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

T.2.1 - SoA-based definition and characterization of BE as network of buildings, infrastructures, connecting space in reference to SLOD occurrence and users' typologies

DELIVERABLE ID	D.2.1.1
Deliverable Title	Built Environment prone to SLOD definition
Delivery month	M3
Revision	1.0
Main partner	POLIMI
Additional partners	
Authors of the contribution	Graziano Salvalai, Manuela Grecchi, Tiziana Poli, Fulvio Re Cecconi, Laura Malighetti, Juan Diego Blanco Cadena, Nicola Moretti, Olga Beatrice Carcassi (POLIMI)
Deliverable type	report
Number of pages	44

Abstract

Resilience of the Built Environment is a primary issue to provide the citizens users a high-quality environment and livable cities. The aim of this report is to critically analyze the state of the art in identifying the Built Environment (BE) typologies prone to the Slow-Onset Disasters (SLODs). A SLOD can be defined as an uninterrupted, gradual or variable, low intensity and high frequency event that generates a negative effect on population, which on the long term can generate significant health and environmental decay. The results of the research have demonstrated that some SLODs type are more impacting within the built environment: the air pollution concentration and the increasing temperatures. Moreover, it has been demonstrated that some urban archetypes: the Piazza, Piazzale and the urban canyon are more prone to produce negative effects on the population through amplification of the consequences of the exposure to the SLODs mentioned above. The report concludes with some insights (solar radiation and wind tunneling analysis) on the most critical architypes, for understanding better how they perform under specific conditions. The following step concerns the detailed investigation of the effects of the SLODs risk on a specific part of the city.

Keywords

Slow-Onset Disasters, Built Environment; Pollution; Urban Heat Island; Climate change

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	14.12.2019	The report has been completed with figures	Graziano Salvalai	POLIMI
0.2	10.01.2020	The conclusion section has been integrated	Juan Diego Blanco Cadena/Graziano Salvalai	POLIMI
1.0	29.01.2020	Minor revision (text editing and proofreading)	Enrico Quagliarini	UNIVPM

Summary

1. Introduction

The concept of resilience has been adopted in different disciplinary fields as ecology, sociology, economy, risk management etc., over the last 40 years. Therefore, it has been adapted, modified and extended, in order to match with different issues coming from several disciplinary fields. Nevertheless, in literature, a unique and acknowledged definition cannot be found. Table 1: Definitions of resilience from Hassler and Kohler (2014). Sources: Bhamra, Ab and Burnard, (2011) and McAslan, (2010). collects some of the definitions that can be found in literature.

Table 1: Definitions of resilience from Hassler and Kohler (2014). Sources: Bhamra, Ab and Burnard, (2011) and McAslan, (2010).

Autor	Context	Definition
(Gere and Goodman 2009)	Physical systems (materials)	Ability of a material to absorb and release energy, within the elastic range
(Holling 1973)	Ecological systems	Measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between state variables
(Walker and Salt 2006)	Ecological systems	Capacity of a system to absorb a disturbance and reorganize while undergoing change while retaining the same function, structure and identity
(Carpenter et al. 2001)	Social-ecological systems	Magnitude of disturbance that a system can tolerate before it transitions into a different state that is controlled by a different set of processes
(Adger 2000)	Social systems	Ability of communities to withstand external shocks to their social infrastructure
(Masten and Coatsworth 1998)	Individual	Process of, capacity for or outcome of successful adaption despite challenging or threatening circumstances
(Bruneau et al. 2003)	Disaster risk management	Ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities that minimize social disruption and mitigate the effects of future earthquakes
(Hollnagel et al. 2006)	Resilience engineering	Ability to sense, recognize, adapt and absorb variations, changes, disturbances, disruptions and surprises
(Hamel, G. and Va¨likangas 2003)	Organizational	Resilience refers to the capacity to continuous reconstruction

All the definitions presented in Table 1: Definitions of resilience from Hassler and Kohler (2014). Sources: Bhamra, Ab and Burnard, (2011) and McAslan, (2010). , despite belonging to different fields, express the concept of "changing" and "function" of an entity or a system. Thus, resilience has been conceived as a possible bridge between the implementation of sustainability objectives and adaptation to changes of the context (environment, climate etc.). Moreover, the focus of resilience management and measures that are undertaken for facing catastrophic events, is strictly related to the risk management. Therefore, resilience is often conceived as a branch of the risk management discipline (Cambridge Institute for Sustainable Leadership 2011). Looking at the Architecture, Engineering, Construction and Operations (AECO) sector, an interdisciplinary discussion on the possible declination of the concept at the scale of the Built Environment (BE) arises. When the focus is the built environment, one of the keywords is complexity, since this peculiar context is characterized by the contemporary presence of buildings, infrastructures, natural elements and human being. The complexity of the Built Environment (BE) leads to profound long-term changes which must be investigated with attention to planning, design, operation, management, value and governance (Hassler and Kohler 2014).

Authors tackled the problem of resilience in different ways. Anderies *et al.* (2013) define a framework to operationalize resilience combining the concept with those of sustainability and robustness, in order to cope with multi-scalar and multi-level challenges . Pickett *et al.* (2014) focus on a general template, identified in the adaptive cycle model of resilience. Hassler and Kohler (2014) in the context of the long term management of the built environment and within the context of sustainability, consider resilience as a key driver. Tainter and Taylor, (2014) define resilience as a mean to achieve the sustainability goals. Bosher (2014) defines the concept of *resilience engineering* as "*the intrinsic ability of a system to adjust its functioning prior to, during,*

or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions". According to Sinclair *et al.* (2012), a good level of resilience is achieved if changes are coped with minimum demolitions, production of waste and costs and with maximum robustness, mutability and efficiency.
All these definitions and approaches assume the strong link between resilience and sustainability and the changing in the system which triggers resilience dynamics. Hence, when the focus is the built environment, it is worthwhile to investigate which are the resilience-related changes that can be managed thanks to a resilient principle. Moreover, some open questions are still to be answered. These questions concern the need for integrated management systems to cope with material and immaterial aspects featuring the built environment, managed to achieve sustainability objectives and the development of indicators able to gather and measure resilience performances of building. Many efforts have been done for a better definition of the resilience principles and approached related to catastrophic and fast events (e.g. earthquakes, hurricanes, floods, tsunami etc.). Fewer studies addressed the resilience to slow changes related, for instance to the effects of pollutants on people living in the urban environment or the effects of the increasing temperatures worsening the heat island phenomenon.

1.1. International researches and research institutes on resilience

Resilience in the BE has not been unambiguously conceptualized yet. Therefore, it is inherently related to an interdisciplinary approach, borrowing definitions and methodologies from different research areas (physical systems, ecological systems, disaster management, etc) (McAslan 2010; Bhamra et al. 2011; Hassler and Kohler 2014).
Below some of these research experiences promoted both by academia and private associations are listed, starting from the most specific on the built environment, to the ones related both to sustainability and resilience in the wider context of the urban ecosystems:

- *Resilient Urban Ecosystem (RUE) Network* has been founded by its 2 directors; Dr. Tuba Kocaturk (University of Liverpool) and Mr. Martin Simpson (ARUP). The scope is to "explore emerging models of innovation through intelligent adoption and use of data and computation in built environment sector" (Resilient Urban Ecosystem (RUE) Network 2016). The aim concerns the creation of a network of scientists, industrial experts and consultants, to provide an interdisciplinary contribution to research and practice in built environment and urban informatics and share best practices and examples of data-driven innovations in Built Environment (Resilient Urban Ecosystem (RUE) Network 2016);
- *Stockholm Resilience Centre (SRC)* was founded in 2007, thanks to a collaboration between Stockholm University and the Beijer Institute of Ecological Economics at The Royal Swedish Academy of Sciences. Among the research lined developed by the SRC can be found the one concerning urban social-ecological systems. This research initiative stems from studies on "how to build resilience in linked social-ecological systems". The aim is to investigate urban resilience science by improving understanding of how to design complex urban systems able to face both known and uncertain outcomes. Urban resilience, in this case, can be intended as the outcome of a cyclical process that includes anticipation, learning and adaptation to changes in circumstances and new events.
- *100 Resilient Cities*—Promoted by the Rockefeller Foundation (100RC) is dedicated to helping cities around the world become more resilient to the physical, social and economic challenges. The view of resilience to adopt and implement thanks to this initiative does not only include shocks as for instance earthquakes, fires, floods, but also the "stresses that weaken the fabric of a city on a day to day or cyclical basis" (100 Resilient Cities 2017);
- *Enhancing resilience of critical road infrastructure: bridges, culverts and flood-ways under natural hazards* is a project, started in 2015, led by RMIT University of Melbourne, which aims at developing

"tools and techniques for implementing strategies to enhance resilience of road infrastructure to multi-hazards of floods, fire and climate change and earthquakes" (University of Huddersfield 2017). The main expected outcomes are the development of vulnerability models for critical road structures: bridges, culverts and flood-ways under natural hazards of flood, bush fire and earthquakes. In the second stage of the project, the optimization of maintenance and strengthening regimes required to enhance resilience of critical road structures will be identified and a decision making tool will be developed (Setunge et al. 2015).

1.2. Resilience required to assess disasters

Nowadays, disasters are and should be subject of great global concern. Twigg and Steiner (2002) reported from gathered data on natural disasters between 1971 and 1995, that these caused more than 128.000 deaths per year and affected at some extent 136 million people; from which mostly where located in developing countries (escalated by their vulnerability). This trend did not change much in the following years, the number of catastrophes and economic losses increased, but the number of mortal victims were diminished (Garatwa 2002; IFRC 2002) and the number of injured, homeless or hungry, as a consequence of the disaster, tripled to 2 billion in the following 10 years (IFRC 2002). These occurred even when the boost program launched by United Nations (UN) "International Decade of Natural Disaster Reduction" was running in the 90's (LECHAT 1990; World Meteorological Organization 1994).
Mitigation strategies yet seem to be scant to prepare the BE and the population to avoid these growing trends, one of the factors that has enhanced the criticality of a disaster is the sprouting and crowding of BE placed in urban areas. For instance, Wolfensohn and Cherpitel (2002) stated that *"Rapid population growth, urbanization, environmental degradation and global climate change are all contributing to an increase in the frequency and magnitude of disasters."* Due to the complex structure and function of urban areas (i.e. cities), these can be exposed to both sudden events (e.g. earthquakes, floods and hurricanes, outbreaks of violence, migration crises, industrial incidents and health epidemics) and to gradual processes (e.g. structural industrial transformations, economic recessions, increasing poverty and social disparities and environmental degradation); to which its inhabitants expect the city to adapt and be resilient to any of these burdens occurrence.
Thus, the attention has been drawn towards the interaction of the BE, the human system (i.e. hosted users, including population when referring to a wide-urban scale perspective) and the natural environment which might favor Slow-Onset Disasters (SLODs) events. This, as a result of: (1) rising densification of urban areas; (2) the actual identified risks or challenges for humanity; (3) the funded and promoted research delivering mitigation strategies, or methodologies, mostly for sudden disasters (focusing on short-term preparation and post-disaster assistance) (UNFCCC 2012); and (4) the low number of research concentrated on assessing disasters caused by long-term frequent exposure agents (Ramieri et al. 2018), such as the ones presented by Mude et al. (2009); Sharifi and Lehmann (2015); Haddad et al. (2018); and Zhong et al. (2019).

2. Definition of SLow-Onset Disasters event

To differentiate better between the disaster types, Siegele (2012) proposed to define them depending on the temporal scale, intensity and frequency:

- They vary in temporal scale. In fact, rapid-onset disaster unfold "almost instantly", slow-onset disasters can be predicted much further in advance and unfold over months or even years. Moreover, slow-onset disasters are heavily related to the effects of the man-made climate change dynamics;

- They vary in impact type. Since rapid-onset disasters tend to create their destruction through the immediate/short-term physical impacts, whereas slow-onset disasters can also create crises through the economic and social impacts of the disaster.

Indeed, in addition to what has already been mentioned in the Deliverable D 1.1.1 (compare Section 2), a Slow-Onset Disaster (SLOD) can be defined as an uninterrupted, gradual or variable, low intensity and high frequency event that generates a negative effect on population, which on the long term can generate significant health and environmental decay. A SLOD can also be described as a resulting disaster of the combination of both natural and human-generated forces; which provoke *"a vast ecological breakdown in the relation between humans and their environment, a serious and slow event on such a scale that the stricken community needs extraordinary efforts to cope with and resolve it"* (Gunn 1989; Noji 1997) (Figure 1; Figure 2 – Examples of SLOD. Image taken from Le parisien (http://www.leparisien.fr/societe/canicule-41-c-a-paris-a-13h42-record-de-chaleur-battu-25-07-2019-8123526.php, last access: 28/01/2020).).

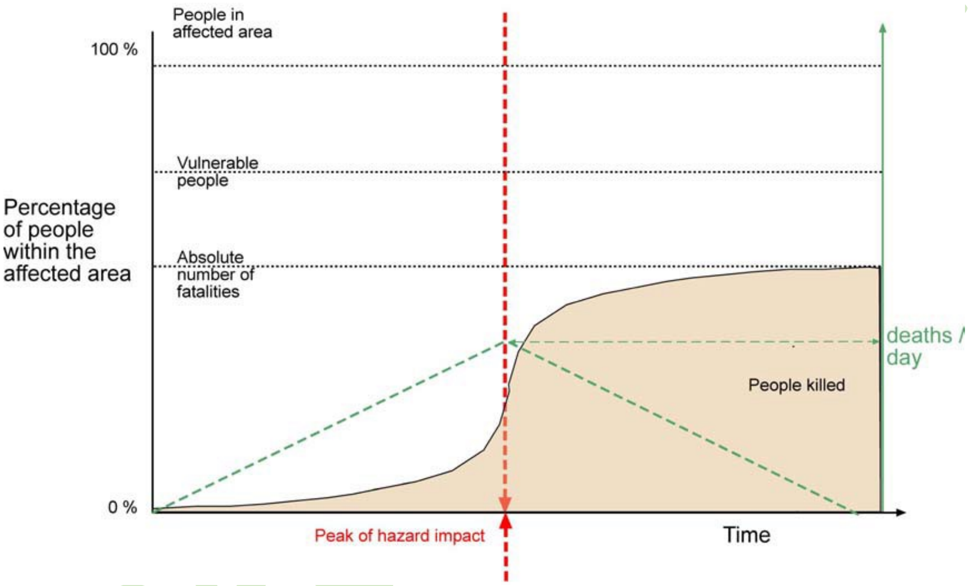


Figure 1 – The absolute number of people killed and the deaths / day in relation to the temporal development of a slow onset disaster (Image taken from Schneiderbauer and Ehrlich (2004)).

Figure 2 – Examples of SLOD. Image taken from Le parisien (http://www.leparisien.fr/societe/canicule-41-c-a-paris-a-13h42-record-de-chaleur-battu-25-07-2019-8123526.php, last access: 28/01/2020).

These events require a complex multi-variable analysis or forecast to determine the real or potential effects on the environment and/or the population immersed within. Therefore, the SLODs are difficult to immediately trace-back or relate to a specific source, cause and/or deterioration to the environment and/or health. In particular, extensive and granular analysis are required to isolate and identify the real influence of the singular factor, parameter or variable. Nevertheless, efforts in research have shown that there are singularities of the environment which favor or diminish their risk which have led to the concept of resilient environments (Musco and Fregolent; Musco 2016; World Health Organization 2016; Bellini et al. 2018).

