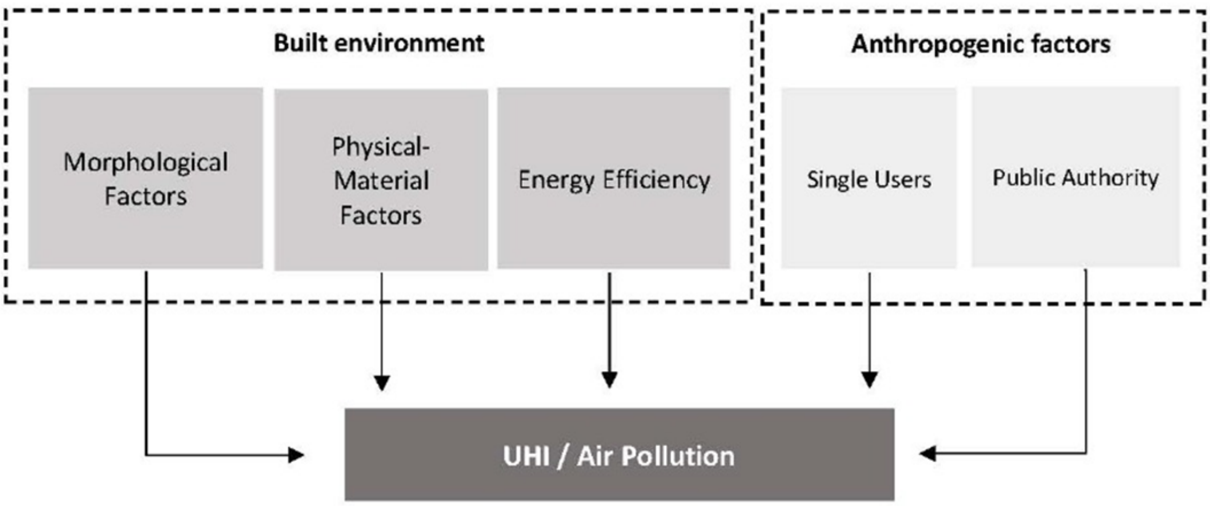
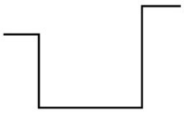
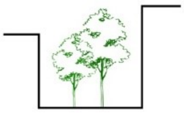
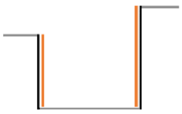
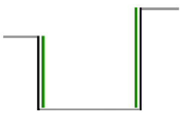
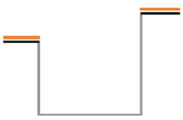
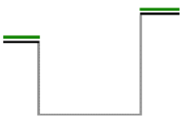


Figure 2 – Built environment and anthropogenic factors that affects UHI and air pollution.

Figure 3 – Overall view of the SLOD mitigation strategies.

2. Overview of the available technologies and strategies to tackle Urban Heat Island

The following section introduces the most diffuse mitigation measures to contrast the UHI phenomena in BE. The UHI effect is a well-known phenomenon that has been documented in hundreds of cities worldwide (Santamouris 2007). Elevated BE temperatures in urban areas lead to rise of energy consumption for cooling increasing the electricity peak demand (Hassid et al. 2000), degradation of air quality (Sarrat et al. 2006), and deterioration of the wellbeing of the citizen (Pantavou et al. 2011). The UHI effects in dense BE can be mitigated with different approaches according to the three factors described in Figure 2. Table 2 collects, divided by categories, the available mitigation measures, described in detail in the sub-chapters 2.1. Hence, both urban planners with authorities and designers can act at different scales to tackle and promote approaches and technologies to decreasing the high temperatures experienced in urban areas. Working on urban layout means to consider aspect in the urbanization that can reduce the heat island effect while for physical-material factors there are specific characteristics that walls, roofs and pavement must have: the way in which the radiation is reflected is the main actors in defining the heat island effect and for this reason vertical surface should not burn the surroundings, ground should work as heat sink and roof has to protect the building and reflect the radiation. Some specific technologies or techniques are detailed within the Annex section in the present document.

Typology	Category	Strategies	Description	Technologies and approaches
Morphological Factors	BE - Built Environment	1. Morphology and layout 	Form and layout: during the design phase, consider the effect of height, distance, orientation and position of buildings on the outside-BE's temperature (work on road section and avoid urban canyon).	Heliodon and ENVI-met software: "feedback" tools able to verify quantitively the environmental behaviour of the project's concept
		2.Vegetation and shading system (I) 	Extend green spaces to create shaded areas in cities. Extend the use of trees in canyons.	Deciduous trees: in summer thanks to their extended and tall crown can provide more shading Evergreen trees: they can block the negative effect of weathering all year long when needed (e.g. strong wind)
			Exploit the presence of green areas to allow a walkable path and sits shaded from radiation.	
Physical-Material Factors	VS - Vertical Surface	3.Urban surface typology and roughness 	Considering the reflectivity of different colours and materials in order to understand the effect of surface characteristics on outdoor-BE. Selecting low heat capacity and high thermal inertia materials and reflective coatings can improve building performance by managing heat exchange at the surface.	The Coolest White paint: ultra-durable paint that protects high-quality metallic facade elements and aluminum, steel or fiberglass structures from excessive solar radiation.
		4.Vegetative cover 	Using vegetation as an envelope of buildings can reduce the reflection of solar radiation and increase the energy behaviour of the building.	BIQ algae building (II): By applying the closed cultivation systems of Microalgae, the photobioreactors, on building facade they become a special solar thermal for the presence of water which absorbs the solar heat. Shading effect by plants: intercept solar radiation, or the cooling effect by means of evapotranspiration from plants.
	HS - Horizontal Surface - Roof	5.Reflective roof / cool roof 	In contrast to the vertical surface, the roof has to protect the building from solar radiation reflecting as much as possible.	Cool roof (III): they are typically white roofs prepared, covered or coated with materials that have special characteristics. Modern cool roofs include highly reflective thermoplastic and liquid-applied membranes
			High albedo coating: the usage of painting and materials with a high albedo coefficient is a good practice to obtain a cool roof.	
		6.Green roof (IV) 	Green roof can reduce heat transmission and moreover with water harvesting can contribute to create the right microclimate.	Polder roof (V): a system for green roof that store rainwater and then distribute it for different functions.

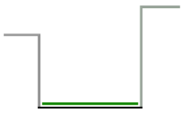
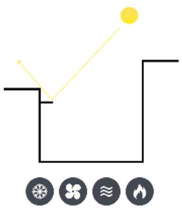
	HS - Horizontal Surface - Pavement	7. Cool pavement (VI) 	Road painted with light colours can reduce the absorbed radiation and increase the reflect one. Moreover, permeable asphalt guarantees an extra cooling in case of rain.	Uchimizu (VII): traditional Japanese technique which provides cooling of surfaces by spraying water on it. CoolSeal (VIII): cladding for asphalt water-based which provides to reflect more solar radiation.
		8.Ground vegetation 	Design green areas in outdoor-BE at ground level helps to decrease the urban heat island effect	
Energy Efficiency	Heat & Cooling and electricity	9.Passive strategies and efficient active system 	Reduce emissions related to building consumption and to the production of building materials can have direct consequences on climate conditions, these can influence indirectly the Urban Heat Island effect. Moreover, the position of outlet device can directly increase the temperature in outdoor spaces where people usually walk.	

Table 2. Strategies and technologies to tackle the urban heat island.

2.1 Urban heat island mitigation measures identification

Urban heat island measure technologies are classified roughly as improvements of the building and pavement coating, promotion of ventilation in the urban area, reduction of the exhaust heat from building and vehicle. On the market it’s possible identifying different technologies to counter the issue. The performance of the different technologies depends on the quantity of reflective solar radiation, in the case of high albedo coating, on the quantity of evaporation, in the one of green roof and water-holding material. To compare their effects on UHI is useful to know their performances, so the strategies listed in Table 2 here argue in detail.

2.1.1 Morphology and layout

There are several parameters to consider that can influence the phenomena of Urban Heat Island: height of buildings, distances between them, orientation and position of buildings and pedestrian path or common space in the outdoor of the BE (Andreou 2014) . This is the first step on which designers should study the effect of a primary design choice on the temperature of surrounding areas around the BE. Having narrow street can create the canyon effect for which temperature increase of 2-4°C, this is affected also by characteristics of surfaces and presence of wind (that can remove the presence of heat) but for sure the shape itself of the BE is the first metric that defines it (Biao et al. 2019) (Figure 4). Moreover, some software can be used during the design phase to understand the existing urban context and act to improve the energy performance of the new buildings (Ratti et al. 2005). These tools, such as ENVI-met and Heliodon, ran simulations based on environmental analysis focused on the microclimatic consequences of different urban forms (Giovagnorio and Chiri 2012). These approaches in the early phase of a project design are simple considerations that can be very effective to avoid having to resort to corrective actions at a later stage.

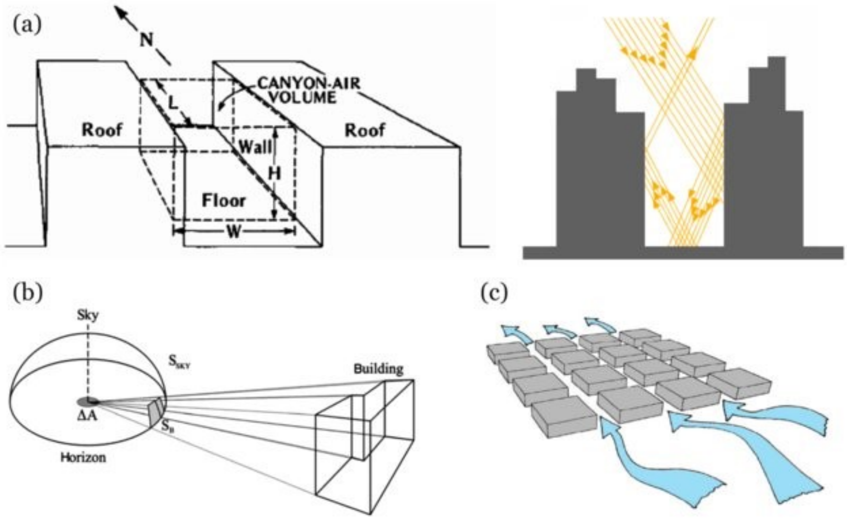


Figure 4 – (a) Schematic representation of urban canyons and multiple reflections and absorption that occurs within it; (b) Schematic representation of the SVF; (c) Schematic representation of urban morphology capable of exploiting the contribution made by natural ventilation in UHI mitigation (extracted from: (Gerundo 2016)*).*

2.1.2 Vegetation as shading system

Vegetation helps to cool the environment, making a simple and effective way to reduce urban heat islands. It can lower surfaces and air temperatures by providing shade, for example shaded surfaces may be 11-25° C cooler than peak temperatures of unshaded materials so it is possible to reduce peak summer temperatures (Akbari et al. 1997). This leads directly to a reduction of building's consumption during summer period (Figure 5).

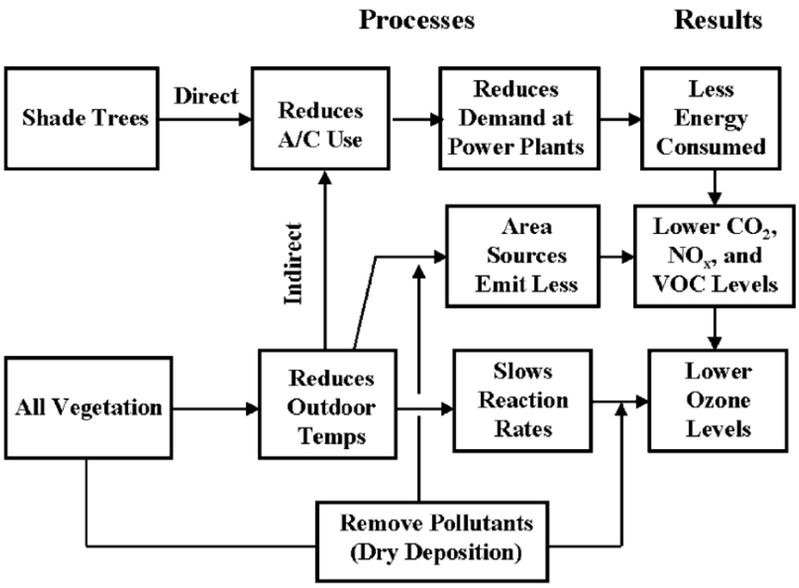


Figure 5 – Methodology: energy and air-quality analysis (extracted from: (Akbari 2002)).

We can subdivide the use of vegetative cooling into two actions: mitigation and adaptation, the first one consist in creating more green areas in the city in order to have more shaded spaces, the second one consist in working on the existing green areas in order to match them with shaded walkable path and sits around them. A problem linked with this strategy could be negative effect of having a dense tree crown: it can form the barrier blocking the wind penetration into street canyon, limiting wind cooling effects and pollutant dispersion (Gromke and Ruck 2007). Moreover, the appropriate tree and plant can be chose according to their seasonality (evergreen/seasonal) and pollutants absorption characteristics. In fact, deciduous species can let the solar radiation heats the BE surfaces in colder weather conditions once the leaves have fallen, whereas the evergreen species guarantee a protection against weathering all year long.

2.1.3 Urban surface and roughness

Buildings can influence the UHI effect in two ways: the quality and characteristics of their envelope and their energy efficiency with the relative consumption of energy. The envelope is not just a barrier between the conditioned space and the outside, but it is also composed by surfaces that can absorb or reflect heat. Thus, properties of surface materials, in particular, high solar reflectance, high thermal emissivity, and low heat capacity can also beneficially influence UHI mitigation, as they determine how the sun’s energy is reflected, emitted, and absorbed (EPA 2008). Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface and is the coefficient that can be used to compare different surface materials (Figure 6).