In fact, in Europe's BE display characteristics that can affect the health of its citizens. High population densities themselves have both positive and negative implications (European Commission - Joint Research Centre 2019). On the one hand, urban citizens can access better health and well-being than people living in rural areas because of better contact to health infrastructure and services in general. On the other hand, poor health conditions that persist in entire cities or specific urban contexts can contribute to health complications closely related to sleep disorders, chronic stress and anxiety and also, respiratory, cardiac and brain damage (Tarnopolsky et al. 1980; Kryter 1985; Stansfeld and Matheson 2003; World Health Organization 2013; de Prado Bert et al. 2018). These complications have been often correlated with the pronounced difference between the urban and rural areas in terms of: higher pollutant concentration, sound-wave pressure, surface and air temperature, poor waste management, less water absorption, vegetation coverage and biodiversity (Guerreiro et al. 2014; Hornikx 2016; European Commission - Joint Research Centre 2019). Hence, research on SLODs has steered towards a deep examination of the BE, its features and the way it adapts to the weather variations and the behavior of its population and the context of analysis, by additionally considering the aforementioned temporal scale for their evidence (Figure 3).

These can be structured to fit and shape the unified concept of seismic risk (*R*), which results from integrating hazard (*H*), vulnerability (*V*) and exposure (*E*) (i.e. $R = E \cdot H \cdot V$) (UNDRO 1980), into a specific definition for SLOD (Figure 4). That is, *H* would be determined by the environmental forces' intensity resulted from the combination of the site contaminants (see Figure 5) and the environmental context (see Figure 6); *V* would be related to the expected microclimates generated from the built environment features and their potential effects on the population immersed in it, based on their susceptibility (see Figure 7 – Population deconstruction features for SLOD assessment. Definition of the population at risk by macro-categories, the left-most are the most generic (based on susceptibility); the right-most, are the most specific that are identified at smaller scale and which fluctuate but could be identified, measured and monitored.); and *E*, would be the expected impact induced directly, or indirectly, by the originated microenvironments expressed in terms of economic losses or victims.

Figure 3 – Disasters' evidence temporal scale (image taken and modified from Climate and Migration Coalition website).

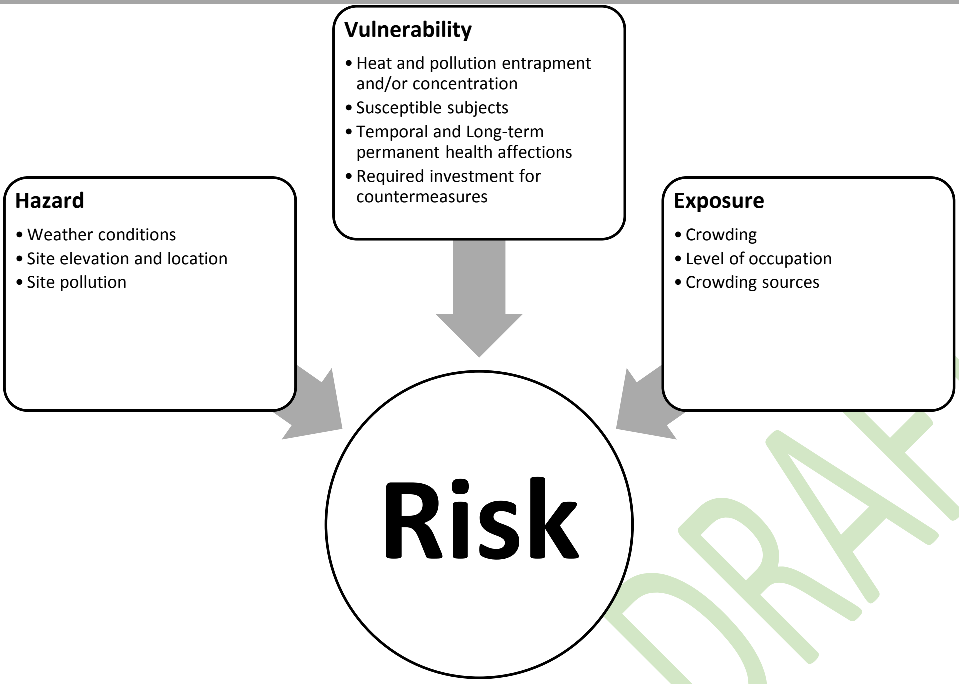


Figure 4 – Risk definition for SLOD, specifying its components (hazard, vulnerability and exposure).

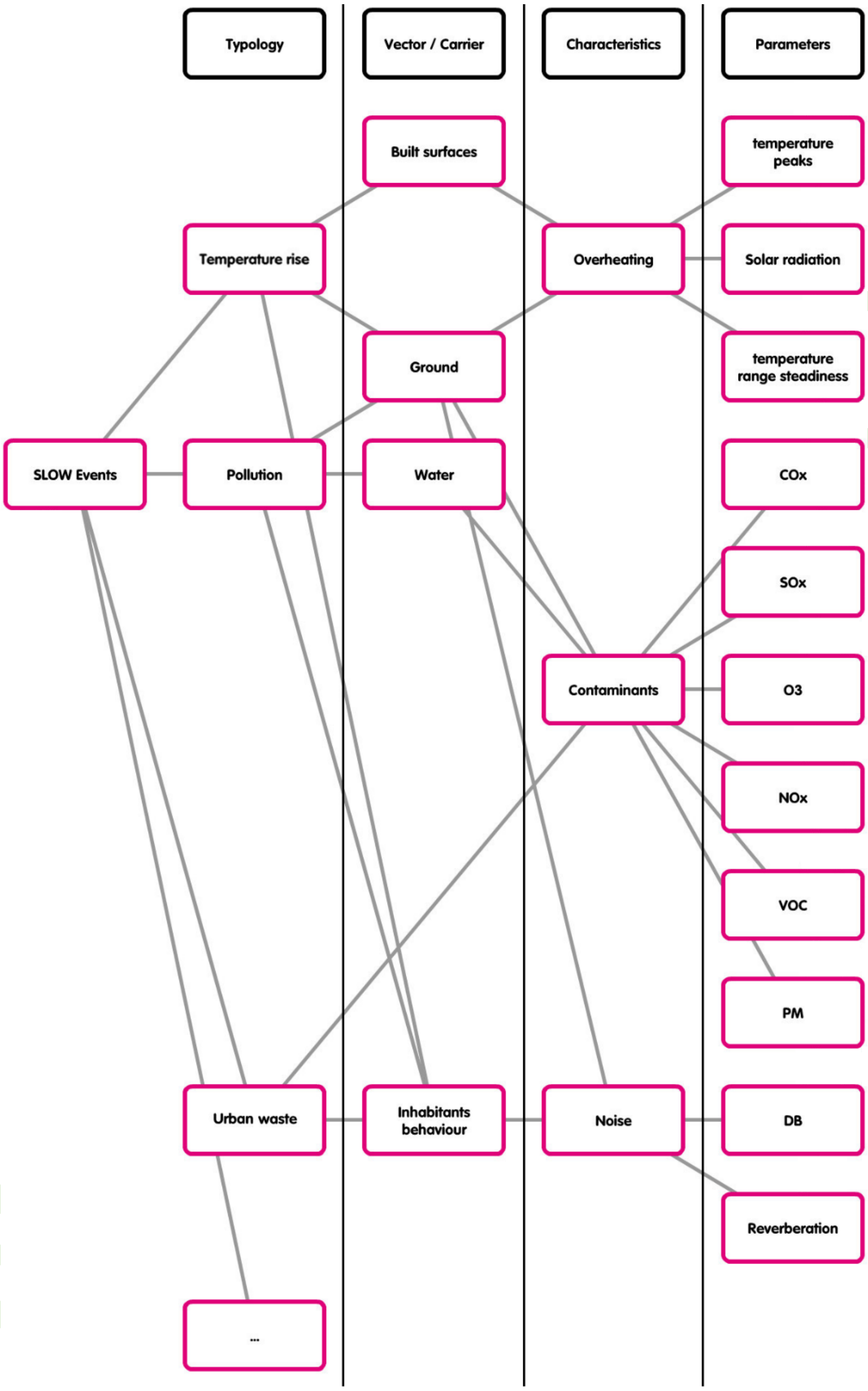


Figure 5 – SLOD deconstruction to display the way these acts on the urban fabric, their carriers and the parameters which can be monitored for attempting to hold back their health effects.

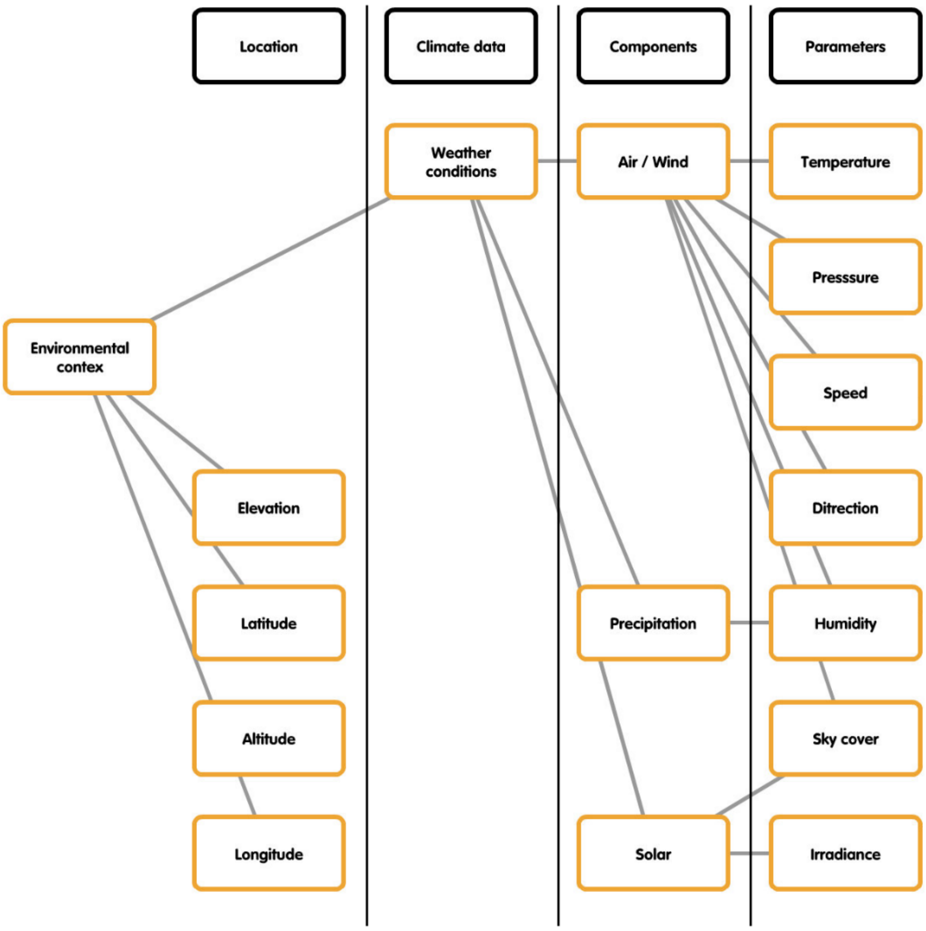


Figure 6 – Environmental context deconstruction for SLOD assessment. Properties definition by macro-categories, the left-most are the more generic (location specific), yet the ones with greater impact; the right-most, the ones that are more specific to the smaller scale location and which fluctuate but can be measured and monitored.

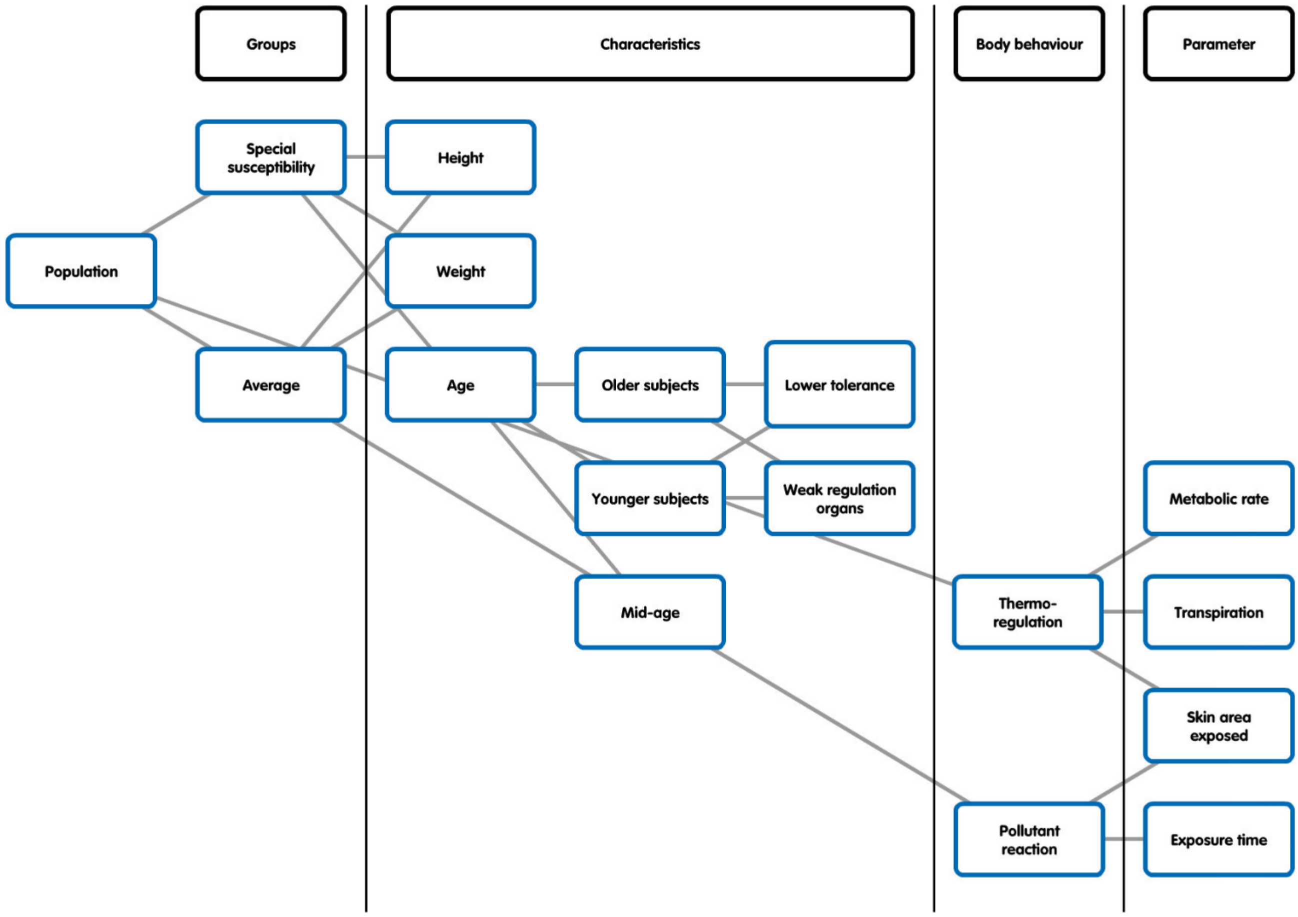


Figure 7 – Population deconstruction features for SLOD assessment. Definition of the population at risk by macro-categories, the left-most are the most generic (based on susceptibility); the right-most, are the most specific that are identified at smaller scale and which fluctuate but could be identified, measured and monitored.