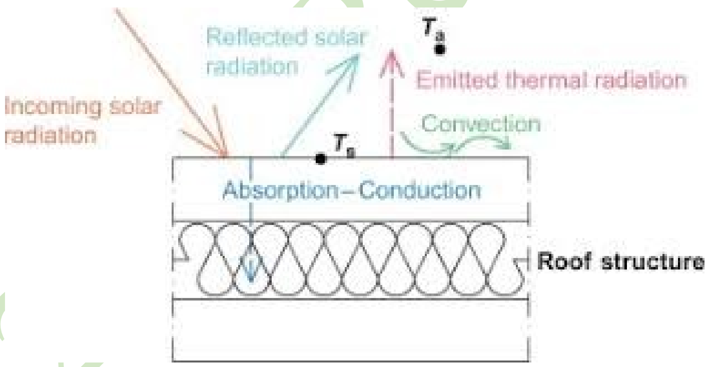


Figure 6 –*Surface behaviour when hits by the solar radiation (extracted from:* (Pisello 2015)*).*

Materials and colours are for sure the most important characteristics that define this behaviour. Usually, darker surfaces have a low albedo value than lighter surfaces. On the other hand, researchers are studying and developing products can be dark in colour but have an albedo close to that of a white or light-coloured material (Synnefa 2007). By increasing reflectivity of the building materials facilitates the reduction of daytime surface temperature mainly during the summer season (high solar radiation) (Synnefa et al. 2008). High reflectivity of walls decreases the canopy air temperature but the impact is marginal (~ 0.1 °C) compared to other urban design parameters (Nazarian et al. 2019). A field study in Athens found that reflective pavements could reduce the surface temperature in an urban park up to 7.61 °C under non-shaded condition (Santamouris et al. 2012). In conclusion, a complete overview of the climate and the urban situation is prior together with the right design choices.

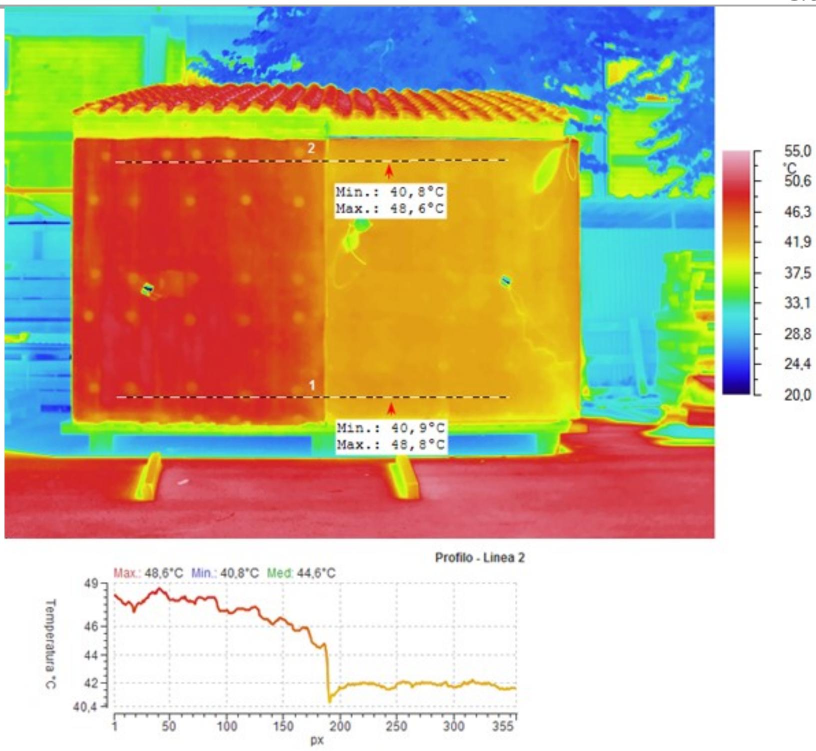


Figure 7 *–Temperature difference between two different wall technologies. Left side: ETICS insulation, right side: micro ventilated façade. (extracted from:* (Salvalai and Sesana 2019)*).*

2.1.4 Vegetative cover

Vegetative facades can be a solution for building energy performance and for mitigating the urban microclimate. They reduce the temperature peaks of the external facades of the building in summer and increase the thermal insulation in winter. The presence of a green layer affects the transfer of heat through the wall allowing for a more adequate internal climate in order to reduce energy consumption (Vox et al. 2017) (Figure 8).

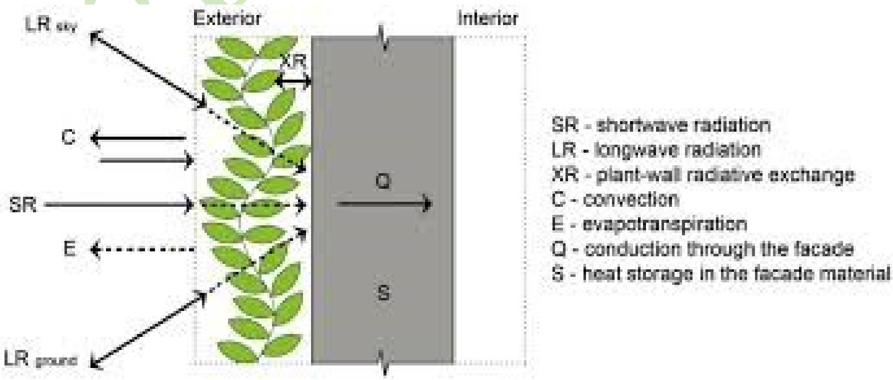


Figure 8 – Energy balance of a green façade (extracted from: (Grabowiecki et al. 2017)*).*

This type of surface allows to create a microclimate in the BE helping to reduce the presence of Urban Heat Islands. A critical aspect of this type of solution is the need to have optimal water management for irrigation, which is not necessary for the green roof (Djedjig et al. 2015). Another technology, still in a development phase, is to apply the closed cultivation system (photobioreactor – pbr) of Microalgae on building facades. The Microalgae are able to capture carbon dioxide and their biomass has a high energy yield and, above all, does not come into competition with agricultural land and sources of drinking water (Nasution et al. 2016). Applying therefore the closed cultivation systems of microalgae become a special solar thermal for the presence of water which absorbs the solar heat. In addition to the well- known solar thermal benefits, the growth of Microalgae produces biomass and captures carbon dioxide, hence it helps to improve the energy performance of the building. Nowadays, the BIQ house in Hamburg built by ARUP and a mixed group of architects and biologists is the first and only existing and inhabited algae-powered building in the world. Despite the holistic energy and social concept, the inclusion of PBR façades alone doesn't make the building completely self-sufficient in terms of the energy needs, not justifying the high-cost investment (BIQ is a 5 stores residential building that cost approximately € 5 million) (Elrayies 2018).

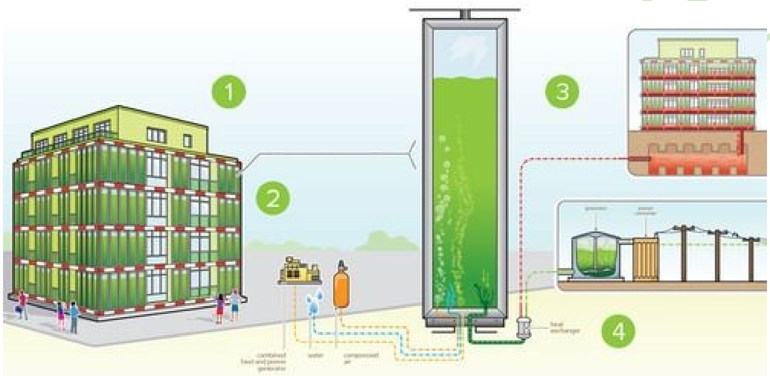


Figure 9 – Algae-powered Bio Intelligent Quotient (B.I.Q.) building in Hamburg, Germany (extracted from: https://www.pinterest.it/pin/412360909604674866/).

2.1.5 Reflective roof/cool roof

The use of cool roofs allows to reduce the temperature of the urban environment, to do this it is useful to use materials with a high albedo coefficient and evapotranspiring surfaces so as to be able to reflect the solar radiation. Together, these properties help roofs to absorb less heat and stay up to 50–60°F (28–33°C) cooler than conventional materials during peak summer weather (EPA 2016) (Figure 10).

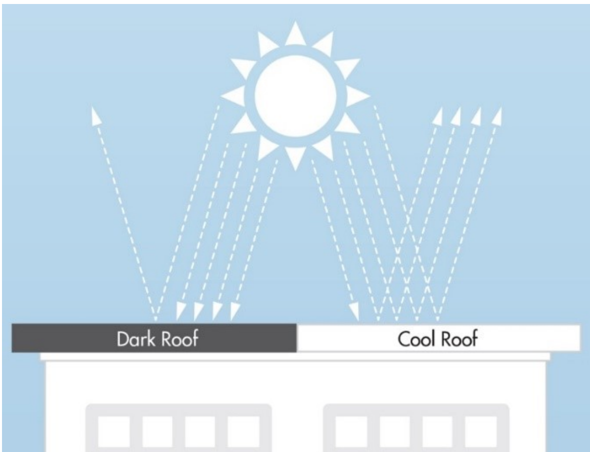


Figure 10 – Comparison between cool roof and dark roof solar radiation reflectance (extracted from: (Grabowiecki et al. 2017)).

Monitoring study carried out in Mediterranean climate demonstrated the impact of the cool roof in reducing the surface temperature of the roof up to 20 °C, with limited profiles excursions during the 24 h (Romeo and Zinzi 2013). Studies made in various cities show that with the use of cool roofs it's possible to improve thermal comfort, reduce the electricity demand and save money (Kolokotroni et al. 2018). The use of highly reflective materials for urban surfaces has been tested for the urban area of Milan (Italy) by means numerical experiments using the Weather Research and Forecasting model coupled with the CHIMERE model (Falasca and Curci 2018). Results show that an increase in albedo from 0.2 to 0.7 for urban roofs, walls and streets leads to a decrease in UHI intensity by up to 2–3 °C and of the planetary boundary layer (PBL) height of about 500 m.

2.1.6 Green roof

The use of green roofs in BE with limited vegetation can moderate the effect of the urban heat island, especially during the day (Shafique et al. 2018). The mitigation impact depends on several parameters: climate (Sun et al. 2016), plants' density foliage (Karachaliou et al. 2016), coverage (Pérez et al. 2015) (Figure 11). Experimental study shows how the green roof temperature, during hot summer day, can be up to 10 °C lower compared to external air temperature, thus reducing also the building energy consumption compared to traditional roofs. (EPA 2019). Results carried out for the City of Melbourne shows that the maximum roof surface UHI is reduced during the day by 1 °C–3.8 °C by increasing green roof fractions from 30% to 90% (Imran et al. 2018).

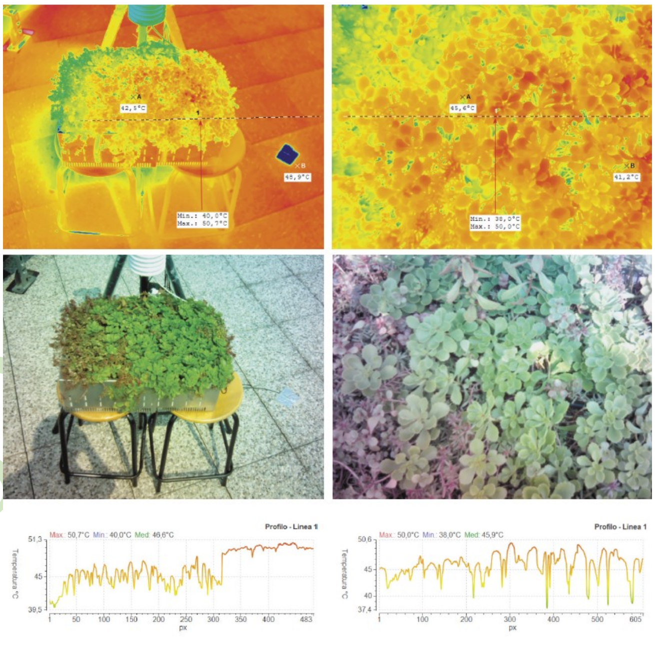


Figure 11 – Classification of green roofs according to the type of usage, construction factors and maintenance requirements.

2.1.7 Cool pavement

The same characteristics of vertical surface for what concern colour and materials apply for pavement: using high albedo coating and light colours can directly influence the surface temperature and indirectly the urban heat island effect (Xie et al. 2019) (Figure 12). Choices on materials can reduce both the surface temperature and the air temperature, however, the degradation of cool pavements can reduce a lot their efficiency due to weathering, dust, vehicles

(Tsoka et al. 2018). In climate where the availability of water is not a problem the use of permeable and retentive pavement can also create benefit in the modification of the existing microclimate. For example, permeable grass pavers can replace traditional pavements in low-traffic parking areas, pedestrian walkways and other paved areas that are seldom used for vehicles, while providing some heat reduction without taking up space (Bell et al. 2008). The real effectiveness of using cool pavements should be implemented with consideration regarding the form and layout of the BE and physical and chemical characteristics of vertical surfaces.

Figure 12 – This picture of Phoenix, Arizona, in the summer shows a variety of conventional pavements that reached temperatures up to 150°F (67°C) (extracted from: (EPA 2016).

2.1.8 Ground as heat sink

In the BE of cities, the other aspect that can be worked on to reduce the problem of Urban Heat Island is to work on the ground level, increasing the green areas so as to use it as a heat sink in order to have a lower temperature at the street level. Several studies have been carried out for this topic including one developed in Australia, the research evaluates the effectiveness of urban vegetation such as mixed forest (MF), a combination of mixed forest and grasslands (MFAG), and combination of mixed shrublands and grasslands (MSAG) in reducing UHI (Imran et al. 2019). According to this study, the MF and MFAG are more effective than the MSAG in order to reduce this phenomenon due to a lower storage heat, which likely results from the higher shade factor produced by the tree canopies.

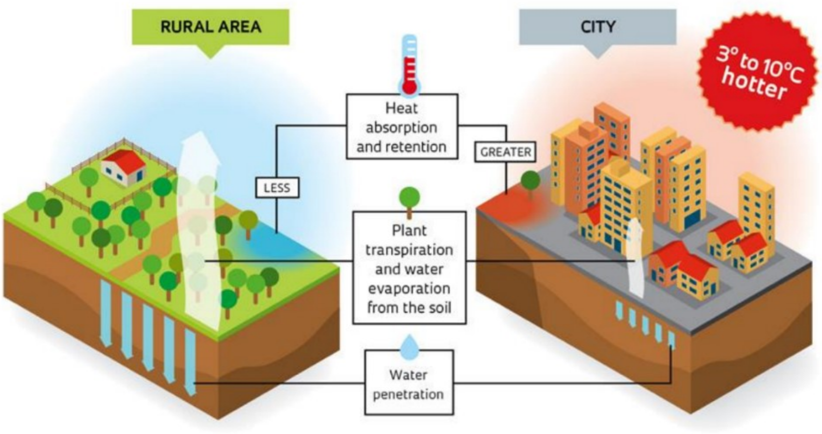


Figure 13 – How green cover influences the formation of UHI (extracted from: (Enviromental Management and Policy Research Institute (EMPRI) 2017).

3. Overview of the available technologies and strategies to tackle air pollution

According to the World Health Organization (WHO) air pollution is one of the main health risk factors mainly in the dense built environment accounting for more than seven million life-losses annually (Landrigan 2017). As mentioned the Po valley is one of the European most populate area with 23 million inhabitants (40% of the total Italian population) (Pernigotti et al. 2012). It's morphological and meteorological conditions considerably hamper the dispersion of air pollutants increasing their concentration in the air. PM pollution in Europe is regulated by the EU Air Quality Directive (2008/50/EC). To protect human health, daily PM10 concentrations are not allowed to exceed 50 mg/m^3 for more than 35 days per year and the mean annual concentration is limited to 40 mg/m3. In densely urbanized built environment like Milan the PM10 day maximum concentration can reach a value higher than 100 mg/m^3 increasing the health disease of citizens (Figure 14). To reduce the exposure to air pollution, generally, legislative and technological approaches must be taken.

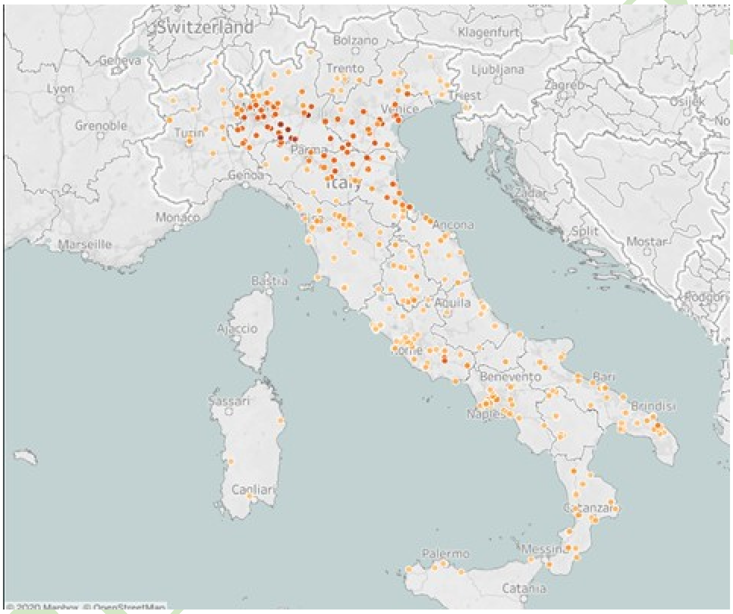
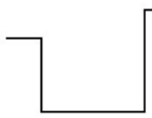


Figure 14 – Detailed air quality parameters: advanced map viewer. The red point shows locations with PM10 level days above the threshold of 50 mg/m3. Source: https://www.eea.europa.eu/data-and-maps/dashboards/air-quality-statistics-expert-viewer.

The methodological approach for the categorization of the air pollution mitigation strategies reflects the same structure of the previous section. Several measures are listed and supported by scientific research showing how in some cases the transferability of the measure (the specific measure can produce a positive effect for UHA mitigation and air quality improvement). The role of the building envelope must be considered as a filtering surface that can interact with the pollution and helps to purify the air of the neighbourhood.

Typology	Category	Strategies	Description	Technologies
Morphological Factors	BE - Built Environment	1. Morphology and layout 	The urban boundary layout could be seen as a potential wind tunnel in which the wind has a behaviour on the street canyon, mitigating air pollution.	Wind tunnel (IX): modifying the form and layout of buildings and urban districts can provide cooling and ventilation that reduces energy use

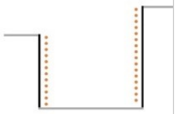
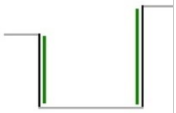
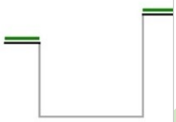
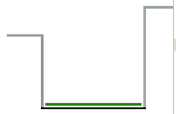
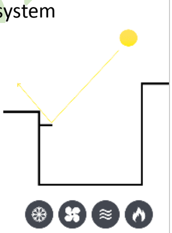
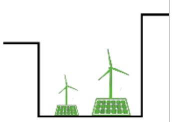
		2.Vegetation as filtering system 	Take advantage of the beneficial effect of urban vegetation on pollution in order to create common areas characterized by good air quality, particularly for sensible areas.	Green Infrastructure: strategically planned network of high quality natural and semi-natural areas aim to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air or water
Physical-Material Factors	Vertical Surface	3.Urban surface typology and roughness 	The painted surface with photocatalytic material based materials helps improving perceived air quality. The products have also high Albedo coating and are eco-friendly in nature which helps to reduce air pollution.	Airlite (X): Powder paint able to activate with the contact of light which transform pollutant agent into salt molecules Hydrotect (XI): technology for coating materials, the treated surfaces react to the action of UV lights by decomposing any organic substance with a cleaning effect Titanium dioxide coating (TiO2): When activated by sunlight, these photocatalytic materials oxidize different kinds of pollutants (NOx and VOC pollutants), which are then precipitated on nearby surfaces and removed by rain or cleaning with water
		4.Vegetative cover 	Installing green facades and living walls has many benefits on environment, buildings and human welfare. During the day plants extract CO2 and other toxins from the air during photosynthesis, resulting in significant reduction of air pollutant.	City Tree (XII): panel composed of mosses (which capture the fine particulate matter) and small plants (necessary to shade the mosses) which performs the purification work BIQ algae building microalgae while performing the photosynthesis, are able to capture the CO_2
	Horizontal Surface - Roof	5.Green roof 	The use of green roof improves the performance of the building and contributes with rainwater collection to reduce pollution.	Polder roof (V): green roof system that stores rainwater and then redistributes it for various functions
		6.Ground vegetation 	Design ground vegetation and porous barriers	
Energy Efficiency	Heat & Cooling and electricity	7.Passive strategies and efficient active system 	In order to reduce the impact of buildings on BE is necessary to consider factors like orientation, window to wall ratio, shading systems and the usage of natural ventilation during the design phase. Alongside the sustainable design is necessary to use high energy efficient system with low consumption. The treatment of air in fundamental both for the inlet outdoor air for HVAC and for ambitious project as	Efficient active system (XIII) Smog Free Tower (XIV)
		7.Energy from renewables 	Promote the installation of renewable energy production systems, developing both guidelines for a correct design and a proper infrastructure in order not to overload the grid	

Table 3. Strategies and technologies to tackle air pollution.

3.1. Air pollution mitigation measures identification

Air pollution management and mitigation aim at the elimination, or reduction to acceptable levels, of airborne gaseous pollutants, suspended particulate matter. According to AIRUSE results (Diapouli et al. 2017), carried out for the city of Milan, road traffic is clearly the main source of PM10 and PM2.5, followed by biomass burning and secondary particles which have an important regional contribution. Air pollution mitigation measures presented in the following section describe in some specific case technologies act directly at the source reducing the emission of the airborne matter and in some cases aims to capture the particulate matter suspended in the air. A range of passive methods have been identified (Table 3) to reduce personal exposure to primary pollutant concentrations in the built environment and are supported by a qualitative literature review. Developing design guidelines is an important next stage in promoting passive methods for reducing air pollution and ensuring their integration into future urban planning strategies (Jeanjean et al. 2017).

3.1.1 Morphology and layout

Street canyons, with long narrow streets with a continuous row of buildings on both sides, are a typical urban geometry in many European cities. This BE configuration is characterized by a poor ventilation leading to accumulation of pollution (and as shown in the previous section heat in the streets). Architects, planners must consider different urban strategies to limit the pollution risks from vehicular emissions using air pollutant dispersion in order to promote outdoor air quality (Hassan et al. 2020). When the street is narrow (H/W>0.7), the resulting flow regime is skimming flow, which is characterized by recirculating air flow within the street and is adverse for ventilation Oke (1988). According to several studies (Kastner-Klein and Plate, 1999), (Wen and Malki-Epshtein 2018) the roof shape represents an important factor determining the vorticity dynamics in the canyon and intensity of the pollutant transport towards the downwind side of the canyon. In general, in dense BE, the spacing between buildings gradually decreases as the building density and number of buildings increase, the area of regions with higher wind speed drops substantially, and the wind is less able to penetrate the inner area of the block. When designing blocks, recreational spaces such as open squares, parks, and green spaces should be upwind to the prevailing wind direction in summer to ensure good ventilation conditions. At the intersections of the main and secondary roads of the city, buildings should be somewhat receded, and open plazas or green spaces should be created to facilitate the diversion and distribution of wind flows of different directions, thus avoid the formation of vortex zones that impair the dispersion of air pollutants (Yang et al. 2020).

3.1.2 Vegetation as filtering system

The use of vegetation in the urban environment has gained prominence in recent years for air pollution exposure reduction along busy roadsides in cities (Abhijith et al. 2017). In general green areas integrated to low density the BE can improve air quality performing an important mitigation action against atmospheric pollutants (ozone, nitrogen oxides, sulphur oxides, heavy metals, benzene, atmospheric particulate) working as natural filters (Janhäll 2015). It has been studied that the leaves trap particulates on their surfaces and that the presence of plants increases the turbulence of the air flows, favouring the dispersion of the particles present. Therefore, it is important to insert green areas during the planning of the BE in order to integrate them in sensitive zone of the city like near schools, hospitals or congested roads (Van Ryswyk et al. 2019). As some studies highline the green infrastructure in BE has to be carefully designed: green infra-structure had both positive and negative impacts on air quality at street levels, depending on the urban and vegetation characteristics. In fact, in a street canyon environment, high-level green infrastructure (i.e. trees) generally has a negative impact on air quality (Abhijith and Gokhale 2015) while low-level dense vegetation with complete coverage from the ground to the top of the canopy (i.e. hedges) hinder the air flow underneath and hence generally show a positive impact ((Gallagher et al. 2015), (Van Ryswyk et al. 2019). Increasing the spacing between trees and reducing the cross-sectional area occupied by tree canopies (through increased pruning and selecting smaller trees) can usually reduce street-level personal exposure through increased ventilation (Buccolieri et al. 2009).

3.1.3 Urban surface typology and roughness

The use of photocatalytic materials as air cleaning technologies whose application until now were restricted to special cases like clean rooms, hospitals or industrial applications, can now be profitable for outdoor spaces contrasting the concentration of the particulate matter. In recent years, many studies have focused on the use of photocatalytic air purifiers for removal of indoor contaminants (Mo et al. 2009), (Pelaez et al. 2012). In the last decade the photocatalytic cement-based paint that helps to improve air quality, indoor and outdoor. The materials include titanium dioxide which, when it is exposed to sunlight, acts as photocatalyst and breaks down organic particles by forming free radicals that then oxidise the surrounding air, leading to a reduction in air pollution (Kolarik and Toftum 2012). The materials are mostly used in outdoor applications on so called self-cleaning facades and for degradation of nitrogen oxides in street canyons and also car parks (Enea and Guerrini 2010).

3.1.4 Vegetative cover

Vertical greenery system is simply defined as greening vertical layer (facades, walls, blind walls and partition walls) and the main intention is to grow the plant on the wall of buildings. The vertical greenery system is also named as a vertical garden, green wall, vertical green, vertical landscaping and bio walls (Manso and Castro-Gomes 2015). The green wall consists of two different systems called green facade and a living wall. The difference between green facades and living walls can be expressed that vegetation grows over the building envelope naturally and growing substrate on the ground as well in green facades. Installing green facades and living walls has many benefits on the environment, buildings and human health. These benefits can involve both the internal comfort in buildings and the quality of outdoor air absorbing pollutants (Viecco et al. 2018), (Ottelé et al. 2010). Large areas of greenery help to suppress dust particles (high surface related to the specific volume), improving air quality around buildings and busy highways and this could also lead to a reduction in respiratory illness. According to the (Kohler 2006; Köhler 2008) if an inner city neighbourhood were greened on all possible facades 4% of annual dust-fall could be trapped on the leaves increasing the air quality. As for the UHI, also the algal applied on building facades can help to purify the air. Microalgae, indeed, are able to capture more CO_2 than plants can store and are besides, directly responsible of almost 50% of the photosynthesis on Earth (Sayre 2010). Even if microalgae are more efficient than plants, they are very delicate microorganisms to cultivate and, as living system, they are subjected to discontinuities and instabilities in performance, ending up with a complex orchestration of monitoring systems and sensors. In fact, the microalgae culture needs to be continuously monitored in order to improve energy efficiency and growth rates by ensuring the right types and amount of nutrients, light and pH value. Differently, the plants need less care to grow.