3. SLODs risk and their criticality on population

The SLODs are defined as a convergence of natural and human-generated forces, depending on the reaction coming from the force's junction. The technical paper *Slow Onset Events*, published by United Nations – Framework Convention on Climate Change (UNFCCC 2012), lists the following 11 slow events that affect our life:

- Increasing temperatures;
- Air quality and Pollution;
- Sea level rise;
- Droughts;
- Extreme precipitation events;
- Ocean acidification;
- Glacial retreat and related impacts;
- Salinization;
- Land and forest degradation;
- Loss of biodiversity;
- Desertification.

However, some of these SLODs could be recognized as the main hazardous agents produced by the human activities. These agents concern the profound and unchangeable modification of land and soil, and the production of harmful emission in the atmosphere. These agents result in activating a set of SLODs that are summarized in Table 2. These SLODs can act as single factors of disruptive events or can exhibit simultaneously, producing joint and more severe damages. Table 2 represents some of these relationships.

Table 2 – SLOD interaction, as disasters which are consequences of the development of the other, some which are normally occurring in parallel, or which the development of one favors the others arousal. The grey cells represent a direct relationship between disaster types.

Disaster Main Type	Increasing temperatures	Air quality and Pollution	Sea level rise	Droughts	Extreme precipitation events	Ocean acidification	Glacial retreat and related impacts	Salinization	Land and forest degradation	Loss of biodiversity	Desertification
Increasing temperatures											
Air quality and Pollution											
Sea level rise											
Droughts											
Extreme precipitation events											
Ocean acidification											
Glacial retreat and related impacts											
Salinization											
Land and forest degradation											
Loss of biodiversity											
Desertification											

All the listed SLODs of Table 2 have been observing for a long time and their development and increasing severity is slow and continuous, in accordance with the habits of today's society (UNFCCC 2012). It is precisely this slow evolution that enables the development of adequate solutions and precautionary strategies.

As stated in the previous paragraphs, the BE presents different characteristics, in terms of response to SLODs, compared to the rural environment. In this context, some SLODs appear to be more impacting than other in term of the negative consequences that they can produce on the inhabitants. Considering the scope of the BE S2ECURE project, the SLODs defined as *Increasing temperatures, Air quality and Pollution and Extreme precipitation events* can be considered as the more hazardous, in terms of potential negative and disastrous effects that they may produce on the urban environment and the population.

In fact, *increasing temperatures* enhance water vapor carrying capacity, moving onto water vapor state what should have been used for land moisture. This could affect the process of desertification, droughts and forest degradation. Thus, *loss of biodiversity* is expected. In addition, higher amount of water vapor in the air would generate a larger risk *for extreme precipitation events* in the eventuality of a pressure and/or temperature drop. Higher temperatures around the globe would also boost the glacial melting making more evident the *glacial retreat, and,* in consequence, *rising the sea level* and decreasing the availability of freshwater can be expected (UNFCCC 2012).
On the other hand, *Air quality and Pollution* represent a risk for the human race, and also for the natural environment when the contaminants production rate surpasses the contaminants assimilation rate. This would promote *land and forest degradation*, and some species would not endure the quality of the air they are breathing, then *biodiversity loss* would be inevitable. As a consequence, the ocean would try to balance the contaminants cycle by absorbing more contaminants at a pace faster than it can process developing its own *acidification.* Finally, some of these contaminants are among those considered Green House Gases (GHG), worsening the heat entrapment in the atmosphere which contributes to the *increasing temperature* trend.
These SLODs are more easily identified by the localized effects generated, and given the evident and projected rapid urbanization rate (Musco and Fregolent; FULADLU et al. 2018; European Environment Agency 2019), the *Urban Heat Island* and *Air Pollution* have been studied in depth.

3.1. Urban Heat island

Urban Heat Island (UHI) has been defined as heat accumulation phenomenon, characterized by further sensed air temperature increase, that develops in urban areas due to constructions and human being activities. Several urban and suburban areas experience higher temperatures compared to the closest rural surrounding areas (EPA 2008). According to EPA (2008), the UHI (Figure 8) can be divided in two different types:

- Surface Heat Island (SHI);
- Atmospheric Heat Island (AHI).

The surface heat island is referred to the effect of the direct sun that heat the exposed built surfaces like roofs, pavement to temperatures hotter than the air (Yang et al. 2016). SHI reaches the maximum level during the day and can prevail during the night depending on the thermal inertia of the built surfaces (i.e. thermal mass). The intensity changes according to the season as well as the ground cover. To identify the SHI, and its intensity, direct and indirect methods can be used; remote sensing for surface temperatures are often employed to better understand the phenomena (e.g. Infrared imagines).
Instead, the atmospheric heat island represents the differences between the air temperature of the urban area and the air temperature of the surrounding area. The air temperature is intended as the air temperature of the space where the pedestrian and residents coexist, that is, from the ground level to the top of the trees and roofs. The AHI intensity fluctuates less that the surface heat island, hence to be able to observe and address this phenomenon a dense network sensor is required.
The actors involved in both Atmospheric and Surface Heat Island have been laid down in Figure 8 for an easier understanding of their interaction. Both of them contribute to the consolidation of the UHI effect, which is worsen by the evident gradual temperature increase described in Section **Errore. L'origine riferimento non è stata trovata.**; a detailed explanation on how this occurs is presented in Table 3.

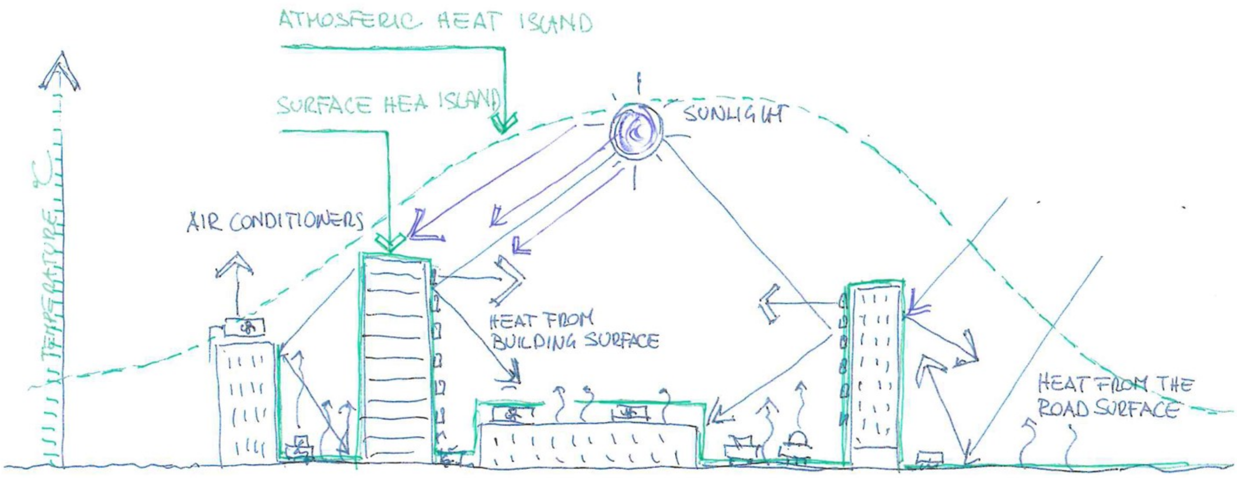


Figure 8 – Schematic UHI representation, including the atmospheric and surface heat island within the BE.

Table 3 – Description of the SLOD incremented risk by the UHI phenomenon

	URBAN HEAT ISLAND					
Causes	Anthropogenic heat	Urban geometry	Properties of urban materials	Lack of greenery	Weather	Geographical location
Agents	Automobiles, Buildings, Industries and air condition units.	Urban morphology modifies the solar radiation exposure.	Opaque surfaces with high absorptivity (e.g. Asphalt, Concrete, black surfaces).	Decreased evaporative heat losses and lower shading potential.	Clear sky, calm wind and excessive solar radiation.	Proximity to large water bodies or mountains.

3.2. Evolvement of the UHI in the BE

As stated by the United Nations, the Intergovernmental Panel on Climate Change (IPCC) has concluded that current rates of climate change are leading to changes in the frequency, intensity, spatial extent, duration and timing of extreme weather- and climate-related events, collectively referred to as climate extremes (Field et al. 2012). Changes in climate extremes reflect the influence of anthropogenic climate change in addition to natural climate variability. According to the IPCC, in the next two to three decades, the increase in climate extremes will probably be relatively small compared to the normal year-to-year variations in such extremes. However, as climate change progresses over the course of the twenty-first century, its effects on climate extremes will become increasingly apparent (Field et al. 2012). Climate change may influence extreme events through long-term global warming as well as through climate regime shifts. The long-term trend of rising temperatures is accelerating, and changes of even 1 °C to 2 °C can have significant effects on extreme events (Field et al. 2012) . Rising temperatures evidence in Sidney (Livada et al. 2019) in south china (Du et al. 2013) have been reported in literature. The correlation between the climate change and diseases has been highlighted by Wu et al. (2016). Severe demographic and climate change projections on deaths have been reported by Lee and Kim (2016).

The heatwave, which is characterized as a SUdden Onset Disaster (SUOD) and has been identified as responsible for a significant amount of deaths around the globe (World Meteorological Organization 1994) (

Table 4), is worsen by the UHI phenomenon (Figure 10 – a - Time series of the ratio of land area affected by an exceedance of 30 extreme warm days (ExD30) per year relative to the 1979–2010 average for the ERA-Interim13 and HadEX2 datasets14. b – Time series of the ration of land affected by exceedances of 10, 30 and 50 extreme warm days per year relative to 1979-2010 average in ERA-Interim (E-Int).(image taken from (Seneviratne et al. 2014)).). Thus, it is important to act on diminishing the risk of the convergence of heatwaves, high UHI and the rising temperatures (which has been proved to be gradually more frequent all over the world in term of percentage of the total land area, see Figure 10 – a - Time series of the ratio of land area affected by an exceedance of 30 extreme warm days (ExD30) per year relative to the 1979–2010 average for the ERA-Interim13 and HadEX2 datasets14. b – Time series of the ration of land affected by exceedances of 10, 30 and 50 extreme warm days per year relative to 1979-2010 average in ERA-Interim (E-Int).(image taken from (Seneviratne et al. 2014)).).

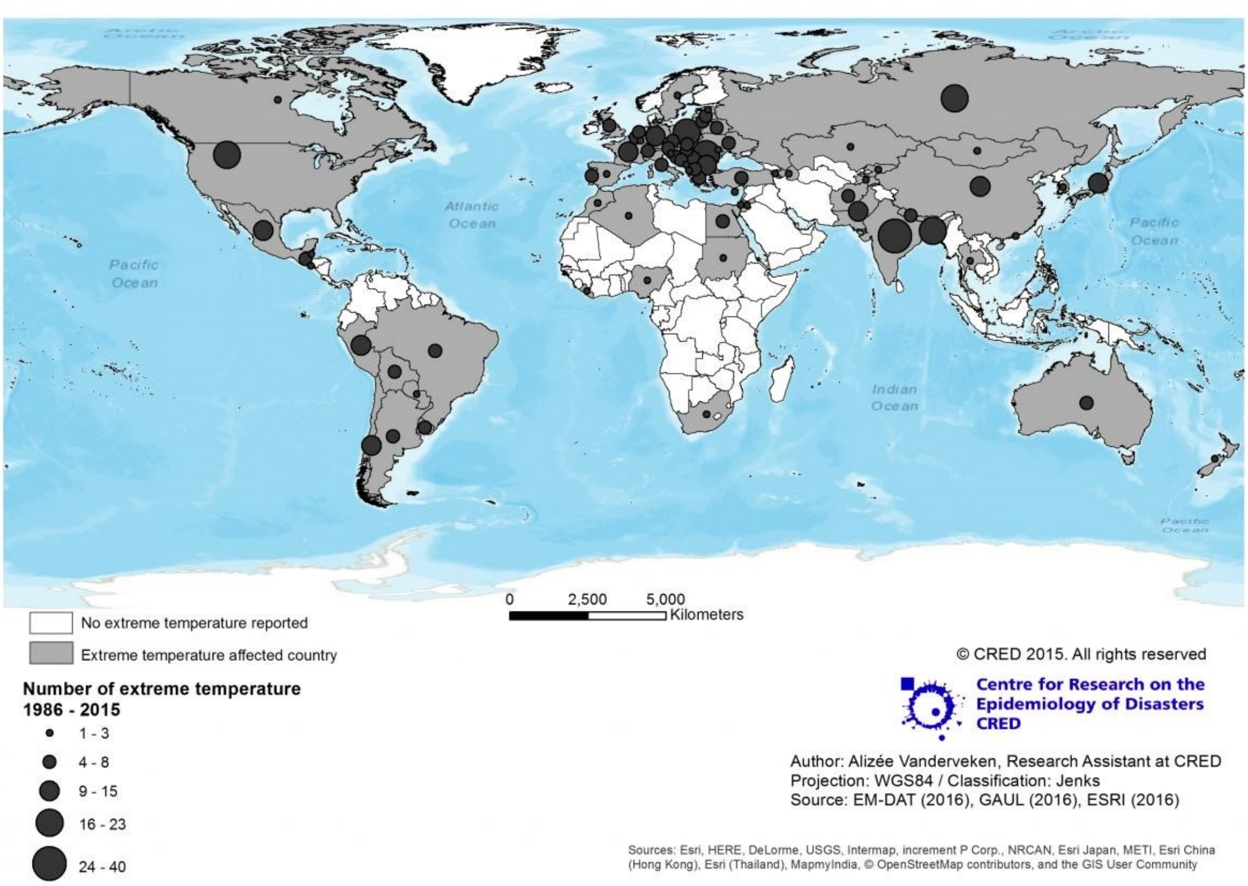


Figure 9 – Frequency of temperature extreme temperatures disaster events from 186 to 2016 (extracted from EM-DAT database (EM-DAT))

Therefore, the UHI can be considered one of the more severe threats to the health of the city population resulting from climate change (**Errore. L'origine riferimento non è stata trovata.**). The increasing value of death per event in the last decade confirms the criticality of the trend of temperature rise (

Table 4, Table 5, Table 6). This phenomenon, may affect more disadvantaged categories as low-income classes (more exposed to the outdoor built environment), elderly, children and people already affected by health conditions (low body thermoregulation capacity, see Figure 7 – Population deconstruction features for SLOD assessment. Definition of the population at risk by macro-categories, the left-most are the most generic (based on susceptibility); the right-most, are the most specific that are identified at smaller scale and which fluctuate but could be identified, measured and monitored.). Some efforts have been done at the European level for developing policy and actions to address the impact of the urban heat island on the inhabitants (Ramieri et al. 2018). The project *Urban Heat Island (UHI) project* (2011–2014), for instance, provides tools for assessing and monitor the UHI in cities' environment for developing effective adaptation strategies (Ramieri et al. 2018).

Table 4 - Meteorological disasters summary from 1900 - 2019 (extracted from (EM-DAT)).