3.1.5 Green roof

Green roofs on building envelopes can also be used as effective air pollution abatement measures (Berardi et al. 2014)). The ability to remove pollutants is normally lesser compared to trees and vegetation barriers and green wall. These interventions require less spatial requirements than trees and green belts and can be part of building surfaces and structures such as bridges, fly-overs, retaining walls, and noise barriers (Abhijith et al. 2017). Green roofs have in fact both a direct and indirect influence on Air Pollution, they can increase energy performances of buildings creating so a decrement in emissions related to buildings and then, they can directly absorb and remove a consistent part of pollutants from air. According to the study made in Chicago green roofs can reduce pollutants impacting half on O_3 and half on NO_2, PM10 and SO_2 (Yang et al. 2008) (Speak et al. 2012). Moreover, if green roofs are designed with the specific aim of reducing air pollution, different species of grasses should be used. The selection must be established according to the climatic conditions, the plant impact on the ecosystems (Getter and Rowe 2006).

3.1.6 Ground vegetation

As state in the previous subsection vehicles in cities are the main source of particulate matters. The limited natural ventilation in the street canyons allow the accumulation of the pollutant street level with high exposure for pedestrians. Besides the direct reductions of traffic emissions (by reducing the cars number or reducing the emissions), passive pollutant control measures are considered suitable for remedy. In this context, solid and porous structures in urban street canyons (low boundary walls, shrubs, hedges), which affect flow and dispersion are increasingly discussed (Gromke et al. 2016) (Gallagher et al. 2015). Low vegetation can be applied with proficiency to filter out the particulate matter due to his proximity to the source. In open road conditions, vegetation barriers have a positive impact on air quality with thick, dense and tall vegetation (Gallagher et al. 2015). Studies observed considerable pollutant removal through designing vegetation barriers closer to the pollutant source and plume's maximum concentration (Al-Dabbous and Kumar 2014). (Yin et al. 2007) analyzed the effect of 15 m wide shrub greenbelts on both sides of a road in Shanghai, China, finding a removal efficiencies between 30 and 65% of the total suspended particulates. (Chen et al. 2015) analyzing the effect of 2.5 e 3.5 m wide shrub greenbelts (high less than 1.6 m) along streets in Wuhan, China highline a PM10 removal efficiencies between 7 and10%.

3.1.7 Passive strategies

The integration of the passive heating/cooling strategies in buildings can help indirectly in increasing the ambient air quality. In fact, reducing the energy needs means to reduce the energy production and its related CO_2 and particulate matter pollutions mainly form biomass burning. The design of low energy buildings is supported by regulation and certification that set standards and limits, but it can be synthetized in a simple way:

- use passive strategies in order to create a building that works with the environment in the best possible way finding the right shape that can exploit the sun, the wind and the climate itself for performing better;
- use an efficient active system in order to have the necessary energy for building use using the low primary energy;

Passive strategies (Alaidroos and Krarti 2016) should act on the form and orientation of building (this drives directly to the urban layout and its effect on energy behaviour of buildings and outdoor climate conditions), on the window to wall ration together with the position of windows and use of shading system on glass surfaces, on characteristics of the envelope. Another important element that must be considered is natural ventilation (Salvalai et al. 2013) (Engelmann et al. 2014), it can be studied and exploited for reducing energy needs: if scheduled in the right way it can be integrated with the night flush and remove the heat absorbed by massive constructions, if used in high close space it can create the stuck effect and helps air recycling. Lastly, the function placement and the exploitation of corridors, terraces and all unconditioned spaces, can define buffer zones that helps buildings to work harmoniously with the environment.

3.1.8 Energy from renewables

In order to achieve the sustainability and environmental objectives stated in the Paris Agreement, in 2016, different "decarbonisation levers" have to be implemented simultaneously, including the massive deployment of renewables (Tévar et al. 2019). For a sustainable approach in the design of buildings, once obtained the best passive behaviour and defined the most efficient active system, it's necessary to provide tools and technologies to produce energy from renewable sources (Doubleday et al. 2019). In the urban context the two main source from which extract renewable energy are wind and sun; exploiting wind need big infrastructure and it can be implemented in the production of energy for a cluster of houses, exploiting sun can be easier and more accessible for everyone. By investing in solar panels, BE could not only lower their dependence on fossil fuels, improve air quality, and lower landfill load, but enjoy savings on monthly energy bills and directly contribute to the reduction of Gren House Gas (GHG) emissions and lower the emission of particulate matter (Kaya et al. 2019). As shown by (Zhu et al. 2020) technological innovations in renewable energy are beneficial to alleviate nitrogen oxides (NOx) and respirable suspended particles (PM10) concentrations. For example, technological innovation can improve the energy efficiency of traditional fossil fuels reducing energy consumption in the production process (Zhu et al. 2020). Moreover, technological innovation can improve the technological level of renewable energy, promoting the production of renewable energy improving the supply capacity of renewable energy to meet energy needs and change energy portfolio (Tilt 2019).

4. User's behaviour measures identification

Ones identified strategies and technologies useful to fight the heat island effect and air pollution, we proceed describing citizens' and public authorities' contributions to mitigate those phenomena.

The following table describes those contributions dividing them as:

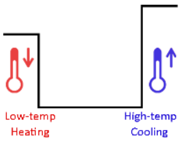
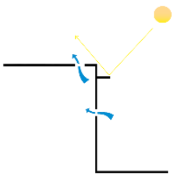
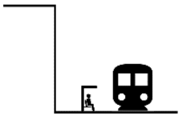
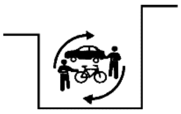
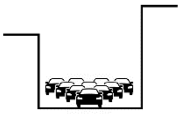
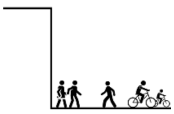
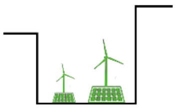
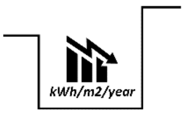
- Building's cooling system;
- Transportation;
- Conscious choice regarding new constructions;

- building energy consumption;
- waste management.

Many different measures exist to reduce our impact on the urban heat island and on the quality of the air in the city. As shown above, some measures could be brought by the individual citizen and others from the public administration. Concerning the private citizens, they can act at an energy level and by adopting few measures. In fact, less energy consumption in terms of electricity demands and less production of goods can help to reduce the emission as well as the pollution at the city level. Furthermore, the energy consumption given by buildings makes up 39% of global carbon emissions (United Nations Environment Programme 2017). The citizen should also adopt measures to protect himself from the extreme temperature that the city can reach during the summer and the pollution in the air, as to:

- Avoid direct sunlight and walk along the shaded side of the streets.
- Wear light and natural fibres made clothes, such as cotton or linen
- Leve home only during the coolest hours, before 11 a.m. and after 6 p.m.
- Choose green areas preferably in the shadow, fountains, rivers and lakes.
- Do not exaggerate with physical activities.
- Avoid outdoor activities during the crash hours.
- Prefer public means of transport to private ones.

Both, Individuals (I) and Public Administration (PA), can have a strong impact on the UHI and on the air pollution, just through careful use of transportation system, choosing and improving less polluting and less heat-emission types of mobility. Part of the air pollution inside cities is caused by transportation. For this reason, it is necessary to make smart choices. The municipality should offer an efficient public transport system to reduce the number of vehicles on the roads. Individuals can use electric vehicles or services such as shared mobility where necessary, but in general, they must prefer walking on foot whenever possible. Finally, it is important to correctly manage waste by doing recycling and composting organic waste.

General	Specific	User's measures
Cooling Systems	1.Reduce heat emission 	Reduce the use of the air conditioning systems
		In case of necessity prefer ventilator
	2.Improve natural cooling during hot seasons 	Open windows to aerate the house during the night
		Shield sunbeams during the day to avoid heat to enter
		Plant trees in private gardens
Transportations	3.Public transportation 	Organize safe affordable and efficient public transport system
		Using public transport systems reduces the number of vehicles in the streets and the consumption of energy.
	4.Shared mobility 	Promoting shared mobility can reduce the number of vehicles on the streets.
	5.Reduce the number of private vehicles 	Provide traffic restrictions
	6.Electric and hybrid mobility 	Promote the use of hybrid or electric vehicles instead of fuel and diesel transportation
	7.Soft mobility 	Realize safer pedestrian and cycle path
		Walk to work or school
		Use bicycle or electrical scooter instead of cars
Conscious build	9.Use of green energy 	Promote the use of solar panel
		Reduce the consumption of energy
	10.Adopt energy-efficient strategies 	Sharing resources
		Less energy consumption in terms of electricity demands less production can help to reduce the emission as well as pollution at the city level.
	11.Be careful about the waste to avoid the production of pollutants 	Do the recycling

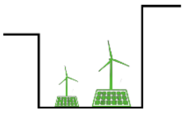
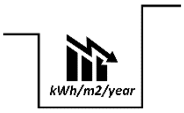
	9.Use of green energy 	Improve domestic, industry and municipal waste management
	10.Adopt energy-efficient strategies 	Compost wastes

Table 4. Strategies and technologies to tackle air pollution.

4.1 Reduce heat emission

The main cause in terms of heat emission is the air conditioning (Abel et al. 2018). The high demand for electricity, necessary to run air conditioner during the hottest days, results in a significant increase in harmful gases released into the atmosphere, such as sulphur dioxide, nitrogen oxide, and carbon dioxide. The human bodies have almost the same perception of the temperatures if using the FAN ventilator or the air conditioning (Jay et al. 2019). The use of the FAN instead of the Air Conditioning should be encouraged. It has a better response in terms of heat stress on the people and also it can help in saving energy and hence decrease the emissions of greenhouse gas. Furthermore, planting plants or placing pots with plants in front of the windows help to reduce the use of air conditioning (Perini et al. 2017), as well as reducing the outdoor temperature thanks to the evapotranspiration activating evaporative cooling effect (Oliveira et al. 2011).

4.2. Improve natural cooling during hot seasons

Ventilating our house during the hot season it's the best sustainable tool we have to keep cool the houses. Ventilating the house during the night lets to reduce the temperature of the building, its efficiency depends on the coolness storage of the building, that means its inertia or its thermal capacity (Blondeau et al. 1997)._Night ventilation succeeds in decreasing the daily indoor air temperature of 1.5°/2°. That is a significant comfort improvement for the occupants. This measure that the single person can adopt in his own house or apartment works also at full scale on an entire building (Geros et al. 1999) reducing the next day peak indoor temperature by up to 3°C. In conclusion, the use of night ventilation can contribute to decrease the cooling load of the A/C, so the emissions of pollutant and the Urban Heat Island effect.

4.3. Public transportation

The energy use in transportation contributes to the urban heat island effect and affect directly the quality of the air (Shahmohamadi et al. 2011). According to the European Environment Agency (European Environment Agency 2008), transport in Europe consumes one third of all final energy. Therefore, transport is responsible for most of the greenhouse gas emissions as well as being the cause of air pollution within cities. The introduction of quality standards for fuels, EURO standards on vehicle emissions (European Union Parliament 2008, 2009) and the use of cleaner technologies (e.g. electric cars) helped to reduce the air pollution, even if it is still not enough.
The pollution given by urban transport is essentially given by the following factors:

- Pollution of private vehicles that contributes to create vehicular traffic.

- Pollution of public transport.

The role of public transportation and how much it works depends on the public administration and single user. Public administration should provide the service to the entire city and the single user should prefer using public transportation instead of private transportation. Not to mention that many citizens using private cars, in addition, to consume more energy, can create traffic congestions that have a negative impact on the urban heat island and air quality. In order to encourage the use of public transport, it is necessary to create an efficient local public transport network, otherwise, citizen will be obliged to keep on using private vehicles for travel in urban contexts. A further reduction in harmful gas emissions can come from the quality of public transportation vehicles: the use of hybrid, electric or "fuel cell" engines would reduce urban pollution. Even if in the city centres the quality of public transportation can be improved, it remains two major issues that need to be taken into account. The first is to handle the access of people coming from neighbouring areas that are not connected with public lines. The second is the emissions of public transportation that continues to release dangerous pollutants and to overheat the central areas. An example of an eco-friendly strategy that tries to solve both these problematics is the case of the Star 1 line in Turin, inaugurated in 2003. This line is run only by electric buses called "Elfo". This line was initially created to connect five parking areas, in order to increase the use of public transport in city areas characterized by high traffic density, together with the extension of the limited traffic area of the city. The vehicles installed on the line have the peculiarity of not emitting harmful gases "on site", a feature that makes them suitable for historic centres, where air quality is, among other things, also important for the preservation of historic monuments (Paietta 2013).