Continent	Disaster subtype	Events count	Total deaths	Deaths/ event	Total affected	Affected/ event	Total damage ['000 US$]
Africa							
	Cold wave	12	81	7	3,727,630	310,636	47,000
	Heat wave	8	291	36	86	11	809
Americas							
	Cold wave	66	3,323	50	4,645,272	70,383	10,833,850
	Heat wave	35	6,177	176	20,221	578	9,025,000
	Severe winter	13	112	9	1,036,364	79,720	1,400,000
Asia							
	Cold wave	86	8,694	101	7,073,889	82,255	3,193,133
	Heat wave	78	16,860	216	299,323	3,837	419,000
	Severe winter	20	2,075	104	80,738,052	4,036,903	21,960,200
Europe							
	Cold wave	140	5,435	39	964,955	6,893	2,424,301
	Heat wave	75	138,566	1,848	2,120	28	12,763,050
	Severe winter	44	1,545	35	490,317	11,144	1,000,000
Oceania							
	Cold wave	8	509	64	4,602,784	575,348	200,000

Table 5 – Meteorological disasters summary from 2000-2019 (extracted from (EM-DAT)).

Continent	Disaster subtype	Events count	Total deaths	deaths/ event	Total affected	affected/ event	Total damage ['000 US$]
Africa							
	Cold wave	9	33	4	2,727,630	303,070	-
	Heat wave	6	237	40	86	14	809
Americas							
	Cold wave	42	2,291	55	4,593,472	109,368	4,204,000
	Heat wave	11	591	54	17,521	1,593	-
	Severe winter	13	112	9	1,036,364	79,720	1,400,000
Asia							
	Cold wave	51	4,679	92	6,307,682	123,680	2,070,133
	Heat wave	50	9,825	197	298,583	5,972	419,000

	Severe winter	19	2,075	109	80,730,052	4,248,950	21,960,200
Europe							
	Cold wave	112	4,016	36	227,055	2,027	648,001
	Heat wave	63	137,319	2,180	1,850	29	12,763,050
	Severe winter	41	1,477	36	483,232	11,786	1,000,000
Oceania							
	Cold wave	4	486	122	2,000	500	200,000

Table 6 - Meteorological disasters summary from 2010-2019 (extracted from (EM-DAT)).

Continent	Disaster subtype	Events count	Total deaths	deaths/event	Total affected	affected/event	Total damage ['000 US$]
Africa							
	Cold wave	7	8	1	2,727,525	389,646	-
	Heat wave	3	137	46	86	29	-
Americas							
	Cold wave	14	1,293	92	533,823	38,130	3,094,000
	Heat wave	5	265	53	17,490	3,498	-
	Severe winter	7	30	4	151,792	21,685	1,400,000
Asia							
	Cold wave	25	1,173	47	5,236,132	209,445	2,008,123
	Heat wave	24	6,224	259	290,522	12,105	18,000
	Severe winter	11	186	17	1,458,218	132,565	20,200
Europe							
	Cold wave	69	1,778	26	194,621	2,821	132,601
	Heat wave	17	60,213	3,542	-	-	400,000
	Severe winter	14	116	8	411,078	29,363	-
Oceania							
	Cold wave	2	139	70	-	-	-

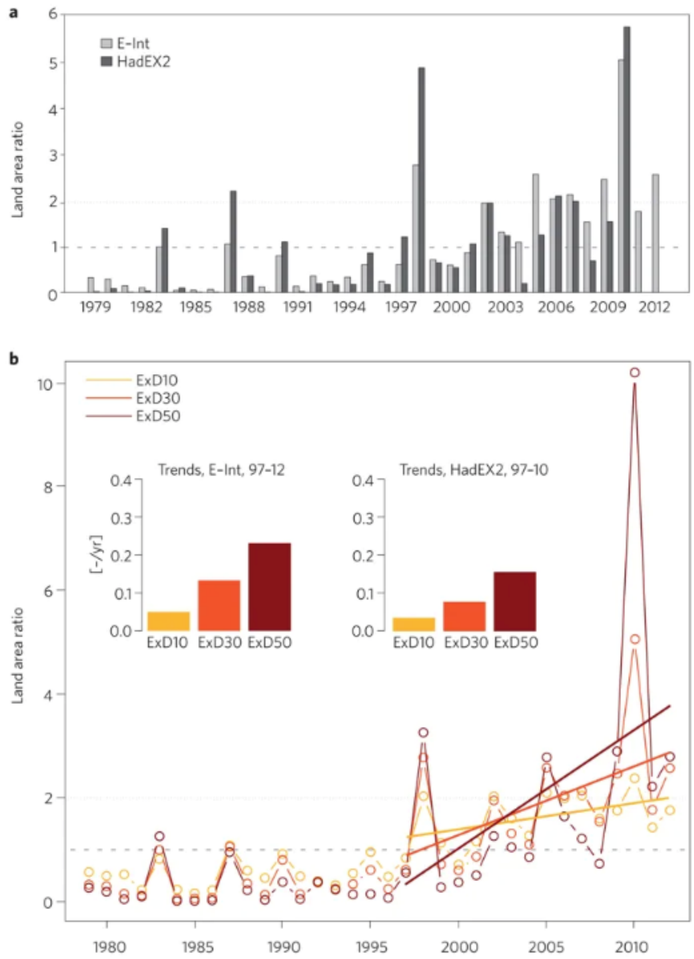


Figure 10 – a - Time series of the ratio of land area affected by an exceedance of 30 extreme warm days (ExD30) per year relative to the 1979–2010 average for the ERA-Interim13 and HadEX2 datasets14. b – Time series of the ration of land affected by exceedances of 10, 30 and 50 extreme warm days per year relative to 1979-2010 average in ERA-Interim (E-Int).(image taken from (Seneviratne et al. 2014)*).*

3.3. Air pollution

Urban outdoor air pollution refers to the air contamination to which the population is exposed, and which is experienced by those living in and around urban areas (i.e. cities). According to the World Health Organization (WHO) actually air pollution represents one of the biggest environmental risk to health (WHO 2016).
The WHO Air Quality Guidelines (AQGs) recommends the lowest concentrations of PM to which a person could be exposed, and yet no severe health effects would arise (WHO 2005). Some of these are (thresholds established for other pollutants are listed in Figure 11 and Figure 12):

- PM2.5 --> 10 µg / m3 annual mean; 25 µg / m3 24-hour mean
- PM10 --> 20 µ / m3 annual mean; 50 µg / m3 24-hour mean

However, 91% of world's population lives in a place with poor air quality, with air pollution indicators above the suggested healthy threshold limits established by WHO. The outdoor ambient air pollution is caused by a range of factors including transportation, agriculture, waste, anthropogenic activities (e.g. respiration), construction and building operation, as shown by the general causes-agents classification of Table 7. For instance, the 39% of global energy-related carbon emissions are attributed to the buildings sector (IEA; WGBC), these emissions are distributed as follows:

- 28% of this is buildings in operation: heating, cooling and lighting. Energy use is heavily impacted by the quality of building envelope, with emissions especially substantial in older building stock.
- 11% of carbon emissions are attributed to emissions embodied in the construction process: waste generation, water use, dust creation and greenhouse gas emissions.

Pollutant	Averaging period	Legal nature and concentration	Comments
PM_{10}	1 day	Limit value: 50 µg/m^3	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 µg/m^3	
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m^3	
		Exposure concentration obligation: 20 µg/m^3	Average exposure indicator (AEI) (^{a}) in 2015 (2013-2015 average)
		National exposure reduction target: 0-20 % reduction in exposure	AEI (^{a}) in 2020, the percentage reduction depends on the initial AEI
O_3	Maximum daily 8-hour mean	Target value: 120 µg/m^3	Not to be exceeded on more than 25 days/year, averaged over 3 years (^{b})
		Long-term objective: 120 µg/m^3	
	1 hour	Information threshold: 180 µg/m^3	
		Alert threshold: 240 µg/m^3	
NO_2	1 hour	Limit value: 200 µg/m^3	Not to be exceeded on more than 18 hours per year
		Alert threshold: 400 µg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	Calendar year	Limit value: 40 µg/m^3	
BaP	Calendar year	Target value: 1 ng/m^3	Measured as content in PM_{10}
SO_2	1 hour	Limit value: 350 µg/m^3	Not to be exceeded on more than 24 hours per year
		Alert threshold: 500 µg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	1 day	Limit value: 125 µg/m^3	Not to be exceeded on more than 3 days per year
CO	Maximum daily 8-hour mean	Limit value: 10 mg/m^3	
C_6H_6	Calendar year	Limit value: 5 µg/m^3	
Pb	Calendar year	Limit value: 0.5 µg/m^3	Measured as content in PM_{10}
As	Calendar year	Target value: 6 ng/m^3	Measured as content in PM_{10}
Cd	Calendar year	Target value: 5 ng/m^3	Measured as content in PM_{10}
Ni	Calendar year	Target value: 20 ng/m^3	Measured as content in PM_{10}

Notes: (^{a}) AEI: based upon measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.

(^{b}) In the context of this report, only the maximum daily 8-hour means in 2017 are considered, so no average over the period 2015-2017 is presented.

Sources: EU, 2004, 2008.

Figure 11 – Air quality standards for the protection of health, as given in the EU Ambient Air Quality Directives (Image taken from European Environment Agency (2019)*).*

Pollutant	Averaging period	AQG	RL	Comments
PM_{10}	1 day	50 µg/m³		99th percentile (3 days per year)
	Calendar year	20 µg/m³		
$PM_{2.5}$	1 day	25 µg/m³		99th percentile (3 days per year)
	Calendar year	10 µg/m³		
O_3	Maximum daily 8-hour mean	100 µg/m³		
NO_2	1 hour	200 µg/m³		
	Calendar year	40 µg/m³		
BaP	Calendar year		0.12 ng/m³	
SO_2	10 minutes	500 µg/m³		
	1 day	20 µg/m³		
CO	1 hour	30 mg/m³		
	Maximum daily 8-hour mean	10 mg/m³		
C_6H_6	Calendar year		1.7 µg/m³	
Pb	Calendar year	0.5 µg/m³		
As	Calendar year		6.6 ng/m³	
Cd	Calendar year	5 ng/m³ (b)		
Ni	Calendar year		25 ng/m³	

Notes: (a) As WHO has not set an AQG for BaP, C_6H_6, As and Ni, the RL was estimated assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

(b) AQG set to prevent any further increase of Cd in agricultural soil, likely to increase the dietary intake of future generations.

Sources: WHO, 2000, 2006a.

Figure 12 – World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs)[(a)] (Image taken from European Environment Agency (2019)*)*

Table 7 – SLOD Urban Air Pollution description

URBAN OUTDOOR AIR POLLUTION						
Causes	Anthropogenic processes	Urban geometry	Properties of urban materials	Lack of greenery	Weather	Geographical location
Agents	Automobiles, Buildings, Industries and air condition units.	Building, road, sidewalks and courtyard morphology. Wind	Opaque surfaces: Asphalt, Concrete, black surfaces.	Decreased particulate matter absorption.	Clouds with high atmospheric pressure, wind intensity, wind direction,	Proximity to three field.

3.4. Evolvement of air pollution effects in the built environment

Pollutants produced by the human activity have a great impact on the health of the European population. Within this context, PM, NO_2 and ground-level O_3 are among the most dangerous pollutants for human health. Among the subjects exposed to these agents, some classes are more subject to negative effects of these agents. Lower socio-economic groups are more exposed to pollutants, older people, children and people with preexisting health conditions are more vulnerable (European Environment Agency 2019). In spite of a noticeable decoupling between the increasing of economic activity reflected on Gross Domestic Product (GDP) and the emissions of pollutants is registered in the period 2000-2017, represented in Figure 13, in 2017 the exposure of pollutants was above the limit thresholds defined by WHO.

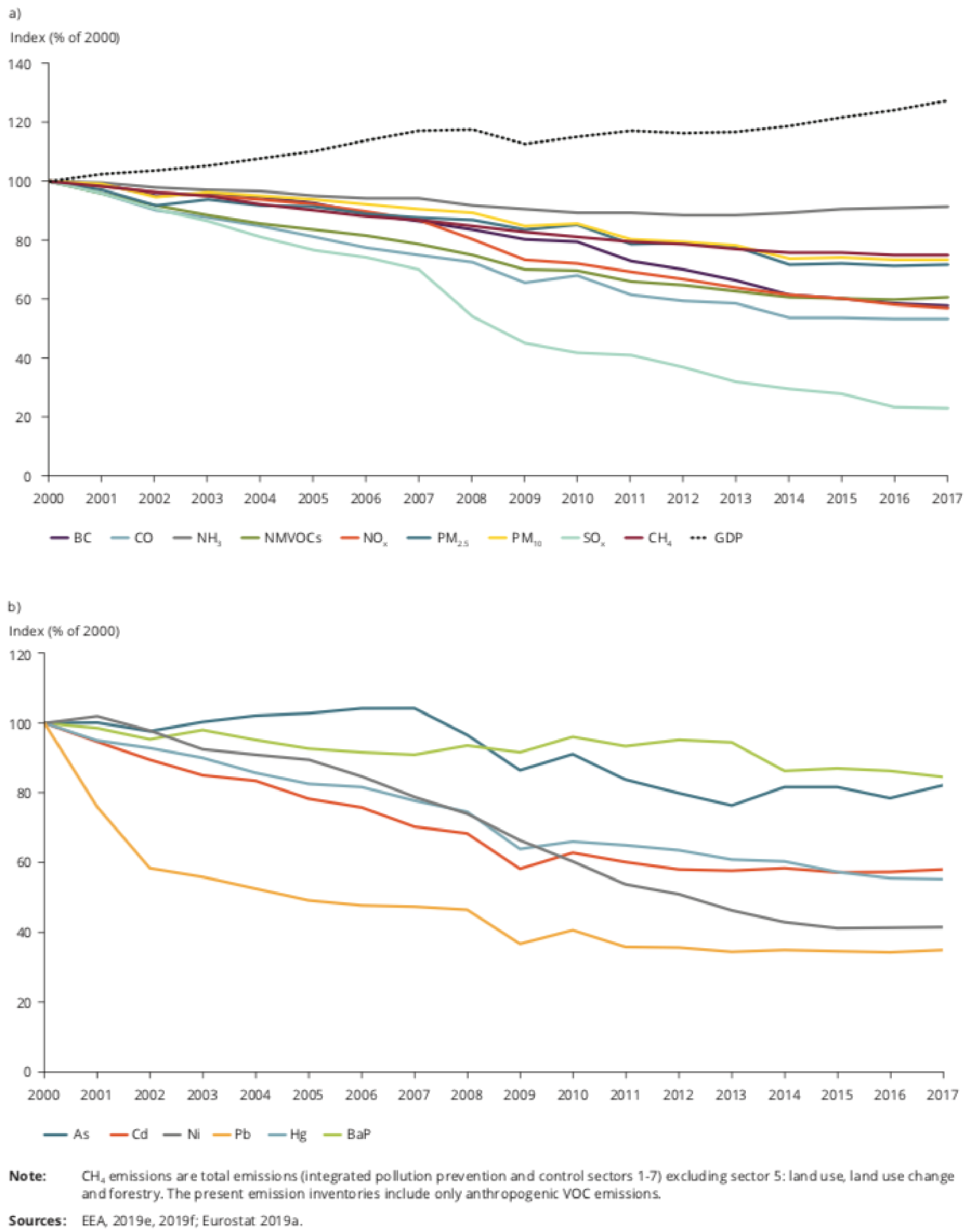
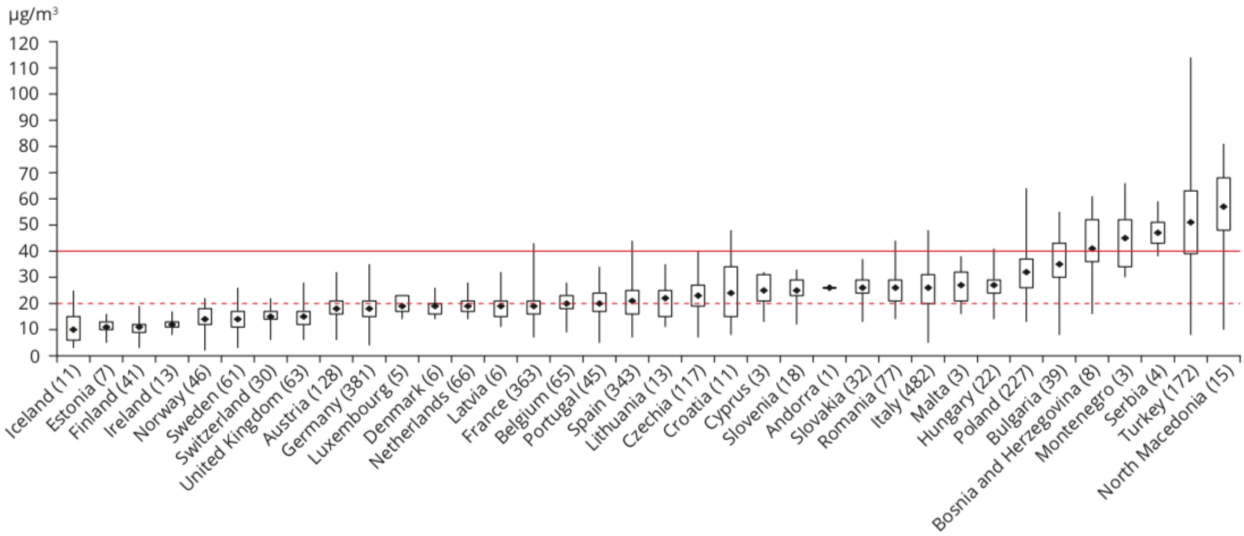