4.4 Shared mobility

Less vehicles in circulation allows to reduce emissions. Until now various cities have promoted some recurring "no smog days" and pollution-free actions with the aim to reduce the use of cars in the city centres. Of course, those are efficient strategies, but it's not enough for a general reduction in pollutants. Hence, the initiative to spread shared mobility. In 2015, Martinez et all. (Martinez and Viegas 2017)have conducted a study named "Lisbon study" in which they examined a "what if" scenario. The scenario starts from the hypothesis of shared vehicles replacing all private cars in Lisbon city. They then removed private car trips and replaced them with trips in shared vehicles, testing different configurations such as: self-driving shared vehicles, electric vehicles, Shared Taxis and "Taxi-Buses" (Figure 15). The results were positive: in shared mobility, only 10% of the total number of cars were needed to transfer citizens to their destinations. Moreover, congestion disappeared, and CO_2 emissions decreased of one third. Finally, shared mobility allows to remove the need for all on-street parking, freeing an area equivalent to almost 20% of the total kerb to kerb street space (Figure 16). So it's possible to feel the new saved spaces with green areas or trees, improving the shaded areas of the urban spaces and the mitigation of the UHI.

Figure 15– Simulation model workflow (extracted from https://www.sciencedirect.com/science/article/pii/S2046043016300442) .

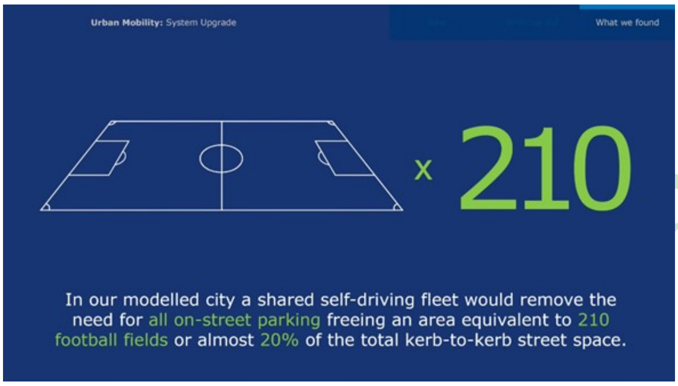


Figure 16 – Effect in the city of Lisbon with an exclusively shared transport system. (extracted from https://www.itf-oecd.org/itf-work-shared-mobility).

4.5 Reduce the number of vehicles

In addition to car's pollutant factors commonly taken into consideration, there are other highly inquinating factors normally less considered. Road transport is estimated to be responsible for up to 30% of particulate emissions (PM) in European cities (WHO 2020). These particulate related to traffic can be distinguished into: exhaust traffic related particles, which are emitted as a result of incomplete fuel combustion and lubricant volatilization during the combustion procedure, and non-exhaust traffic related particles, such as brake, tyre, clutch and road surface wear or already exist in the environment as deposited material and become resuspended due to the turbulence generated by the traffic. These sources contribute almost equally to total traffic-related PM10 emissions. However, as exhaust emissions control become stricter with the introduction of quality standards for fuels, the non-exhaust sources to traffic and their related emissions will increasingly become more significant (Grigoratos and Giorgio 2014). In this regard, local authorities can thus put in place some measures to reduce the viability and lower the traffic. An example of such measures can be found in Milan city. Here, the public authority created "Limited Traffic Areas" to the most polluting vehicles. In this way, both the air pollution can be controlled together with the number of vehicles that can actually run the roads lowering the recirculation of the deposited dangerous particles.

4.6 Electric and hybrid mobility

Conventional cars with combustion engines, are alimented by petrol, diesel or gas. Another option is given by electric cars witch power comes only from electric energy. The study conducted by the Paul Scherrer Institute (Grigoratos and Giorgio 2014) provides an overview of the environmental impact of today and tomorrow cars with different propulsion technologies. The main advantage is the production of substantially smaller quantities of greenhouse gases (about 30t of Co2 less every 200.000 km). On the other hand, electric car production has an environmental impact greater than the conventional ones. However, due to lower emission produced during use, in Switzerland the largest greenhouse gas emission from electric cars production are compensated after about 30.000 km.

4.7 Soft mobility

But its definition can be extended to all environmentally-friendly modes of transportation, like electromobility for example, including electric scooters. Using slow mobility, such as bicycles, electric scooters and walking can increase urban liveability keeping the individual right to move. In this sense, slow mobility can improve the urban environment referring to air pollution, traffic congestion and road safety. Of course, the increase of soft mobility would reduce private car traffic, especially for short trips. To encourage the use of soft mobility, many cities promote the development of specific infrastructures and services dedicated to its use and promote walking, for example, to reach the school or the working place, when is possible. This should ensure the highest levels of urban safety increasing occasions of public spaces regeneration (La Rocca 2010). There are big differences between the various European countries. In some countries, cycling is seen as something for the sport, whereas in Denmark or the Netherlands it is more in their cultural habits to cycle (CIVITAS (Cleaner and better transport in cities) 2016). As seen above, one of the most successful solutions to reduce the UHI and air pollution is the equipment of vegetation increase. Using the necessity to build new infrastructures for pedestrian and cycle routes, could represent a possibility to increase green areas and their overlap with these ecological corridors.

4.8 Use of green energy

Green energy and technologies, which are abundantly available, can help to reduce air, water and soil pollution and the loss of forests. It is thus possible to reduce gas emissions in the atmosphere by reducing energy consumption or using energy from renewable sources instead of energy from the combustion of coal and oils. Moreover, equipping the house with solar and photovoltaic panels can improve the energetic efficiency of the house and lowering the dependency on fossil-fuels. (Midilli et al. 2006)

4.9 Adopt energy-efficient strategies

There are several ways to reduce the energy consumption and the consequent gas emissions released in the atmosphere. Here, some examples of the adjustment of the day-to-day users' behaviours have been proposed. First of all, although household appliances have become fundamental in our homes, it is always possible to try to minimize their use by preferring manual skills. For example, wet clothes can be hung out instead of putting them in the dryer. Setting the thermostat to a lower and constant temperature in winter and to use less air conditioner in summer is also a way to reduce useless consumptions. Another idea is to replace the light bulbs. There are light bulbs that allow to use from 25-80% less electricity and last 3 to 25 times longer. Among them: halogen incandescent bulbs, compact fluorescent lights (CFLs), and light-emitting diode bulbs (LEDs) (ENERGY SAVER-US departement of energy 2020). Also, by shutting off the power to electronics when they are not in use, power and purchase energy efficient appliances, such as energy star certified clothes washers consume less energy and less water than conventional ones, can eliminate some energy loads problem. Indeed, together with a conscious reduction of the use of water, efficient water heaters or a combination of them with solar devices can be more energy efficient than a conventional storage water heater (European Commission 2009). Moreover, the installation of a programmable or smart thermostat that can be set to automatically or controlled by apps to be turned on when there are actually people in the house can further help in the energy saving objectives. Furthermore, in terms of costs, a study in the Energy Start, a government-backed symbol for energy efficiency, shows that a programmable thermostat allows to save up to $180 per year (ENERGY STAR 2020). Installing energy efficient windows allows to reduce a significant source of energy waste. A possible strategy to prevent heat loss through windows is the replacement of single-pane windows with double or triple-pane ones (European Commission – DG Environment 2010). Another strategy is the optimization techniques of choosing the right window glazing. In fact, offering a balance solution in selecting a the proper window glazing and the right quantity needed of daylighting can lead to an energy-efficient building that, at the same time, benefits from natural light (Hee et al. 2015). Finally, a good insulation plays a key role in lowering the energy loss through retaining heat during the winter and keeping heat out of buildings during the summer (European Commission - Joint Research Centre 2018). Other systems, are to share resources, e.g. having one washing machine for few apartments when is possible, and reduce the consumption of products by buying what is really necessary and more consciously. The latter, could help in the energy consumptions of products production itself.

4.10 Been careful about the waste to avoid the production of pollutants

Recycling and waste management are processes that start with the individual citizen and end with the proper municipal and administrative waste management. The Citizen has the role and the duty to separate the waste produced by him in the home and work environment, following the instructions given to him by the municipality. There are valid alternatives to open incineration of solid waste. These options, achievable at a lower cost, allow the reduction of waste, its separation, recycling and reuse. An alternative is also an improved biological waste management method such as anaerobic digestion of waste to produce biogas. In all cases where the use of an incinerator is unavoidable, it is essential to impose strict controls on emissions. It is possible to reduce the amount of undifferentiated waste destined for burners through correct regulations imposed by the municipality and by a more correct recycling of waste conducted by individual citizens. Reducing waste to be incinerated directly affects the pollution levels and greenhouse gases in the air. Obviously, to reach these objectives the first necessary step is to sensitize citizens. A study conducted in Hangzhou, China highlights how residents' ties to the neighbourhood and their attachment to the community have positive impacts on waste recycling intentions. In essence, the more an individual has social ties, the more willing he is to engage in common causes such as waste recycling. Therefore, helping residents to get involved in civic groups and initiatives is recommended to increase social ties and good neighbour behaviour (Pei 2019).

5 Discussion

The Deliverable aims to collect suitable reduction strategies for air pollution and heat wave mitigation in the BE. The work has been carried out classifying the potential mitigation measures according to 4 categories:

- Morphological factors
- Materials
- Energy efficiency
- User transportation
- User behaviour

For each categories, several measures have been identified and described in terms of potential impact by means of a deep literature review. Table 5 collects a synthetic conclusion of the analysis showing for each measures the potential mitigation effect for the two analysed SLOD.

As analysed in the previous sections, the mitigation impact varies from case to case due to a very complex nature of the SLODs phenomena. For this reason, the comparison has been done considering a qualitative scale reflecting the general mitigation potential (*very high*, *high*, *medium*, *low*, *negligible.).*However a precise effect must be calculated considering the specific context taking into account the microclimate conditions, the geometrical configuration of the area, the geometrical characteristic and the quality of the vegetation.

Table 5 contains also a parameter called "level of implementation" for identifying how much the specific mitigation measure can be implemented. To this parameter has been assigned a qualitative scale assigning *"+", "++" and "+++"* if the measure is respectively, rarely implemented, often implemented and very often implemented.

From a synthetic analysis of the results collected in Table 5 can be derived that the proper BE morphology design and the presence of vegetation can have a very high impact on UHI mitigation as well as on air pollution reduction (particulate matter dissipation and reduction). While increasing the vegetation by means of tree ad road barrier is an easy and well implemented measure, the proper BE morphology design is often hard to implement due to several factors among which those related to the urban and technical standard and norm. The ground vegetation presents also a big impact for both the SLODs but due to the high cost of maintenance, it is often rarely implemented. The cool pavement and the cool roof measures are getting more and more interest due to an easy implementation, cost and temperature reduction impact.

Considering the air pollution mitigation measures, in addition to the presence of greenery (allowing mainly the particular matter dissipation) the most impacting strategies are those able to reduce the emission at the source. Increasing the energy production from renewables, increase the quality of public transportation with electric vehicles and the increase soft mobility allow a high reduction of airborne pollutants.

Category	Measures identification	Urban heat island (UHI)					Air pollution		
		Level of implementation	**Effect on UHI**			**Potential impact**	**Effect on air pollution**		**Potential impact**
			air temperature level reduction	Solar radiation reflection	Heat dissipation		Particulate matter dissipation	Particulate matter reduction	
Morphological Factors	BE morphology	+	✓		✓		✓		
	Vegetation (tree and barriers)	+++	✓				✓	✓	
Materials	Urban surface and roughness	+	✓	✓	✓				
	Façade vegetation cover	+	✓					✓	
	Photocatalytic surface	+						✓	
	PBR façades	+	✓					✓	
	Reflective/Cool roof	+ +	✓	✓	✓				
	Green roof	++	✓	✓				✓	
	Cool pavement	++	✓	✓	✓				
	Ground vegetation	+	✓	✓				✓	
Energy efficiency	Passive strategies and energy active systems	++	✓	✓				✓	
	Energy from renewable	++						✓	
User' s transportation	Public transportation and shared mobility	++	✓					✓	
	Soft mobility	+++	✓					✓	
	Electric and hybrid mobility	+	✓					✓	
	Reduction of exhaust heat	+	✓					✓	
User' s behaviour	Reduce heat emission								
	Natural cooling	++	✓		✓			✓	
	Use of green energy	+	✓					✓	
	Adopt energy-efficient strategies	++	✓					✓	
	Improve domestic waste management	+++	✓					✓	

Table 5. Comparison on the effects of the different strategies and technologies. Level of implementation of technologies: + rarely implemented, ++ often implemented, +++ very often implemented. Potential impact: very high, high, medium, low, negligible

6 Conclusion

The aim of the present deliverable is to provide an overview of the most suitable mitigation measures for contrasting the UHI and the air pollution effect in BE. The classification of the mitigation measures is complex due to the fact that the specific effect is influenced by many parameters. So that measures applied in a specific urban context re not suitable for others and vice versa. The present document is based on deep literature studies for the most diffuse mitigation strategies and the classification has been carried out according to the main direct effects on the analysed SLODs. As demonstrated by the deep review some measures show positive impact on mitigating the effect of both the analysed SLODs, some other only for one at time. In fact, there are many effects that affect each other's, as UHI has a strong impact on urban air pollution, and air pollution on climate change, so it's a vicious cycle. Looking beyond the mitigation potentials of specific techniques city planners and policy makers should consider all the alternatives and emerging new technologies. As state, is quite hard to define "the optimal strategy" for urban heat island and air pollution mitigation, it is more likely to invoke a portfolio of different options. Neither high albedo materials nor green roofs or any other individual technology, seem to be a silver bullet for mitigating the SLODs, moreover, the impact varying from city to city, rather than relying on a "one-solution-fits-all" strategy. Nevertheless, some strategies show in general higher mitigation potential than others in a dense BE contest and specifically to our latitude (Jeanjean et al. 2017).