Figure 13 – Trends in EU-28 emissions, 2000-2017 (% of 2000 levels): (a) SOX, NOX, NH3, PM10, PM2.5, NMVOCs, CO, CH4 and BC. Also shown for comparison is EU-28 gross domestic product (GDP, expressed in chain-linked volumes (2010), % of 2000 level); (b) As, Cd, Ni, Pb, Hg and BaP (Image taken from European Environment Agency (2019)*).*

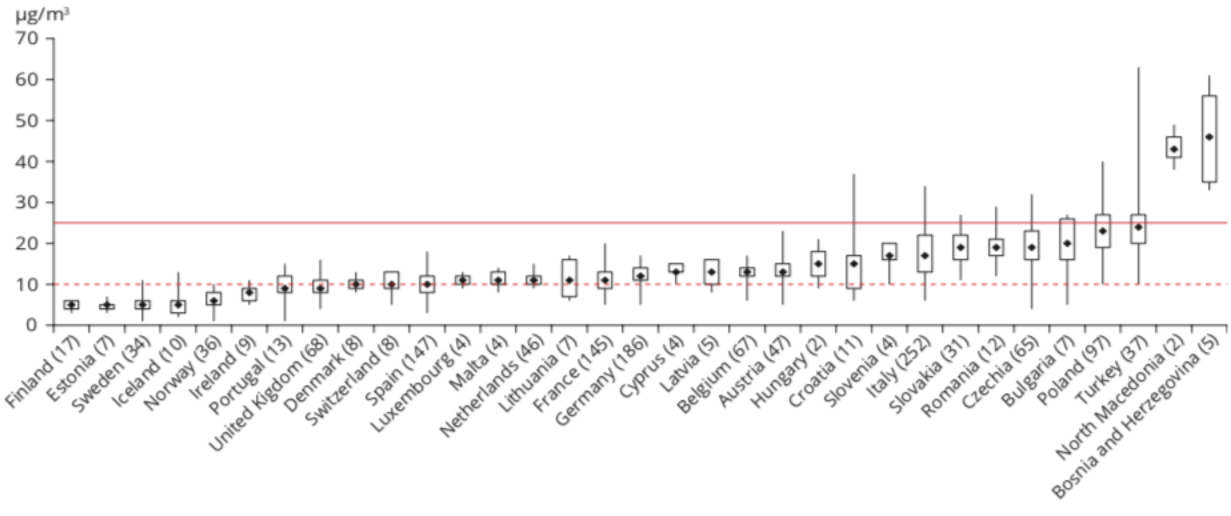
For instance, the concentration of PM_{10} in 2017 was approx. 75% (approx. 21.6 μg/m^3) of the value registered for 2000 (approx. 28.9 μg/m^3). Figure 14 and Figure 15 represent the value of PM_{10} and $PM_{2.5}$ in Europe. Among air pollutants, the Particulate Matter has been classified as carcinogenic by The International Agency for Research on Cancer (IARC 2013).



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The annual limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 3.2, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

Figure 14 – PM_{10} concentrations in relation to the annual limit value in 2017 and number of stations considered for each country (Image taken from the European Environment Agency (2019)*).*



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 3.3, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

Figure 15 – $PM_{2.5}$ concentrations in relation to the annual limit value in 2017 and number of stations considered for each country (Image taken from the European Environment Agency (2019)*).*

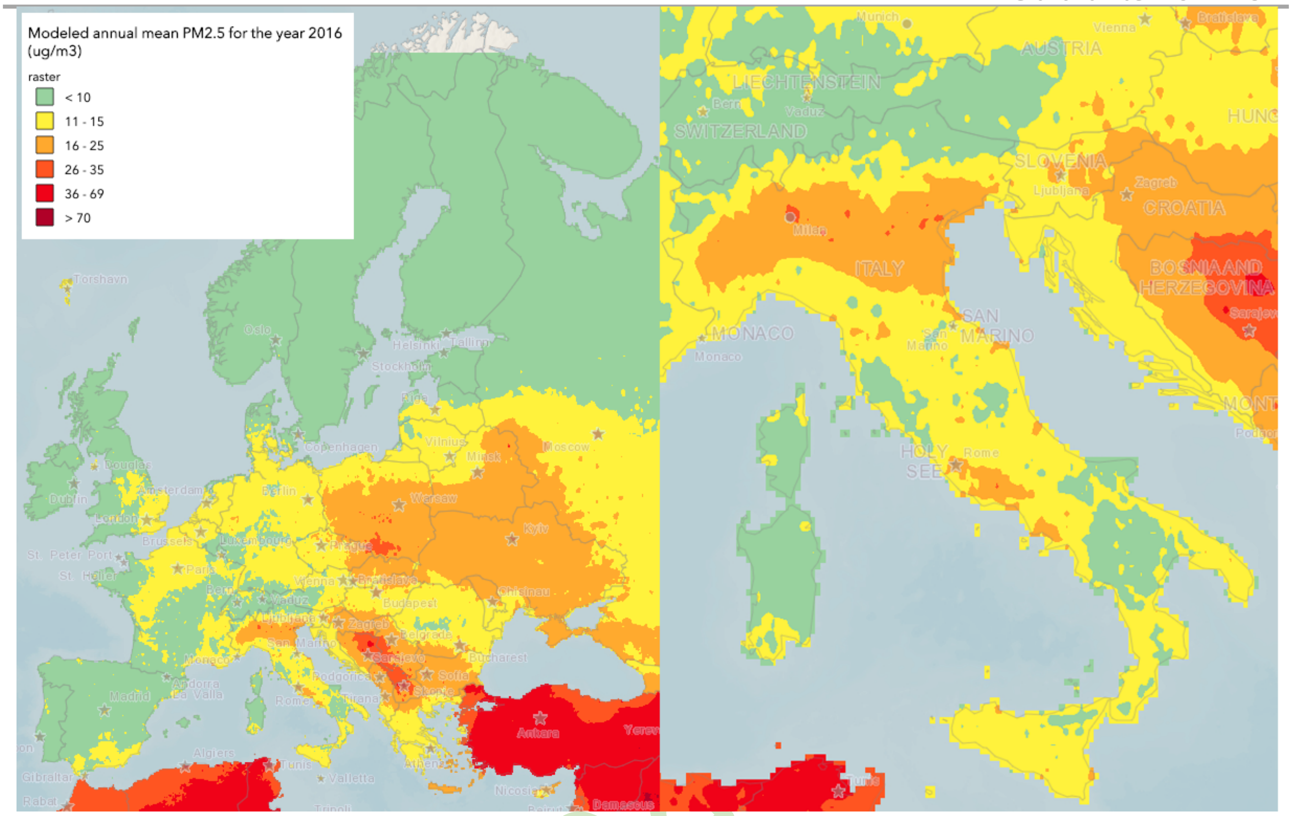


Figure 16 – Mapping of Air pollution in Europe and Italy by means of Modeled annual mean of PM2.5 for the year 2016 (image taken from World Health Organization (2019)).

Figure 16 represents the concentration of one of the most hazardous pollutants in Europe and Italy ($PM_{2.5}$ given its complexity in being captured or filtered). This image shows that Italy is one of the most polluted countries in western Europe. Moreover, the Pianura Padana and the central Italy area (corresponding to the metropolitan area of Rome), are the most polluted places within the national territory. Peaks of >60 µg/m^3 are reached in some cities of northern Italy as Milano, Brescia, Cremona, Verona, Padova and Venezia. This trend is also confirmed considering other pollutants (e.g. PM10) by Legambiente, as shown by the data collected in Figure 17 and Figure 18.

n.	Città	Centralina	Superamenti da gennaio 2018	data aggiornamento
1	Torino	Rebaudengo	87	31/12/2018
2	Frosinone	Frosinone scalo	83	31/12/2018
3	Lodi	Viale Vignati	78	31/12/2018
4	Milano	Marche	74	31/12/2018
5	Venezia	V. Tagliamento	63	31/12/2018
6	Padova	Arcella	60	31/12/2018
7	Alessandria	D'Annunzio	59	31/12/2018
8	Asti	Baussano	57	31/12/2018
9	Reggio Emilia	Timavo	56	31/12/2018
10	Cremona	via Fatebenefratelli	56	31/12/2018
11	Pavia	Piazza Minerva	53	31/12/2018
12	Treviso	S.Agnese	53	31/12/2018
13	Modena	Giardini	51	31/12/2018
14	Monza	via Machiavelli	51	31/12/2018
15	Rovigo	Centro	49	31/12/2018
16	Terni	Le Grazie	49	31/12/2018
17	Vicenza	Quartiere Italia	48	31/12/2018
18	Brescia	Villaggio Sereno	47	31/12/2018
19	Avellino	AV42	46	31/12/2018
20	Parma	Montebello	45	31/12/2018
21	Verona	Borgo Milano	44	31/12/2018
22	Como	Viale Cattaneo	43	31/12/2018
23	Bergamo	via Garibaldi	42	31/12/2018
24	Ferrara	Isonzo	41	31/12/2018
25	Napoli	Ferrovia	37	31/12/2018
26	Rimini	Flaminia	36	31/12/2018

Fonte: elaborazione Legambiente su dati Arpa o Regioni.

Figure 17 – Ranking of the capoluoghi di provincial in Italy that overcame with at least one detection station the PM10 threshold of 50 mg/m3 for one day/yea (Image taken from Legambiente (2019)*).*

Inquinamento atmosferico: le città che hanno superato almeno uno dei limiti giornalieri previsti per il Pm10 o per l'ozono nel 2018

Brescia	150	Genova	103	Vercelli	41
Lodi	149	Avellino	89	Ferrara	41
Monza	140	Lecco	88	Bologna	39
Venezia	139	Terni	86	Trento	38
Alessandria	136	Rimini	82	Udine	37
Milano	135	Vicenza	82	Sondrio	35
Torino	134	Piacenza	80	Pisa	32
Padova	130	Varese	78	Trieste	32
Bergamo	127	Roma	72	Macerata	31
Cremona	127	Napoli	72	Rieti	31
Rovigo	121	Mantova	65	Savona	28
Modena	117	Lucca	61	Aosta	27
Treviso	116	Forlì	48	Benevento	27
Frosinone	116	Firenze	45	Pistoia	27
Pavia	115	Grosseto	44	Agrigento	26
Verona	114	Pordenone	44	Bolzano	26
Asti	113	Como	43	Enna	26
Parma	112	Biella	42		
Reggio Emilia	111	Ravenna	42		

Fonte: elaborazione Legambiente su dati Arpa o Regioni

***NB: in rosso** i giorni totali di superamento delle città in cui si è registrato nel 2018 sia il superamento dei limiti del Pm10 che dell'ozono. **In nero** i giorni di superamento del limite previsto per l'Ozono (25 giorni all'anno); per la città di Ferrara si riportano i giorni di superamento previsti per le polveri sottili (35 giorni all'anno).*

Figure 18 – Cities that overcame at least one of the daily limits for PM_{10} or O_3 (image taken from Legambiente (2019)*).*

4. Built environment characteristics which favor SLOD occurrence or severity

The BE has demonstrated to have an inherent mesoscale environment and dynamism, compared to the urban areas; but also, within the same urban entity, quadrants would behave differently depending on certain factors (Stewart and Oke 2012; Paolini et al. 2014a; Jamei et al. 2016; FULADLU et al. 2018; Colaninno and Morello 2019). These factors can be divided into macro-categories such as:

- Urban fabric materials, density and geometry;
- Greenery location, coverage and density;
- Water bodies location and coverage;
- Degradation of the vegetation, water bodies ecosystem and urban fabric.

To further understand and analyze this mesoscale unicity of the environment within cities, it is important to identify which parameters to address when determining the area's criticality, or the inclination, of a much larger risk of a certain type of SLOD.

4.1. Built environment characteristics

The urban fabric greatly alters the normal functioning of the natural environment. Large constructed volumes modifies the solar energy capture and re-reflection to the environment, changes the wind-flow trajectories and velocities (thus, air, water and particles transport as well), and re-directs sound waves to extend their propagation (Arnfield 2003; Ghiaus et al. 2006; Echevarría Sánchez et al. 2015; Lee and Kang 2015; Salvati et al. 2017). Moreover, constructed surfaces tend to have larger absorption coefficients and lower albedo compared to organic surfaces. All these together stimulate the heat and pollutant entrapment within cities, or the street canyon, contributing to the temperature increase and pollution concentration.

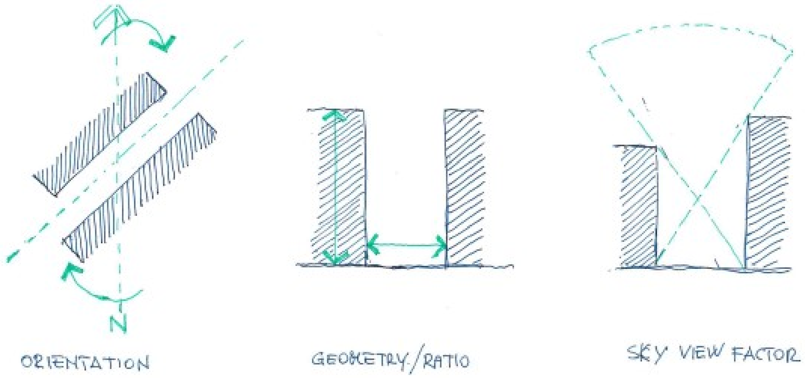


Figure 19 – Building form factor: orientation, high-width ratio, sky view factor (diagram edited by the authors).