7 References

Abel DW, Holloway T, Harkey M, et al (2018) Air-quality-related health impacts from climate change and from adaptation of cooling demand for buildings in the eastern United States: An interdisciplinary modeling study. PLoS Med 15:1–27. https://doi.org/10.1371/journal.pmed.1002599

Abhijith K V., Gokhale S (2015) Passive control potentials of trees and on-street parked cars in reduction of air pollution exposure in urban street canyons. Environ Pollut. https://doi.org/10.1016/j.envpol.2015.04.013

Abhijith K V., Kumar P, Gallagher J, et al (2017) Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. Atmos. Environ.

Akbari H (2002) Shade trees reduce building energy use and CO2 emissions from power plants. Environ Pollut 116:119–126. https://doi.org/10.1016/S0269-7491(01)00264-0

Akbari H, Kurn DM, Bretz SE, Hanford JW (1997) Peak power and cooling energy savings of shade trees. Energy Build 25:139–148. https://doi.org/10.1016/s0378-7788(96)01003-1

Al-Dabbous AN, Kumar P (2014) The influence of roadside vegetation barriers on airborne nanoparticles and pedestrians exposure under varying wind conditions. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2014.03.040

Alaidroos A, Krarti M (2016) Evaluation of passive cooling systems for residential buildings in the Kingdom of Saudi Arabia. J Sol Energy Eng Trans ASME. https://doi.org/10.1115/1.4033112

Andreou E (2014) The effect of urban layout, street geometry and orientation on shading conditions in urban canyons in the Mediterranean. Renew Energy 63:587–596. https://doi.org/10.1016/j.renene.2013.09.051

Bell R, Cole D, DeAngelo B, et al (2008) Reducing Urban Heat Islands : Compendium of Strategies Trees and Vegetation

Berardi U, GhaffarianHoseini AH, GhaffarianHoseini A (2014) State-of-the-art analysis of the environmental benefits of green roofs. Appl. Energy

Biao L, Cunyan J, Lu W, et al (2019) A parametric study of the effect of building layout on wind flow over an urban area. Build Environ. https://doi.org/10.1016/j.buildenv.2019.106160

Bigi A, Ghermandi G (2014) Long-term trend and variability of atmospheric PM10 concentration in the Po Valley. Atmos Chem Phys. https://doi.org/10.5194/acp-14-4895-2014

Blondeau P, Spérandio M, Allard F (1997) Night ventilation for building cooling in summer. Sol Energy 61:327–335. https://doi.org/10.1016/S0038-092X(97)00076-5

Buccolieri R, Gromke C, Di Sabatino S, Ruck B (2009) Aerodynamic effects of trees on pollutant concentration in street canyons. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2009.06.016

Chen X, Pei T, Zhou Z, et al (2015) Efficiency differences of roadside greenbelts with three configurations in removing coarse particles (PM10): A street scale investigation in Wuhan, China. Urban For Urban Green. https://doi.org/10.1016/j.ufug.2015.02.013

CIVITAS (Cleaner and better transport in cities) (2016) Cycling in the City Smart choices for cities. 1–22

Diapouli E, Manousakas MI, Vratolis S, et al (2017) AIRUSE-LIFE +: Estimation of natural source contributions to urban ambient air PM10 and PM2. 5 concentrations in southern Europe - Implications to compliance with limit values. Atmos Chem Phys. https://doi.org/10.5194/acp-17-3673-2017

Djedjig R, Bozonnet E, Belarbi R (2015) Analysis of thermal effects of vegetated envelopes: Integration of a validated model in a building energy simulation program. Energy Build 86:93–103. https://doi.org/10.1016/j.enbuild.2014.09.057

Doubleday K, Hafiz F, Parker A, et al (2019) Integrated distribution system and urban district planning with high renewable penetrations. Wiley Interdiscip. Rev. Energy Environ.

Elrayies GM (2018) Microalgae: Prospects for greener future buildings. Renew Sustain Energy Rev 81:1175–1191. https://doi.org/10.1016/j.rser.2017.08.032

Enea D, Guerrini GL (2010) Photocatalytic properties of cement-based plasters and paints containing mineral pigments. Transp Res Rec. https://doi.org/10.3141/2141-10

ENERGY SAVER-US departement of energy (2020) How Energy-Efficient Light Bulbs Compare with Traditional Incandescents. In: Lighting

ENERGY STAR (2020) Proper Use Guidelines for Programmable Thermostats. In: Program. thermost

Engelmann P, Kalz D, Salvalai G (2014) Cooling concepts for non-residential buildings: A comparison of cooling

concepts in different climate zones. Energy Build. https://doi.org/10.1016/j.enbuild.2014.07.011
Enviromental Management and Policy Research Institute (EMPRI) (2017) Urban Planning Characteristics to Mitigate Climate Change in context of Urban Heat Island Effect. 82
EPA (2008) Urban heat island basics. In: Reducing Urban Heat Islands: Compendium of Strategies | Heat Island Effect | US EPA
EPA (2016) Using Cool Roofs to Reduce Heat Islands. In: Heat Islands
EPA (2019) Using Green Roofs to Reduce Heat Islands. In: Heat Islands
European Commission (2009) A Consumer ' s Guide to Energy-Efficient Tyres More information
European Commission - Joint Research Centre (2018) Competitive landscape of the EU ' s insulation materials industry for energy-efficient buildings. Eur Com 2018 1–14. https://doi.org/10.2760/251981
European Commission – DG Environment (2010) Windows Technical Background Report
European Environment Agency (2008) Transport
European Union Parliament (2009) European Parliament Directive 2009/30/EC. Off J Eur Union L140/88-L140/113
European Union Parliament (2008) Renewable energy directive. Eur Wind Energy Conf Exhib 2008 1:32–38
Falasca S, Curci G (2018) Impact of Highly Reflective Materials on Meteorology, PM10 and Ozone in Urban Areas: A Modeling Study with WRF-CHIMERE at High Resolution over Milan (Italy). Urban Sci. https://doi.org/10.3390/urbansci2010018
Gallagher J, Baldauf R, Fuller CH, et al (2015) Passive methods for improving air quality in the built environment: A review of porous and solid barriers. Atmos. Environ.
Geros V, Santamouris M, Tsangrasoulis A, Guarracino G (1999) Experimental evaluation of night ventilation phenomena. Energy Build 29:141–154. https://doi.org/10.1016/s0378-7788(98)00056-5
Gerundo C (2016) PLANNING CITIES'ADAPTATION TO CLIMATE CHANGE. APPLICATION TO NAPLES METROPOLITAN AREA. SMC Sustain Mediterr Constr L Cult Res Technol
Getter KL, Rowe DB (2006) The role of extensive green roofs in sustainable development. HortScience. https://doi.org/10.21273/hortsci.41.5.1276
Giovagnorio I, Chiri GM (2012) The Environmental Dimension of Urban Design: A Point of View. Intech i:13. https://doi.org/10.1016/j.colsurfa.2011.12.014
Grabowiecki K, Jaworski A, Niewczas T, Belleri A (2017) Green Solutions-Climbing Vegetation Impact on Building - Energy Balance Element. Energy Procedia 111:377–386. https://doi.org/10.1016/j.egypro.2017.03.199
Grigoratos T, Giorgio M (2014) Non-exhaust traffic related emissions. Brake and tyre wear PM
Gromke C, Jamarkattel N, Ruck B (2016) Influence of roadside hedgerows on air quality in urban street canyons. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2016.05.014
Gromke C, Ruck B (2007) Influence of trees on the dispersion of pollutants in an urban street canyon—Experimental investigation of the flow and concentration field. Atmos Environ 41:3287–3302. https://doi.org/10.1016/j.atmosenv.2006.12.043
Hassan AM, ELMokadem AA, Megahed NA, Abo Eleinen OM (2020) Urban morphology as a passive strategy in promoting outdoor air quality. J Build Eng. https://doi.org/10.1016/j.jobe.2020.101204
Hassid S, Santamouris M, Papanikolaou N, et al (2000) Effect of the Athens heat island on air conditioning load. Energy Build. https://doi.org/10.1016/S0378-7788(99)00045-6
Hee WJ, Alghoul MA, Bakhtyar B, et al (2015) The role of window glazing on daylighting and energy saving in buildings. Renew Sustain Energy Rev 42:323–343. https://doi.org/10.1016/j.rser.2014.09.020
Imran HM, Kala J, Ng AWM, Muthukumaran S (2018) Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia. J Clean Prod. https://doi.org/10.1016/j.jclepro.2018.06.179
Imran HM, Kala J, Ng AWM, Muthukumaran S (2019) Effectiveness of vegetated patches as Green Infrastructure in mitigating Urban Heat Island effects during a heatwave event in the city of Melbourne. Weather Clim Extrem 25:. https://doi.org/10.1016/j.wace.2019.100217
Janhäll S (2015) Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmos. Environ.
Jay O, Hoelzl R, Weets J, et al (2019) Fanning as an alternative to air conditioning – A sustainable solution for reducing indoor occupational heat stress. Energy Build 193:92–98. https://doi.org/10.1016/j.enbuild.2019.03.037
Jeanjean APR, Gallagher J, Monks PS, Leigh RJ (2017) Ranking current and prospective NO2 pollution mitigation strategies: An environmental and economic modelling investigation in Oxford Street, London. Environ Pollut. https://doi.org/10.1016/j.envpol.2017.03.027

Karachaliou P, Santamouris M, Pangalou H (2016) Experimental and numerical analysis of the energy performance of a large scale intensive green roof system installed on an office building in Athens. Energy Build. https://doi.org/10.1016/j.enbuild.2015.04.055
Kaya O, Klepacka AM, Florkowski WJ (2019) Achieving renewable energy, climate, and air quality policy goals: Rural residential investment in solar panel. J Environ Manage. https://doi.org/10.1016/j.jenvman.2019.109309
Kohler M (2006) Living wall systems - a view back and some visions . 4th Annu Green Rooftops Sustain Communities Conf Award Trade Show
Köhler M (2008) Green facades-a view back and some visions. Urban Ecosyst. https://doi.org/10.1007/s11252-008-0063-x
Kolarik J, Toftum J (2012) The impact of a photocatalytic paint on indoor air pollutants: Sensory assessments. Build Environ. https://doi.org/10.1016/j.buildenv.2012.06.010
Kolokotroni M, Shittu E, Santos T, et al (2018) Cool roofs: High tech low cost solution for energy efficiency and thermal comfort in low rise low income houses in high solar radiation countries. Energy Build 176:58–70. https://doi.org/10.1016/j.enbuild.2018.07.005
La Rocca RA (2010) Soft Mobility and Urban Transformation. Some European Case Studies. J L Use, Mobil Environ 3:85–90
Manso M, Castro-Gomes J (2015) Green wall systems: A review of their characteristics. Renew. Sustain. Energy Rev.
Martinez LM, Viegas JM (2017) Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. Int J Transp Sci Technol 6:13–27. https://doi.org/10.1016/j.ijtst.2017.05.005
Midilli A, Dincer I, Ay M (2006) Green energy strategies for sustainable development. Energy Policy 34:3623–3633. https://doi.org/10.1016/j.enpol.2005.08.003
Mo J, Zhang Y, Xu Q, et al (2009) Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmos. Environ.
Nasution B, Jansen K, Afari-Kwarteng J, Ten Pierik S (2016) Algae as Filter for Air Quality in Buildings
Nazarian N, Dumas N, Kleissl J, Norford L (2019) Effectiveness of cool walls on cooling load and urban temperature in a tropical climate. Energy Build 187:144–162. https://doi.org/10.1016/j.enbuild.2019.01.022
Oliveira S, Andrade H, Vaz T (2011) The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. Build Environ 46:2186–2194. https://doi.org/10.1016/j.buildenv.2011.04.034
Ottelé M, van Bohemen HD, Fraaij ALA (2010) Quantifying the deposition of particulate matter on climber vegetation on living walls. Ecol Eng. https://doi.org/10.1016/j.ecoleng.2009.02.007
Paietta P (2013) NOTE SUL PROBLEMA DELL'INNOVAZIONE DEI VEICOLI PER IL TRASPORTO PUBBLICO URBANO SU GOMMA
Pantavou K, Theoharatos G, Mavrakis A, Santamouris M (2011) Evaluating thermal comfort conditions and health responses during an extremely hot summer in Athens. Build Environ. https://doi.org/10.1016/j.buildenv.2010.07.026
Pei Z (2019) Roles of neighborhood ties, community attachment and local identity in residents' household waste recycling intention. J Clean Prod 241:118217. https://doi.org/10.1016/j.jclepro.2019.118217
Pelaez M, Nolan NT, Pillai SC, et al (2012) A review on the visible light active titanium dioxide photocatalysts for environmental applications. Appl. Catal. B Environ.
Pérez G, Vila A, Solé C, et al (2015) The thermal behaviour of extensive green roofs under low plant coverage conditions. Energy Effic. https://doi.org/10.1007/s12053-015-9329-3
Perini K, Bazzocchi F, Croci L, et al (2017) The use of vertical greening systems to reduce the energy demand for air conditioning. Field monitoring in Mediterranean climate. Energy Build 143:35–42. https://doi.org/10.1016/j.enbuild.2017.03.036
Pisello AL (2015) High-albedo roof coatings for reducing building cooling needs. In: Pacheco-Torgal F, Labrincha JA, Cabeza LF, Granqvist C-G (eds) Eco-Efficient Materials for Mitigating Building Cooling Needs. Woodhead Publishing, Oxford, pp 243–268
Ratti C, Baker N, Steemers K (2005) Energy consumption and urban texture. Energy Build 37:762–776. https://doi.org/10.1016/j.enbuild.2004.10.010
Romeo C, Zinzi M (2013) Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study. Energy Build. https://doi.org/10.1016/j.enbuild.2011.07.023
Salvalai G, Pfafferott J, Sesana MM (2013) Assessing energy and thermal comfort of different low-energy cooling

concepts for non-residential buildings. Energy Convers Manag. https://doi.org/10.1016/j.enconman.2013.07.064
Salvalai G, Sesana MM (2019) Experimental analysis of different insulated faÇade technologies in summer condition. J Green Build. https://doi.org/10.3992/1943-4618.14.4.77
Santamouris M (2007) Heat island research in Europe: The state of the art. Adv Build Energy Res. https://doi.org/10.1080/17512549.2007.9687272
Santamouris M, Gaitani N, Spanou A, et al (2012) Using cool paving materials to improve microclimate of urban areas - Design realization and results of the flisvos project. Build Environ. https://doi.org/10.1016/j.buildenv.2012.01.022
Sarrat C, Lemonsu A, Masson V, Guedalia D (2006) Impact of urban heat island on regional atmospheric pollution. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2005.11.037
Sayre R (2010) Microalgae: The Potential for Carbon Capture. Bioscience 60:722–727. https://doi.org/10.1525/bio.2010.60.9.9
Shafique M, Kim R, Rafiq M (2018) Green roof benefits, opportunities and challenges – A review. Renew. Sustain. Energy Rev.
Shahmohamadi P, Che-Ani AI, Etessam I, et al (2011) Healthy environment: The need to mitigate urban heat island effects on human health. Procedia Eng 20:61–70. https://doi.org/10.1016/j.proeng.2011.11.139
Speak AF, Rothwell JJ, Lindley SJ, Smith CL (2012) Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2012.07.043
Sun T, Grimmond CSB, Ni GH (2016) How do green roofs mitigate urban thermal stress under heat waves? J Geophys Res. https://doi.org/10.1002/2016JD024873
Synnefa A (2007) Cool-colored coatings fight the urban heat-island effect. SPIE Newsroom. https://doi.org/10.1117/2.1200706.0777
Synnefa A, Dandou A, Santamouris M, et al (2008) On the use of cool materials as a heat island mitigation strategy. J Appl Meteorol Climatol. https://doi.org/10.1175/2008JAMC1830.1
Tévar G, Gómez-Expósito A, Arcos-Vargas A, Rodríguez-Montañés M (2019) Influence of rooftop PV generation on net demand, losses and network congestions: A case study. Int J Electr Power Energy Syst. https://doi.org/10.1016/j.ijepes.2018.09.013
Tilt B (2019) China's air pollution crisis: Science and policy perspectives. Environ. Sci. Policy
Tsoka S, Theodosiou T, Tsikaloudaki K, Flourentzou F (2018) Modeling the performance of cool pavements and the effect of their aging on outdoor surface and air temperatures. Sustain Cities Soc 42:276–288. https://doi.org/10.1016/j.scs.2018.07.016
United Nations Environment Programme (2017) Towards a zero-emission, efficient, and resilient buildings and construction sector
Van Ryswyk K, Prince N, Ahmed M, et al (2019) Does urban vegetation reduce temperature and air pollution concentrations? Findings from an environmental monitoring study of the Central Experimental Farm in Ottawa, Canada. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2019.116886
Viecco M, Vera S, Jorquera H, et al (2018) Potential of particle matter dry deposition on green roofs and living walls vegetation for mitigating urban atmospheric pollution in semiarid climates. Sustain. https://doi.org/10.3390/su10072431
Vox G, Blanco I, Schettini E (2017) Green façades to control wall surface temperature in buildings. Build Environ. https://doi.org/10.1016/j.buildenv.2017.12.002
Wen H, Malki-Epshtein L (2018) A parametric study of the effect of roof height and morphology on air pollution dispersion in street canyons. J Wind Eng Ind Aerodyn. https://doi.org/10.1016/j.jweia.2018.02.006
WHO (2020) Air pollution. In: Heal. Environ. Sustain. Dev.
Xie N, Li H, Abdelhady A, Harvey J (2019) Laboratorial investigation on optical and thermal properties of cool pavement nano-coatings for urban heat island mitigation. Build Environ 147:231–240. https://doi.org/10.1016/j.buildenv.2018.10.017
Yang J, Shi B, Shi Y, et al (2020) Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form. Sustain Cities Soc. https://doi.org/10.1016/j.scs.2019.101941
Yang J, Yu Q, Gong P (2008) Quantifying air pollution removal by green roofs in Chicago. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2008.07.003
Yin S, Cai JP, Chen LP, et al (2007) Effects of vegetation status in urban green spaces on particles removal in a canyon

street atmosphere. Shengtai Xuebao/ Acta Ecol Sin. https://doi.org/10.1016/s1872-2032(08)60007-4
Zhu Y, Wang Z, Yang J, Zhu L (2020) Does renewable energy technological innovation control China's air pollution? A spatial analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.119515

- **Annex**

I. Vegetation

Technical description	Trees and vegetation work as a mitigation strategy especially if planted in strategic position around buildings or to create shade on sidewalk, parking and streets. Researchers noticed that at least 40% of urban surface should be covered by green in order to obtain good results.	
Performance	Shaded surfaces can reach temperature 11-25°C cooler than pick temperature of unshaded materials. Evapotranspiration, on its own or combined with shading, can help to reduce the summer pick of temperature between 1 and 5°C.	
Pro/Cons/Special request	Pro	Trees and vegetation that create shade on buildings, reduce the need of air conditioning. As a consequence, reducing the energy need they reduce the emission and so pollutants and greenhouse gasses. Moreover, the remove pollutants from air and they store Carbon dioxide. Vegetation reduce washout and improve the quality of water absorbing and filtering the rainwater. The shade created by trees can slow down the deterioration of streets pavement, reducing so the maintenance. Finally, the can add aesthetic values to the place in which they are planted, helping to develop the right habitat for animals and reducing the noise in the surrounding areas.
	Cons	/
	Special request	Researchers found that on west side, deciduous trees and vines are more efficient to cool down a building and they can work better creating shade on windows and roof.
Cost	Primary costs comprehend the purchase of materials, the starting sowing and the future maintenance as pruning, parasites and illnesses check, watering. Annual costs vary between 15 and 65$ for each tree. Pruning is usually the most consistent part of expenses covering 25-40% of the total cost, administration's costs cover 8-35% of the annual cost.	
City in which it is applied	South-West region of the desert, Berkeley (California)	
Additional information	The analysis showed that cities gained between 1,5 and 3$ for each dollar invested for each tree.	
Sources	* https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands#3 * https://www.earth.com/news/tree-cover-urban-heat-island/	

II. BIQ Algae House

<table>
<tr><td>Technical description</td><td colspan="2">BIQ is a cubic, five-floors passive house with two differently designed façade types. The sides of the building that face the sun have a second outer shell that is set into the façade itself. Microalgae – tiny plants, no larger than bacteria – are produced within this shell, enabling the building to supply its own energy. This façade is the first of its kind.</td></tr>
<tr><td>Performance</td><td colspan="2">Due to sunlight and a constant turbulence to avoid algae aggregation, microalgae grow inside the PBRs (photobioreactors) producing heat (38% of efficiency vs 60-65% with a conventional solar thermal) and biomass (10% of efficiency vs 12-15% with a conventional PV). The associated heat production of about 40ºC (150KWh/m2y) is reintroduced to the system via the heat exchanger in the heating network or stored in the geothermal boreholes.</td></tr>
<tr><td rowspan="3">Pro/Cons/Special request</td><td>Pro</td><td>Façade can absorb the solar heat; Reduced CO2 emissions; Production of energy;</td></tr>
<tr><td>Cons</td><td>Costs</td></tr>
<tr><td>Special request</td><td>/</td></tr>
<tr><td>Cost</td><td colspan="2">5 million €</td></tr>
<tr><td>City in which it is applied</td><td colspan="2">Hamburg, Germany</td></tr>
<tr><td>Additional information</td><td colspan="2">Prize winner in the competition 'Land of Ideas' – 'Ausgezeichnete Orte im Land der Ideen' 2013/14. 3rd prize in the 'Deutsche Fassadenpreis 2013' in the category 'special prize' (remarkable artistic design). Zumtobel Group Award 2014 in the category "Applied Innovations".</td></tr>
<tr><td>Sources</td><td colspan="2">* https://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world</td></tr>
</table>

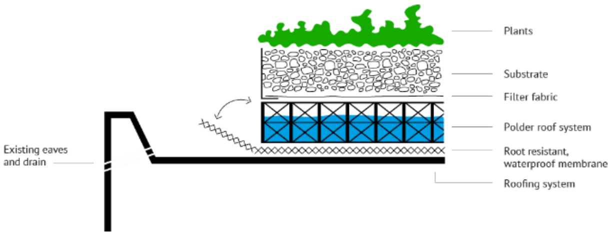
III. Cool roof

Technical description	Cool roof is a system for roof that offer greater solar reflectance and thermal transmittance.	
Performance	Cool roof transfers less heat to the building and so the building itself remain cooler and use less energy to treat the air needed for air conditioning. Reducing energy consumption cool roof can lead to an annual money saving of 0,50€ for square meter. During a typical summer afternoon a coloured roof that reflect 35% of solar light can be 12°C cooler than a traditional roof, and a white roof can reflect 60% more than a grey roof.	
Pro/Cons/Special request	Pro	It can be installed both on flat and inclined roofs. Since the effect of cool roof on the energy behaviour of buildings, it reduces indirectly the air pollution related to emission of buildings. On Urban Heat Island effect cool roofs act reducing the heat transferred from roof to outdoor air, they reduce also the absorbed heat and the surface temperature. The reduction of energy need for cooling will moderate the pick of energy need during heat waves in summer period, reducing so the risk of blackouts.
	Cons	During winter month, cool roofs increase the energy need for heating in cold climate even if this cons is less relevant the the associate pro in summer cooling. If a very light colour is used on the roof of low buildings, it can lead to dazzle effect for users of tall buildings next to it, for this reason is better to use coloured roof.
	Special request	Cool roofs mean reduction of costs related to energy consumption and this is particularly visible where prices of electricity are very high.
Cost	/	
City in which it is applied	California	
Additional information	Roof's materials with Energy Star label had satisfied all the minimum criteria for solar reflectance and reliability.	
Sources	* https://www.epa.gov/heat-islands/using-cool-roofs-reduce-heat-islands * https://www.nytimes.com/2018/07/24/climate/heat-waves-cities.html * https://heatisland.lbl.gov/coolscience/cool-roofs	

IV. Green roof

Technical description	Green roofs can be installed on different kind of buildings, from industrial ones to public or private ones and they can be intensive or extensive.	
Performance	The use of green roof in cities where there is a limited vegetation can mitigate the Urban Heat Island effect, especially during daytime. Roof's temperatures can decrease of 1-5°C from a conventional to a green roof. They have good thermal properties and so they can reduce the energy consumption of buildings around 0,7% reducing the pick of electrical energy need and creating an annual money saving of 0,23$ for square meters.	
Pro/Cons/Special request	Pro	Green roofs can reduce air pollution and greenhouse gasses emission. They remove heat form outside air thanks to the evapotranspiration process and works also as insulation for buildings reducing the energy need for heating and cooling. Reducing the transfer of heat through the roof, green roofs can improve the internal comfort and reduce the effect of thermal stress linked to heat waves. They can reduce and slow down the outflow of rainwater in urban context and they can also filter pollutant substances in rainwater.
	Cons	Intensive green roofs, compared to extensive ones, need a greater maintenance to guarantee their aesthetic use, functional use and public access.
	Special request	Extensive green roofs are lightweight and does not need extra structural support while intensive ones are heavy and imply modification in structural project.
Cost	/	
City in which it is applied	/	
Additional information	The analysis showed that the total covering of more than 215k square meters of green roof in Kansas City installed between 1999-2020 would result in avoided emissions of 384 pounds of nitrogen oxide, 734 pounds of sulphur dioxide, and 269 tons of carbon dioxide in 2020. These emissions reductions equate to monetized health benefits of $35,500–$80,500. Typical maintenance includes fertilization, irrigation, weed control and replanting if necessary.	
Sources	* https://www.epa.gov/heat-islands/using-green-roofs-reduce-heat-islands	

V. Polder Roof – MetroPolder Company (NL)



Name	Polder Roof	
Company	MetroPolder Company (NL)	
Technical description	This product consists in a base system for green roof that works as a rainwater storage: Polder Roof store rain water on the whole surface and then it redistributes it for different functions (water the green roof itself, other watering etc.). The whole system is connected to a personal online page where you can control data and administrate the Polder Roof work.	
Application	Roofs.	
Performance	/	
Pro/Cons/Special request	Pro	It is used for installing green roof, the water storage guarantees a good acoustic insulation and it is also useful to prevent flooding risk. The system helps to prevent the Urban Heat Island effect having the common advantages of normal green roofs.
	Cons	/
	Special request	The roof structure must consider the additional weight of the water stored.
Cost	/	
City in which it is applied	/	
Additional information	The system is still on developing and it is not commercialized yet, the Perugia University, together with Delft University of Technology are conducting tests on the product. It can be used in cities with flooding risk. It was finalist in the “Open Innovation Call in NY targeting Air Quality and Urban Heat Island Effect”.	
Sources	* https://metropolder.com/polder-roof/	