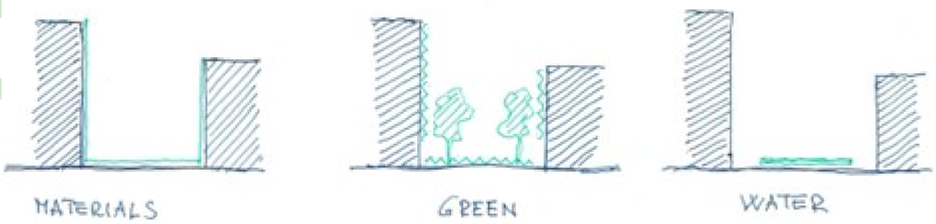


Figure 20 – Building material and natural elements (diagram edited by the authors).

Figure 19 and Figure 20 graphically trace such aspects according to a general schematization approach.

Many authors have concentrated on studying the effects of urban morphology and materiality on environmental conditions that influence the SLOD risk occurrence. Mostly tend to scale down the analysis into the urban canyon shape, and their node link connections (e.g. piazzas, intersections and roundabouts), and the material type coverage. Therefore, these urban spaces types are the focus of the study in the following sections. These elements, in terms of defining metrics (see Figure 21 – Built environment deconstruction and relevant parameters for SLOD. Definition of the BE categories which would modify the SLOD risk by macro-categories, the left-most are the largest (based on the scale); the right-most, are the specific features of the BE that are identified at a localized element and which do not rapidly fluctuate, thus can be identified and measured.), converge on most of the following:

- **Morphology:**
  Figure 19
    - Orientation;
    - height-to-width ratio (H/W);
    - height-to-length ratio (H/L);
    - sky-view factor;
    - façade protrusion length;
    - street-width.
- **Materiality:**
  Figure 20
    - Land-use-land-cover (LULC);
    - albedo (i.e. optical-radiative properties);
    - mass (i.e. thermal capacity and acoustic absorption);
    - permeability (i.e. water, pollution)/porosity;
    - roughness.

4.2. Greenery and water bodies

Green areas and water bodies can mitigate the effects of the increasing temperatures, air pollution and extreme precipitation occurring in the built environment. Concerning the extreme temperatures, green areas and water bodies in the urban environment can contribute to the mitigation of the UHI (Kubilay et al. 2019). The presence of vegetation and water bodies has demonstrated to avoid large temperature shifts between day and night, as well as avoiding such extreme temperature peaks in winter and/or summer (Crum et al. 2017; Santamouris et al. 2018; Wu and Zhang 2019; Colaninno and Morello 2019). Indeed, one of the ways that cities can address the worsen UHI effects is through green and blue infrastructure (GI and BI), e.g. urban forestry (Hewitt et al. 2019). This is due to the tendency of plants to react to changing temperatures, humidity rates and hours of sun, over the seasons and the large thermal capacity of water.
In fact, the mitigation strategies could result in a combination of enhanced nature-based and low impact solutions that can help urban communities to adapt to the effects of climate change, by taking into account the specific urban climates (hot, mild, cold climates), by strategically choosing the appropriate tree and plant according to their seasonality (evergreen/seasonal) and pollutants absorption characteristics.. Trees can naturally provide cooling shade with their foliage by reducing the need for air conditioning (Kara E. Reeve; Ryan Kingston 2014) and helping to remarkably cool the urban air (Doick and Hutchings 2013). However, if they are deciduous species and once the leaves have fallen, they can let the sun radiation heats the BE surfaces in colder weather conditions, whereas the evergreen species guarantee a protection against weathering all year long.

Moreover, the water released from the trees' leaves through evapotranspiration has a cooling effect. The effect of evapotranspiration - the evaporation of water from vegetation and surrounding soils (Desario and Gray 2012)- is minimal in winter because of the absence of leaves on deciduous trees and the lower ambient temperatures. On the other hand, water bodies (e.g., oceans, lakes, rivers and streams) may provide temperature mitigation through the their slow warming-up rate, as water bodies have a greater specific heat capacity compared to other physical objects (Manteghi et al. 2015; Wu and Zhang 2019). Therefore, the influence of green areas in the urban environment depends on a wide variety of factors, such as size and vegetation structure of the green space and their species, season and time of the day, sky obstruction in the built-up and green areas, the prevailing local weather conditions and the climatic zone where the green area is integrated (Oliveira et al. 2011; Yan et al. 2020).
Regarding the air pollution, large trees are excellent filters for urban pollutants and fine particulates. They consume pollutant gases (such as carbon monoxide, nitrogen oxides, ozone and sulfur oxides) and clean the air from fine particulates such as dust, dirt or smoke by trapping them on leaves and bark (FAO 2016).
Besides, all plants use the process of photosynthesis to take carbon dioxide (CO_2) from the air and water from the ground while using the sun radiation (Drahansky et al. 2016). As a matter of fact, the restoration of trees remains among the most effective and accessible strategies for climate change mitigation (Friedlingstein et al. 2019).
Oceans can be considered as large natural "sinks" for CO_2, since they spontaneously absorb a significant fraction of the fossil CO_2 emissions. The carbon capture and mitigation procedures provided by oceans are essentially two:

- CO_2 is diluted, it is dissolved in the deep layers where carbon can be stored for decades to centuries (Rackley 2017).
- The algal growth stimulation through the fertilization of oceans, allows to capture the greenhouse gases in the algal biomass through the chemical reaction of the photosynthesis (Sayre 2010).

In conclusion, the incorporation of living systems into the urban environment can contribute not only in terms of mitigation of the increasing temperatures effect on UHI phenomenon and reduction of the air pollution, but also in noise abatement, improving quality of life, enhancing biodiversity and storm water runoff mitigation. Within the context of this research, the amount and level of soil sealing can play an important role In BE climate regulation and adaptation. Having surfaces and urban elements permeable to water is hence a promising strategy to tackle the issues coming from extreme precipitation events in the cities context (Frantzeskaki et al. 2017).

4.3. Degradation

The degradation of vegetation, water bodies and urban fabric would hamper any of the good effect that these were having to its surrounding. For instance, a decay on vegetation coverage would significantly reduce the capacity to assimilate pollution (Naeem et al. 2018). In addition, a reduced urban fabric reflectance, and, as a consequence, the reduced overall urban area albedo, would inhibit its capacity to deal with excess heat; degraded built surfaces tend to become more porous and bolster the pollutant deposition (Paolini et al. 2014b; Paolini 2015); likewise, sewage infrastructure deterioration, or saturation due to solid waste accumulation, would reduce its capacity to capture and manage storm-water flow becoming more vulnerable to floods (Lamond et al. 2012).

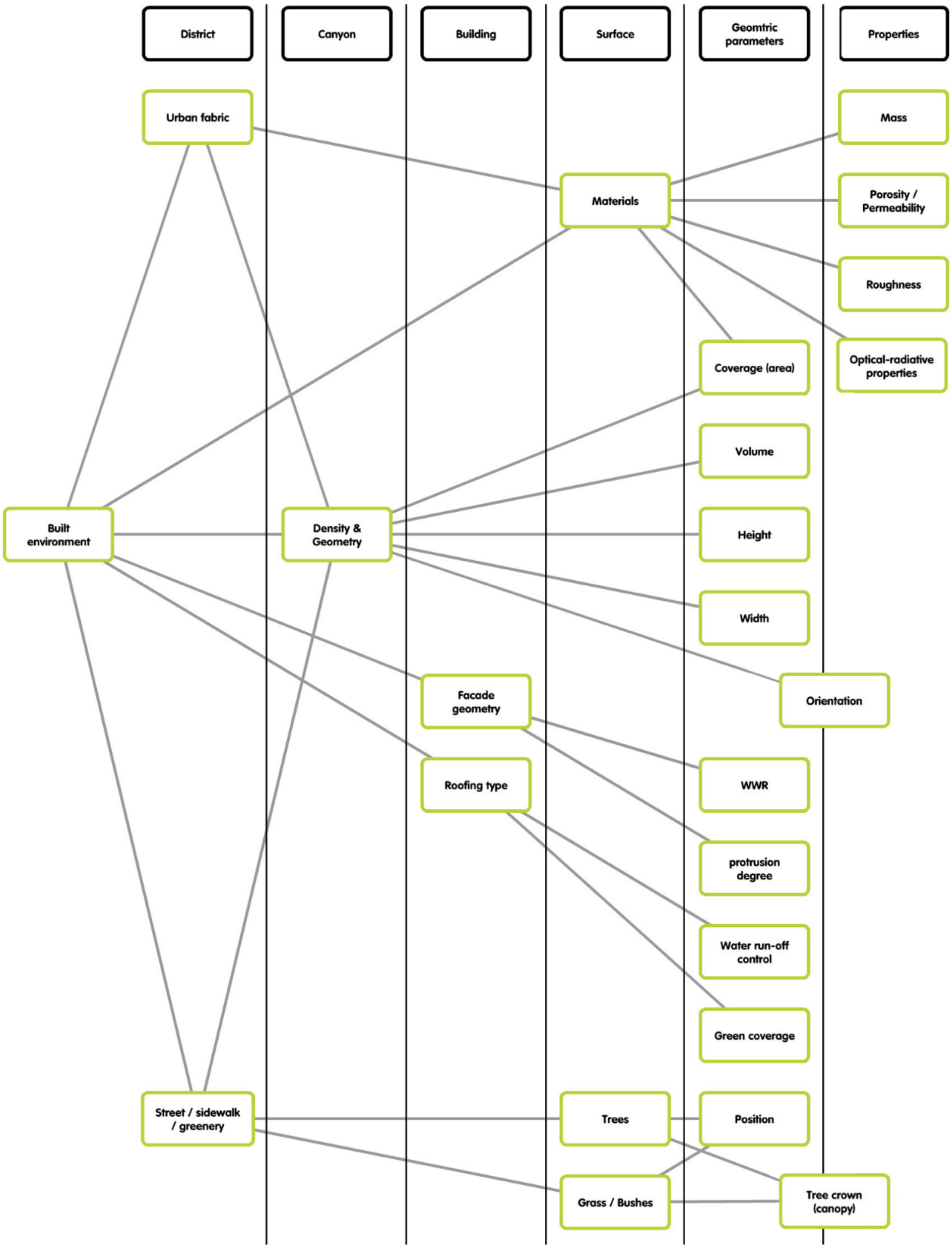


Figure 21 – Built environment deconstruction and relevant parameters for SLOD. Definition of the BE categories which would modify the SLOD risk by macro-categories, the left-most are the largest (based on the scale); the right-most, are the specific features of the BE that are identified at a localized element and which do not rapidly fluctuate, thus can be identified and measured.

5. Criteria for BE Classification according to Building-related typological and SLOD features

The criteria for classifying the main typologies of the BE prone to SLODs (Figure 22) and their severity have been identified after the studies described in the previous paragraphs, and according to D1.1.1 - Section 3.3.2 outcomes. The results are presented in Figure 22, Figure 23 , Table 8, Table 9 and eventually summarized in

Figure 28. The severity of the different configuration of the piazza, Piazzale and urban canyon related to the considered SLODS has been assessed through a qualitative scale from 1 to 3; where 3 represents the highest potential damage to the population. The factors listed in Section 4 combined together with the climate conditions are also considered for determining the severity value. Figure 28 contains an schematic description of the agents relationship which might favor the risk of SLODs, combining the BE, the population actions and vulnerability, and environmental context for generating heat and pollution entrapment and developing health affections.

5.1. Areal BE: the piazza and Piazzale

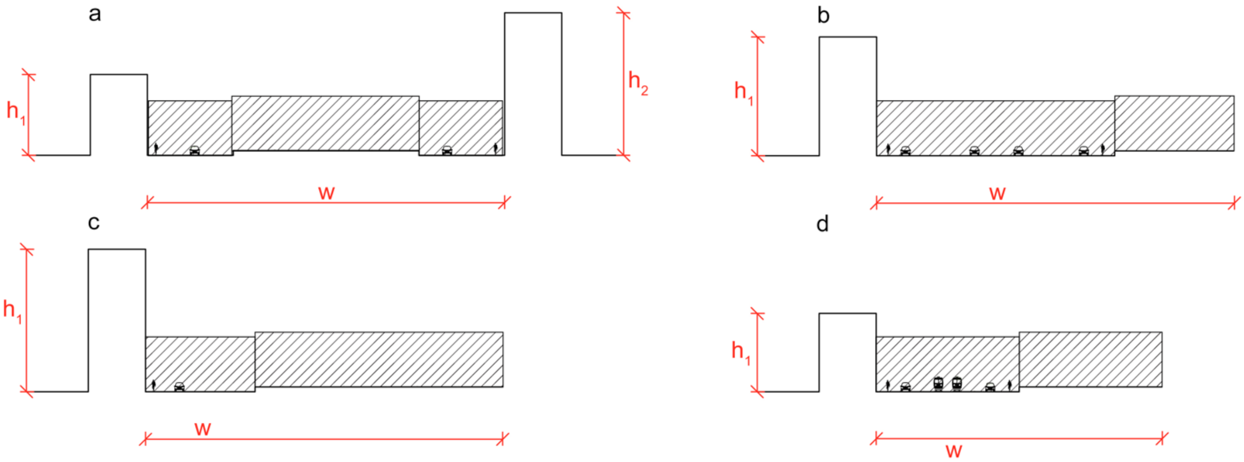


Figure 22 – Type of prone to SLOD Built Environment (BE). The piazza and Piazzale.

Table 8 – Parameters used for the evaluation of the severity of the piazza and Piazzale. The scale goes from 1: no risk severity to 3: high risk severity. I : Irradiance.

BE type	h*/w ratio	Trees presence	Albedo	Main related SLOD	Severity
a) Piazzale	Low				
		On all available area	Low	Accumulation of pollutants	1 (low I) 2 (average I)
		Not present	High	Heat island	2
		On the Piazzale	Average	Accumulation of pollutants	3
		On the streets	Average	Heat island, accumulation of pollutants	2
b) Piazza next to a large street	Very low				
		On all available area	Low	Accumulation of pollutants	1 (low I) 2 (average I)
		Not present	Very high	Heat island	2
		On the Piazza	Average	Accumulation of pollutants	2
		On the streets	High	Heat island, accumulation of pollutants	2
c) Piazza next to a small street	Very low				
		On all available area	Low	Accumulation of pollutants	1 (low I) 2 (average I)
		Not present	Average	Heat island	2 (average I) 3 (high I)
		On the Piazza	Average	Accumulation of pollutants, Heat island	2 (average I) 3 (high I)

BE type	h*/w ratio	Trees presence	Albedo	Main related SLOD	Severity
		On the streets	High	Heat island, accumulation of pollutants	2
d) Piazza next to an average street	Very low				
		On all available area	Low	Accumulation of pollutants	1
		Not present	Very high	Heat island	2
		On the Piazza	Average	Accumulation of pollutants, Heat island	1 (low I) 2 (average I)
		On the streets	High	Heat island, accumulation of pollutants	2

5.2. Linear BE: the urban canyon

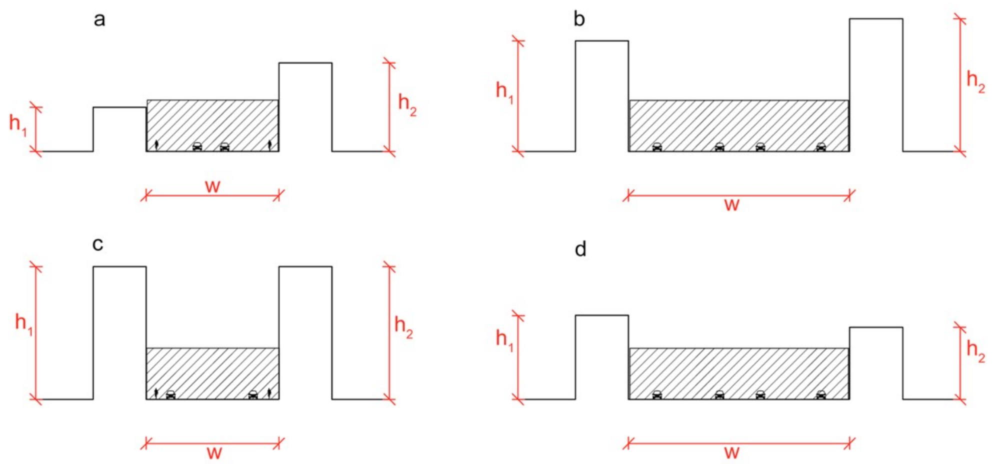


Figure 23 – Type of prone to SLOD Built Environment (BE). The urban canyon.

Table 9 – Parameters used for the evaluation of the severity of the urban canyon. The scale goes from 1: no risk severity to 3: high severity.

BE type	h*/w ratio	Trees presence (green A/tot A)	Albedo	Related SLOD agent	Severity
a) Urban canyon low h, small street	Average/high				
		Yes	Low	Accumulation of pollutants	1 (low I) 2 (average I)
		No	High	Heat island	2 or 3 (high I)
b) Urban canyon high h, large street	Average				
		Yes	Low	Accumulation of pollutants	2
		No	High	Heat island	2 or 3 (high I)
		No	Average	Heat island	3 (high I)
c) Urban canyon high h, small street	High				
		Yes	Average	Accumulation of pollutants	3

BE type	h*/w ratio	Trees presence (green A/tot A)	Albedo	Related SLOD agent	Severity
		No	High	Heat island, Accumulation of pollutants	3+
d) Urban canyon low h, large street	Low				
		Yes	Average	Heat island	2
		No	High	Heat island	3

5.3. An insight on most critical urban canyon types

To demonstrate even further the performance variability of urban spaces, solar radiation analysis and wind tunnel tests were performed for different configuration and orientation of BE units, aided by computer-based simulations. The results have been condensed in Figure 24, Figure 25, and Figure 27. These analyses are mainly to demonstrate the weight that the weather/environmental conditions have on the intensity of the SLOD risk for the population.

Heat concentration

For instance, for a narrow urban canyon (Figure 24), with buildings at different heights, the way their oriented with respect to the sun position will greatly alter the BE surface temperatures providing shade from a side and exposing significantly the opposite area (severity risk 3 for high temperature exposure). Differently for a narrow urban canyon with both sides of considerable height, in which both sides would provide sufficient shade that would allow the pedestrians to avoid such higher short-wave radiation direct exposure which would increase their overall body temperature (risk severity 1) (Zani et al. 2018); nevertheless, during mid-day hours these BE typology would escalate to risk severity 3 for a clear sky, under high radiation, given that the radiation would penetrate even when the *sky view factor* is low and the proximity to high BE surface temperatures would intensify the heat exchange by radiation (Al-hafith et al. 2019), as shown by Figure 26.
On the other hand, the risk severity of a rather wide urban canyon (e.g. “Piazza”, “Piazzale”, Figure 25) will highly depend on the irradiance conditions, the BE albedo and the presence of green structures as shadings. All sun radiation will strike the surface and the heat management capacity, thus, the risk severity, would depend on the BE materiality mentioned in Section 254.
In addition, the wind velocity cooling capacity would only be favored in rather wide urban canyons; the wind speed is largely diminished by rough and low air-permeable elements (green structures included), as shown by Figure 27.

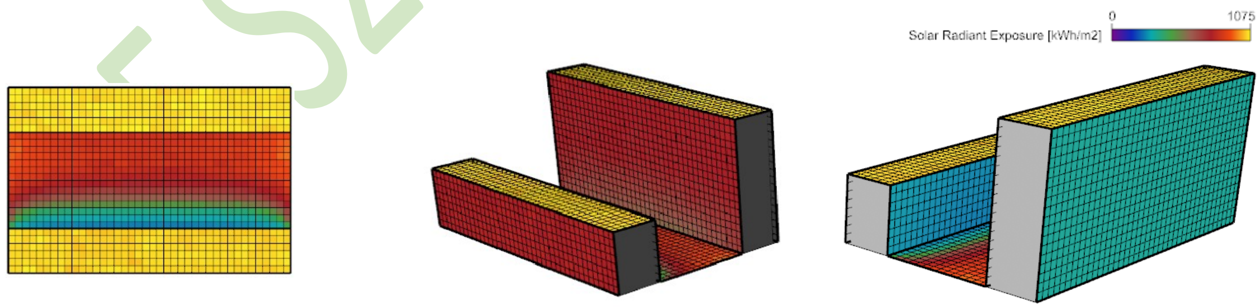
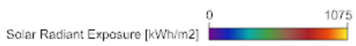


Figure 24 – Urban canyon type a. Canyon orientation East/West, with the tall building at north.



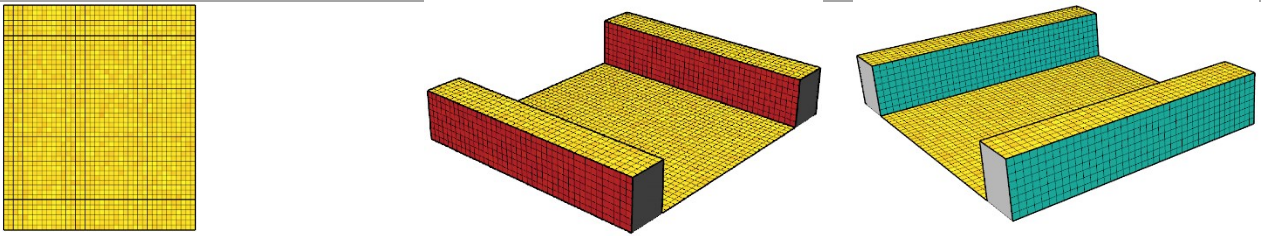
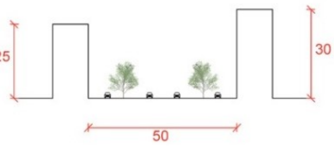


Figure 25 – Urban canyon type d. Canyon orientation North/South. Buildings have both low heights.