VI. Cool Pavement

Technical description		Pavements make up 35/40% of the urban area. During the summer, solar radiation can bring these surfaces to surface temperatures between 48-67 ° C, favouring the phenomenon of the heat island. The "cool pavement" technique consists simply in using a high albedo coefficient material in order to reduce absorbed radiation and the reflect one is favoured. This technique can be applied in 2 ways: if the road is newly made, a clearer coloured asphalt can be used directly; if the roads already exist, light-coloured coating products are also available on the market to be applied on the existing asphalt. Finally, there is a third type of cool pavement that consists of permeable asphalt: this is a more porous asphalt than the classic one and activates its cooling power mainly in case of rain, through the evaporation of water in the cavities.
Performance		Researchers from the LBNL (Lawrence Berkeley National Laboratory) energy department estimated that every 10 percent increase in solar reflectance could reduce the surface temperature by 4 ° C. In addition, they predicted that if the reflectance on the pavement in a city would increase by 10 % to 35%, the air temperature could potentially be reduced by 0.6 ° C.
Pro/Cons/Special request	Pro	Reduction of heat island phenomenon; Reduced storm water runoff and improved water quality; Better night-time visibility (asphalt and clear coatings); Greater adhesion on asphalt (porous asphalt); Lower tire noise;
	Cons	Cost
	Special request	/
Cost		(see table below)

Cost:

Basic Pavement Types	Example Cool Approaches	Approximate Installed Cost, $/square foot*	Estimated Service Life, Years
New Construction			
Asphalt (conventional)	Hot mix asphalt with light aggregate, if locally available	$0.10–$1.50	7–20
Concrete (conventional)	Portland cement, plain-jointed	$0.30–$4.50	15–35
Nonvegetated permeable pavement	Porous asphalt	$2.00–$2.50	7–10
	Pervious concrete	$5.00–$6.25	15–20
	Paving blocks	$5.00–$10.00	> 20
Vegetated permeable pavement	Grass/gravel pavers	$1.50–$5.75	> 10
Maintenance			
Surface applications	Chip seals with light aggregate, if locally available	$0.10–$0.15	2–8
	Microsurfacing	$0.35–$0.65	7–10
	Ultra-thin whitetopping	$1.50–$6.50	10–15

City in which it is applied	Los Angeles
Additional information	Research has analyzed a combination of mitigation measures in the Los Angeles area, including changes in solar reflectance on pavement and roofing and increased use of trees and vegetation. The study identified a temperature improvement of 0.8 ° C. A subsequent report analyzed the monetary benefits associated with these temperature improvements and estimated the indirect benefits (energy savings and smog reduction) of more than $ 90 million. year.
Sources	* https://www.epa.gov/heat-islands/using-cool-pavements-reduce-heat-islands * https://heatisland.lbl.gov/coolscience/cool-pavements

VII. Uchimizu

Technical description	Uchimizu is a traditional Japanese technique coming from the 17th century for which water is sprayed around houses to cool down the ground surface and the outdoor air due to the evaporative cooling effect.	
Performance	It was analysed the air temperature with DTS (distributed temperature sensing) in a high spatial and temporal definition in a cube meter of air on an urban surface. Six experiments where done to evaluate the effect of (1) quantity of water applied; (2) starting surface temperature; (3) shading effect on Uchimizu technique. Measures showed a decrement of air temperature around 1,5°C (related to a height equal to 2m) and 6°C (near the ground level). The most efficient cooling down was obtained in the shaded experiments. Changing from 1 to 2mm of water the effect is the same while using more than 5mm the effect is duplicated.	
Pro/Cons/Special request	Pro	Relevant reduction of the air temperature.
	Cons	High need of water.
	Special request	It is demonstrated that shaded areas works better and the technique is efficient increase with a middle-high temperature while it does not work in area with really high temperature.
Cost	/	
City in which it is applied	Tokyo	
Additional information	/	
Sources	* https://phys.org/news/2017-04-traditional-japanese-uchimizu-technique-cool.html * https://www.mdpi.com/2073-4441/10/6/741/pdf * http://nymag.com/intelligencer/2016/06/how-cities-are-combating-rising-temperatures.html	

VIII. CoolSeal – GuardTop (USA)

Name	CoolSeal	
Company	GuardTop (USA)	
Technical description	Coolseal consists of a water-based asphalt coating and allows to reflect more solar radiation than traditional asphalt, thanks to the lighter colour of its surface. In this way the heat is not stored on the surface of the roads and it results in a mitigation of the effect of the Urban Heat Islands.	
Application	Roads.	
Performance	Producers claims that it can reduce surface temperature of the asphalt from 5 to 15°C. On Los Angeles road it was tested in 2017 that the reduction of surface temperature was exactly 5°C.	
Pro/Cons/Special request	Pro	It doesn't produce dazzle during daytime but it increase the night visibility.
	Cons	Elevated cost.
	Special request	/
Cost	25 000$ for 1 km of road, 4/5 $/l	
City in which it is applied	Los Angeles (starting in 2017 and implemented in 2019)	
Additional information	It is compatible with EPA and LEED standards and it is composed by recycled materials.	
Sources	* http://www.mikeontraffic.com/cities-take-on-heat-island-effect-with-cooling-technology/ * https://guardtop.com/coolseal/	

IX. Wind Tunnel

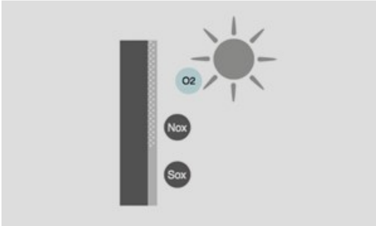
Technical description	This technique is based on the study of wind flux in order to exploit these movement of air for creating wind tunnel in cities. Streets can be used to provide enough space to let the air pass and pull away both overheating and pollutants.	
Performance	/	
Pro/Cons/Special request	Pro	Reduction of pollutants and good effect on Urban Heat Island effect.
	Cons	It is a difficult technique that can be really expensive in an already built urban context.
	Special request	This approach can be use only with specific climate condition to be efficient.
Cost	/	
City in which it is applied	Strutgard, Beijin	
Additional information	/	
Sources	* http://nymag.com/intelligencer/2016/06/how-cities-are-combating-rising-temperatures.html * https://www.nytimes.com/2018/07/24/climate/heat-waves-cities.html * https://www.sciencedirect.com/science/article/pii/S0198971516300138 * https://www.sciencedirect.com/science/article/pii/S1687404814000959	

X. **Airlite – Airlite (IT)**

Name	Airlite	
Company	Airlite (IT)	
Technical description	Powder paint that is able, by adding water containing titanium dioxide, to activate itself in contact with light (natural or artificial) and transforms pollutants such as nitrogen and sulphur oxides, benzene, carbon monoxide into molecules of salt.	
Application	It can be applied both on internal and external walls.	
Performance	It can reduce the energy consumption by reflecting the most of the infrared radiation with a save of electrical energy equal to 15%-50%.	
Pro/Cons/Special request	Pro	It eliminates 99,9% of bacteria and viruses; it reduces the energy consumption reflecting the most of the infrared solar radiation. Il eliminates smells form ambient and the dirty from walls (thanks to a protective invisible layer). It prevents the mould formation.
	Cons	Elevated cost.
	Special request	/
Cost	150€ (5l that makes 10-12 m2/l)	
City in which it is applied	Commercialized in Mexico, United Arab Emirates, Qatar, Thailand, Italy, England, France, Ireland	
Additional information	Winner of "Open Innovation Call in NY targeting Air Quality and Urban Heat Island Effect"	
Sources	* http://www.airlite.com/it/ * https://www.lifegate.it/persone/stile-di-vita/airlite-pittura	

Utilizzo di Aitlite per un murales a Roma

XI. Hydrotect – TOTO (JP)



Name	Hydrotect	
Company	TOTO, Laminam	
Technical description	Technology for the cladding of materials (for example tiles and ceramics). In external ambient, surfaces treated with Hydrotect react to solar ultraviolet radiation decomposing any organic substances and neutralizing nitrogen oxides with a cleaning effect. It can be used also for internal surfaces.	
Application	It can be used both on internal and external walls, on pavement and claddings.	
Performance	/	
Pro/Cons/Special request	Pro	When it rains a thin layer of water remain on the surface and when it falls it removes the dirty. When the material it's exposed to sunrays it reacts creating active oxygen, when pollutants meets the active oxygen they are neutralized. If it used in internal ambient it has an antibacterial function and it can remove bad smalls (even without lights).
	Cons	/
	Special request	/
Cost	/	
City in which it is applied	Sudan, Darfur, Modena, Ferrara, Saint-Gilles-Croix-de-Vie, Berlin	
Additional information	The antibacterial efficiency of Laminam panels was tested and verified by ISO 27447.	
Sources	* https://it.toto.com/tecnologie/tecnologie-singolo/Technology/show/HYDROTECT/ * https://www.laminam.it/it/hydrotect	

Utilizzo della tecnologia Hydrotect per il rivestimento esterno del complesso residenziale Sapphire a Berlino.

XII. CityTree – Green City Solutions (DE)

Name	CityTree	
Company	Green City Solutions (DE)	
Technical description	It consists in a 3,5 square meter panel composed by mosses (that naturally catch fine particulate matter and nitrogen dioxide) and small plants (necessary to guarantee shade to mosses) that works with small dimensions at the same way of 275 woods. It contains also a self-watering system and the whole energy need is covered by photovoltaic panels integrated with the structure.	
Application	It works as an autonomous station that can be installed around streets or in city gardens.	
Performance	Average observed filtration efficiencies are 19±7%, 15±5% and 11±5% for PM10, PM2.5 and PM1, respectively.” (ISAC-CNR, Bologna, Italia, November 2017). “Despite some fluctuations, the mean value from the time series was 0.77 therefore, resulting in a reduction of the mass fraction after active filtering by the CityTree of 23%.” (Tropos, Leipzig, September 2017). “… at a constant air flow of 5.5 m^3/min, aerodynamic related efficiencies varied according to the moss species and ranged from 20%-53%, 26%-64% and 56%-86% for PM1, PM2.5 and PM10 respectively.” (Fiatec, Mainleus, April 2017). “Finally, results indicated that deposition of NOx were very different for the investigated materials with values ranging from 0 to 8%.” (ILK, Dresden, März 2018)	
Pro/Cons/Special request	Pro	It purifies air from pollutants and the high humidity necessary for mosses can involve process of evaporative cooling around it; it is totally natural and autonomous and self-controlled, it is ecstatically pleasant and functional and gives benefits in term of public appearances to the holder.
	Cons	High
	Special request	Installation comes after a detailed study from the producer in order to guarantee the maximum efficiency.
Cost	25 000$ each	
City in which it is applied	Oslo, Essen, Berlin, Hamburg, London	
Additional information	It is connected to a cloud system that transfer information regarding conditions and performances of the installed system. Data can be view on the AirCare programme. It means that it has a IoT integrated system. Additionally, it can be implemented with a fan system that spread the purified air around the station. Winner of the project Horizon 2020 for urban mosses.	
Sources	* https://greencitysolutions.de/en/ * https://urbannext.net/citytree/	

XIII. Pressure Independent Balancing Control Valves (PICV) – Danfoss (DK)

Name	Pressure Independent balancing Control Valves	
Company	Danfoss (DK)	
Technical description	These valves function as limited consumption control valves in two or four pipe heating and / or cooling systems	
Application	Mechanical heating and cooling systems	
Performance	It allows energy savings. They reduce maintenance costs.	
Pro/Cons/Special request	Pro	It allows the maintenance of a stable temperature in the room. It improves internal comfort. It allows energy savings. It reduces maintenance costs. Differential pressure is not created.
	Cons	The valves must be set to the design flow before mounting the actuators.
	Special request	Installation is recommended in countries where energy costs are high.
Cost	80-100 €	
City in which it is applied	Budapest, Singapore, Stettin (Poland)	
Additional information	Finalist “Open Innovation Call in NY targeting Air Quality and Urban Heat Island Effect”	
Sources	* https://www.danfoss.com/en/products/valves/dhs/hydronic-balancing-and-control/pressure-independent-balancing-control-valves-pibcv/#tab-overview * https://www.youtube.com/watch?v=s_HWw-5dU5E	

XIV. Smog Free Tower – Studio Roosegaarde (NL)

Name	Smog Free Tower	
Company	Studio Roosegaarde (NL)	
Technical description	This product consists is a tower, 7 meters high and 3.5 wide, which sucks the air contaminated by smog in the city, ionizes it, forfeiting the smog and isolating the fine dust, and returns 75% purified air. An internal system isolates and compresses the polluting particles contained in the sucked air. Static electricity fields are therefore created inside the tower which attract and retain fine particles (especially PM10 and PM2.5). The tower takes the energy it needs from an integrated wind system inside.	
Application	Independent tower placed in public places (parks)	
Performance	Cleans 30 000 cubic meters of air per hour.	
Pro/Cons/Special request	Pro	It is aesthetically nice; It is autonomous, with use of green energy; Purifies large quantities of air.
	Cons	Costs and huge dimensions.
	Special request	Dimensions require ample space.
Cost	54 000 $	
City in which it is applied	Rotterdam, Bejing, Poland	
Additional information	Winner of the Grand Award for Sustainability, Europe 40 Under 40 Awards, Design That Educates Award, Gold Award Design for Asia, Platinum A'Design Award, and German Design Award Excellent Product Design. The creators have created in collaboration with the bike sharing company "ofo" a bicycle with a small machine integrated with a function similar to the Smog Free Tower, in order to provide the biker with clean air while traveling around the city. Studied with the Eindhoven University of Technology.	
Sources	* https://www.studioroosegaarde.net/project/smog-free-tower * https://ideas.ted.com/this-tower-sucks-up-smog-and-turns-it-into-diamonds/ * https://www.infobuildenergia.it/progetti/smog-free-tower-396.html#	