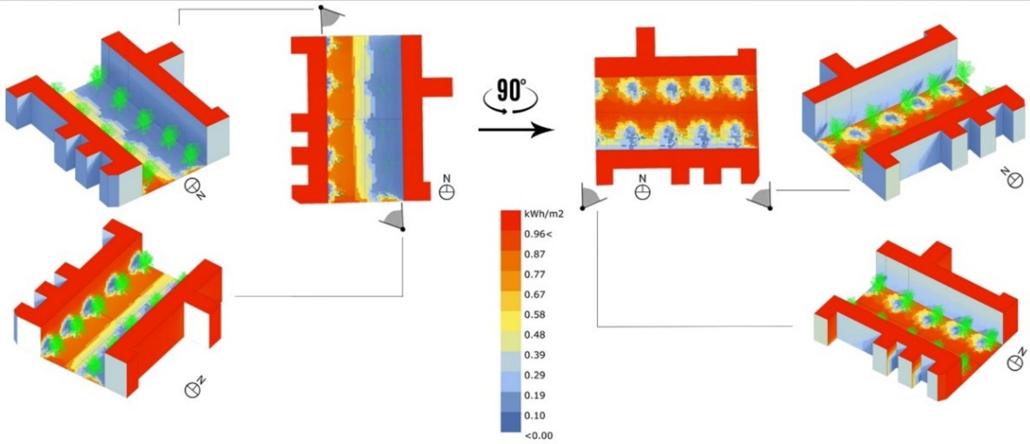
Solar radiation studies

Dimensions of the urban section analized

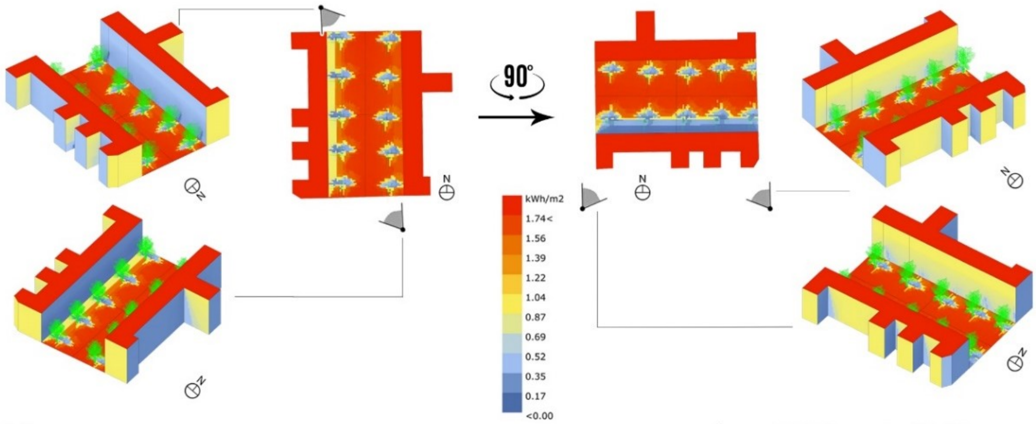


Average h/w = 0.55

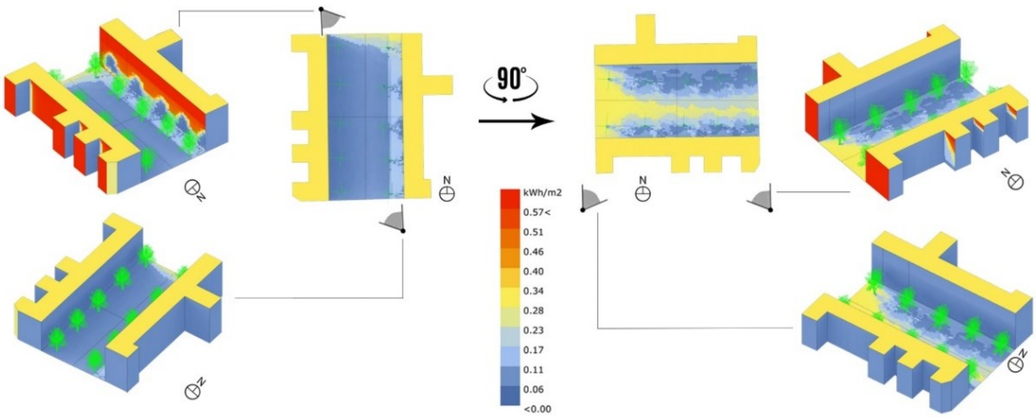
21 June **from 8:00 am to 9:00 am**



21 June **from 12:00 am to 13:00 pm**

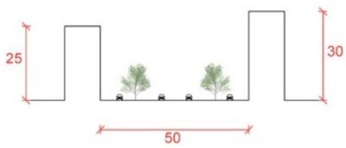


21 June **from 18:00 am to 19:00 pm**



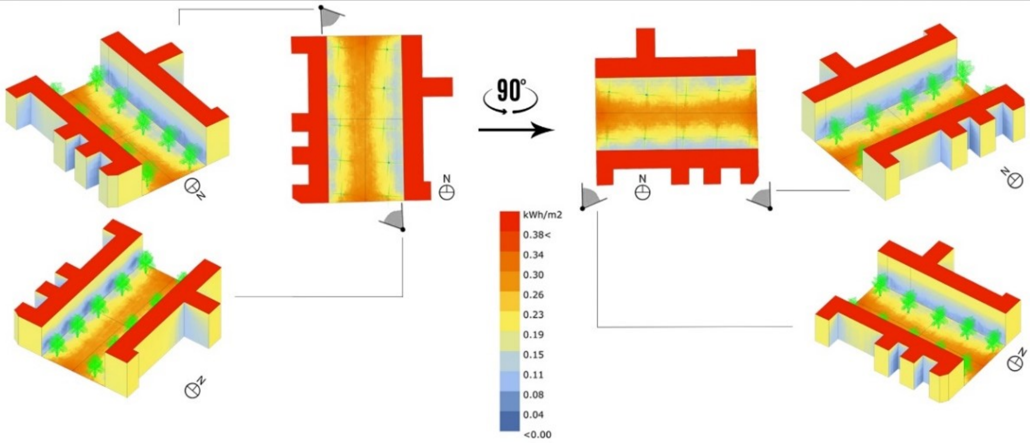
Solar radiation studies

Dimensions of the urban section analized

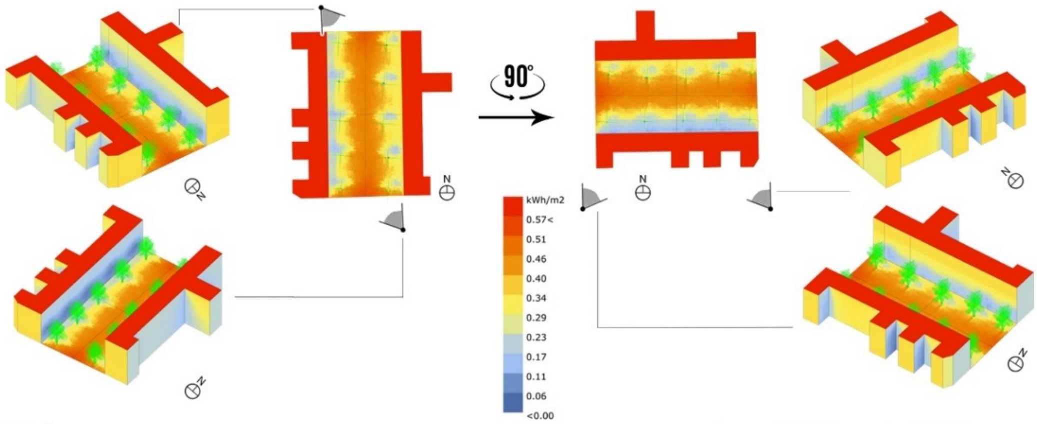


Average h/w = 0.55

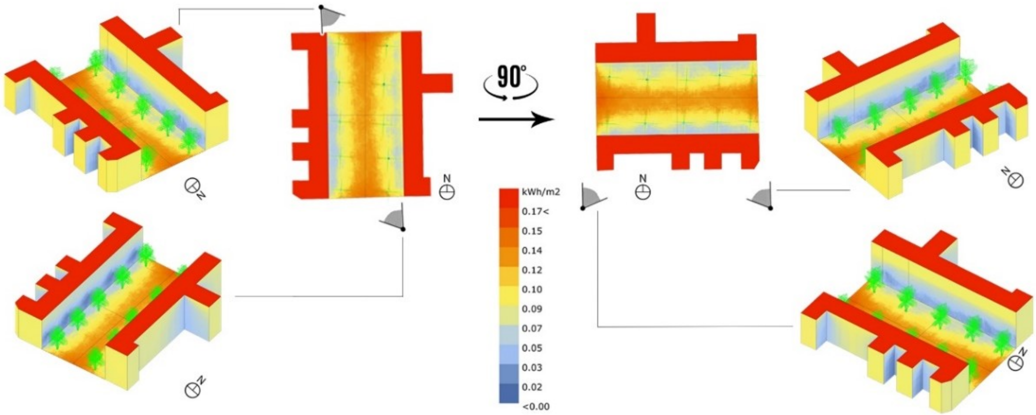
21 July from 8:00 am to 9:00 am



21 July from 12:00 am to 13:00 pm



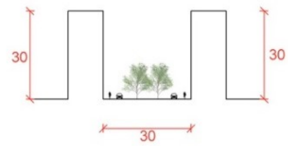
21 July from 18:00 am to 19:00 pm



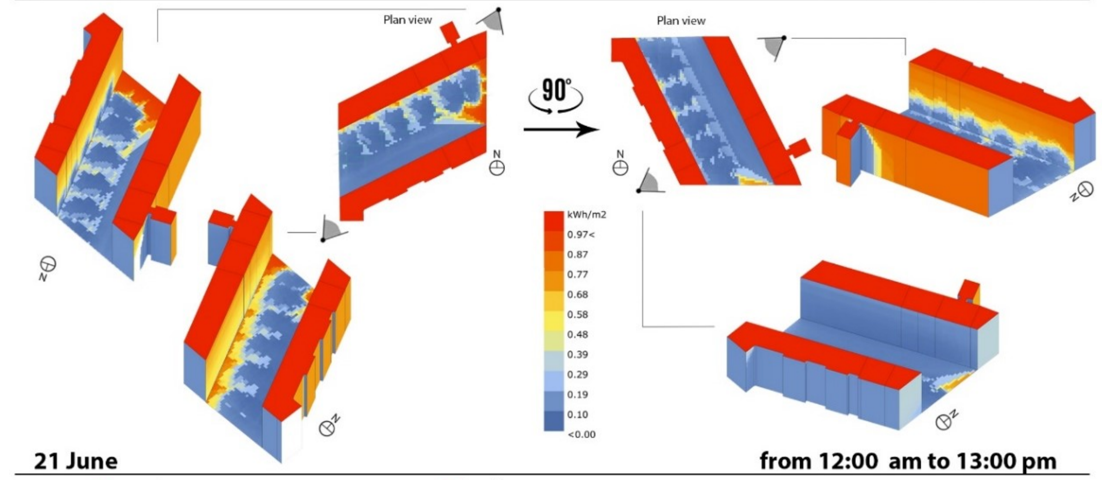
Solar radiation studies

Average h/w = 1

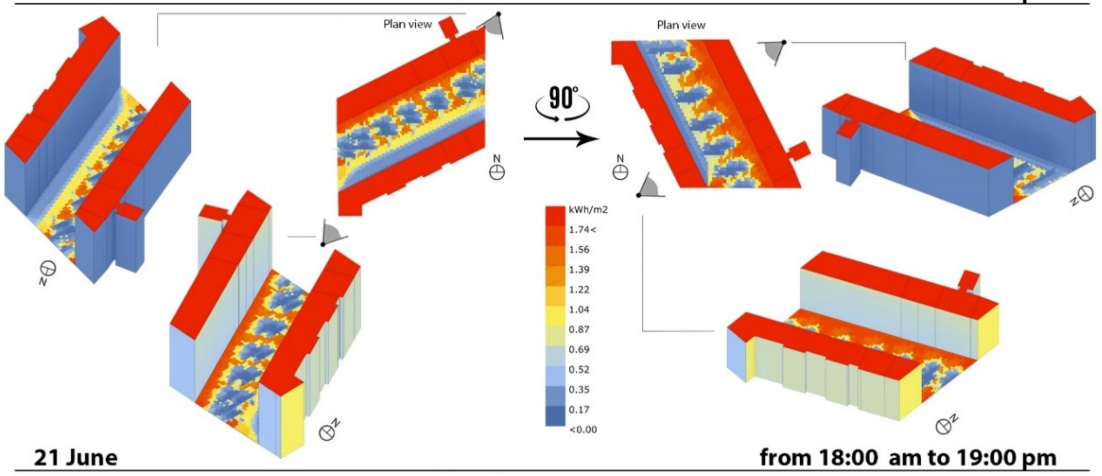
Dimensions of the urban section analized



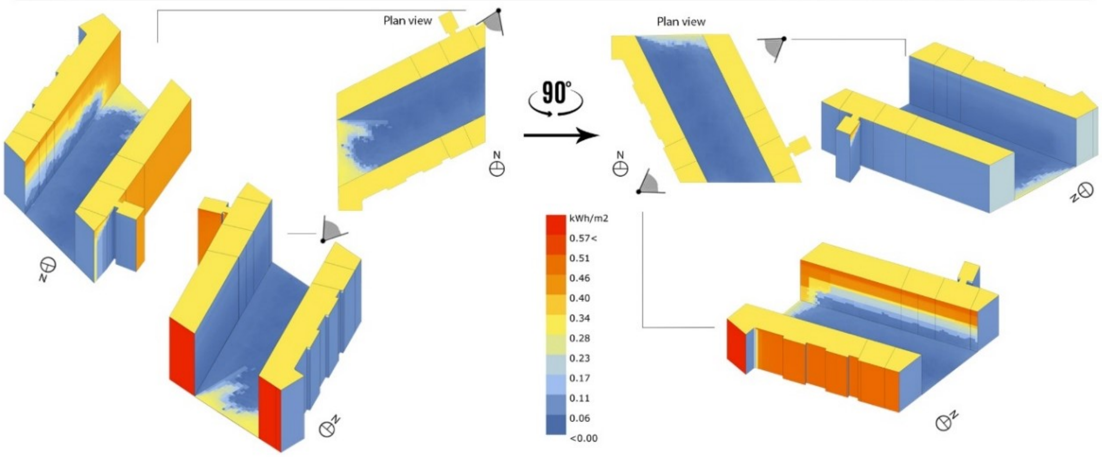
21 June **from 8:00 am to 9:00 am**



21 June **from 12:00 am to 13:00 pm**



21 June **from 18:00 am to 19:00 pm**



Solar radiation studies

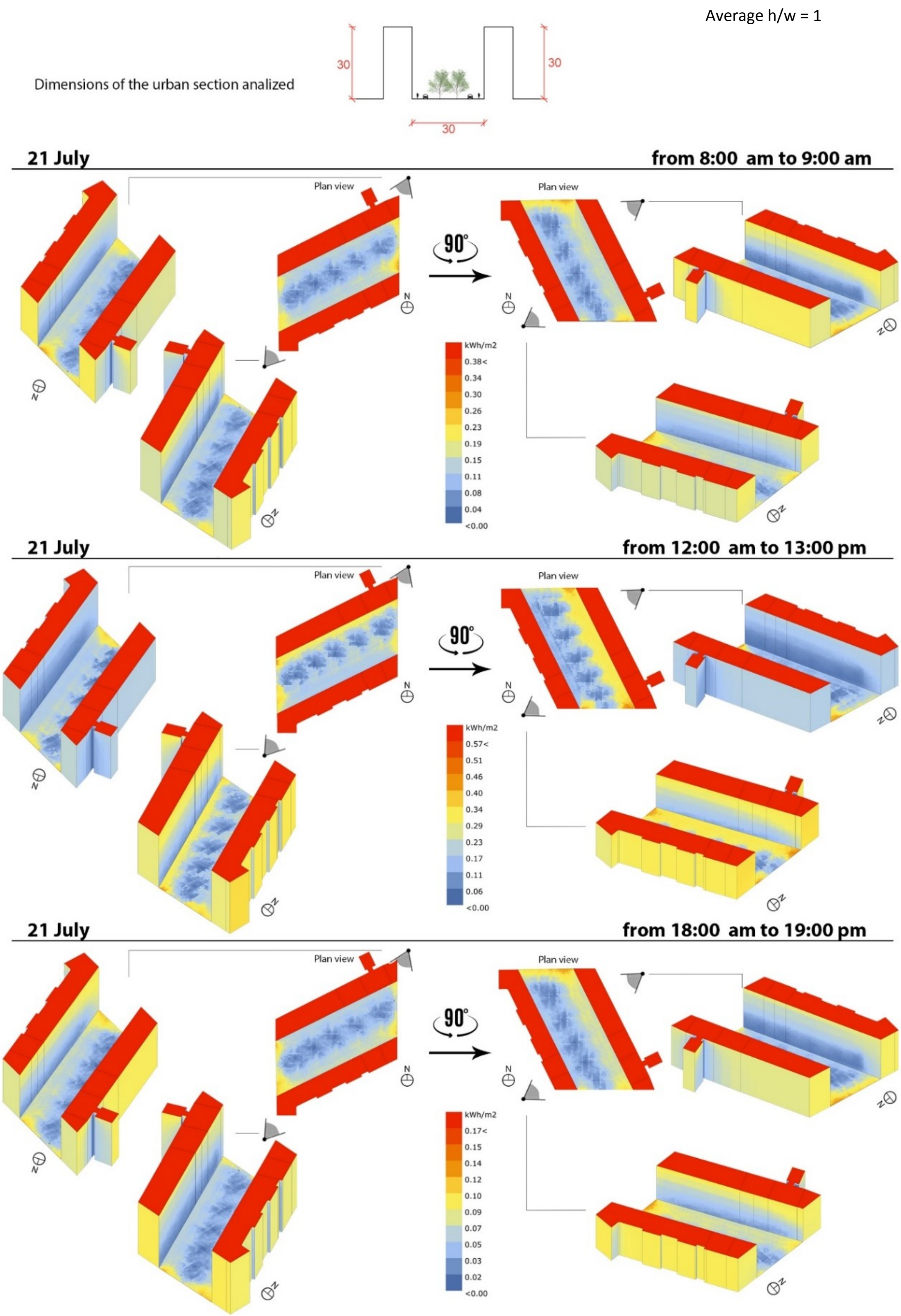
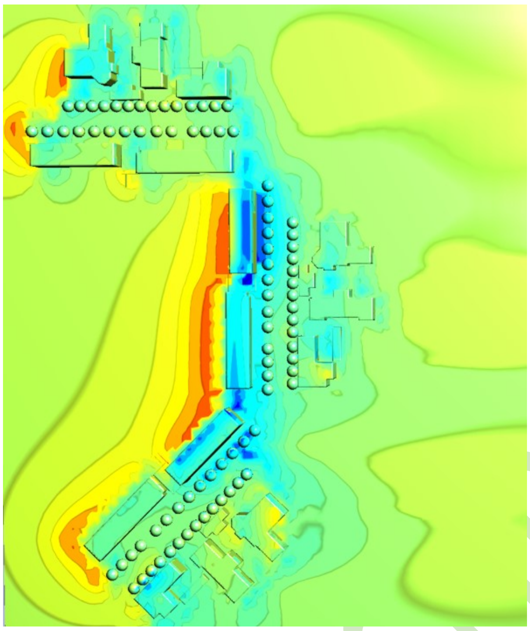


Figure 26 – Simulation of Irradiance falling on the urban canyon, with different configurations and orientations, at different moments of the year

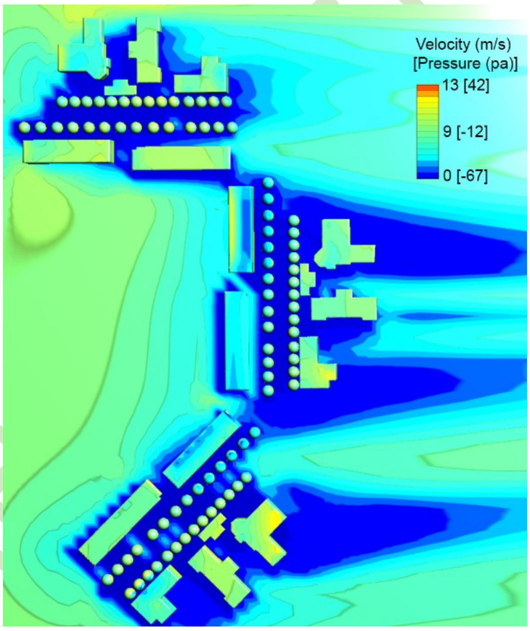
Air pollution concentration

Air movement within the BE would determine the way the pollutants are transported from the source. Hence, understanding their dynamics, together with the presence of green structures or water bodies (see Section 4.4.2), becomes key to approximately determine the pollution absorption or concentration. As mentioned above, the wind velocity is reduced by rough and low air-permeable elements, especially if these items are placed perpendicular to the wind direction see Figure 27.

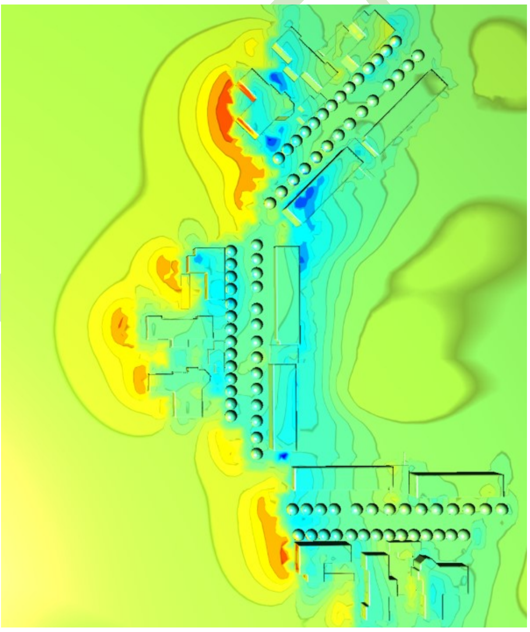
The lower is the wind speed, the lower is the pollutants transportation/movement, thus, the lower is their dilution. For example, Figure 27.b, Figure 27.f and Figure 27.g are clear examples in which the pollution emitted by traffic would probably remain (severity risk 3), given the obtained lower wind velocities.



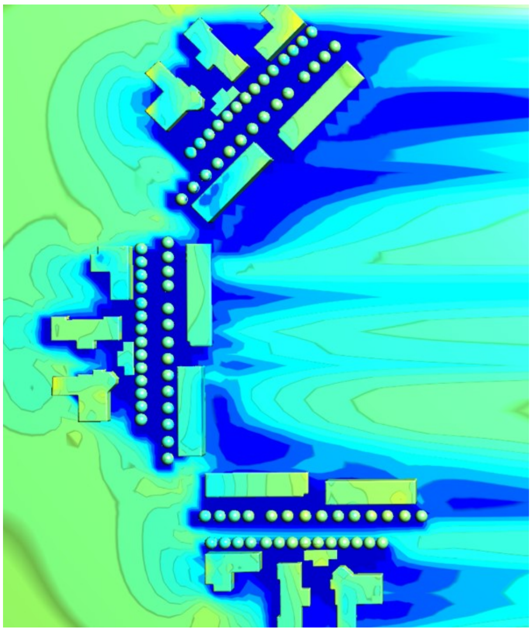
(a) High-low buildings – On-Surface values



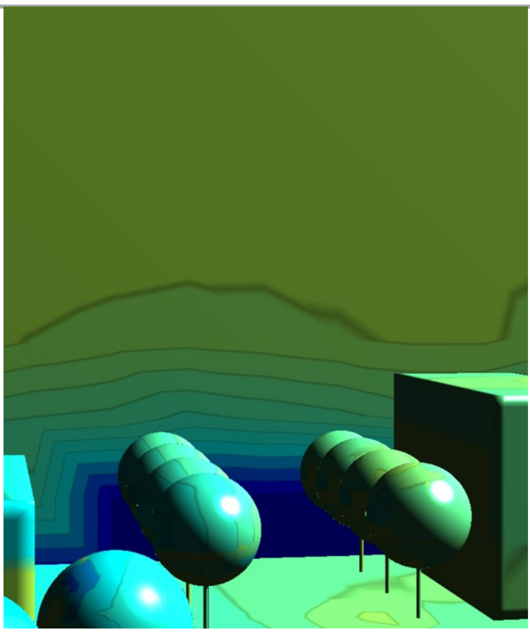
(b) High-low buildings – Values at pedestrian level

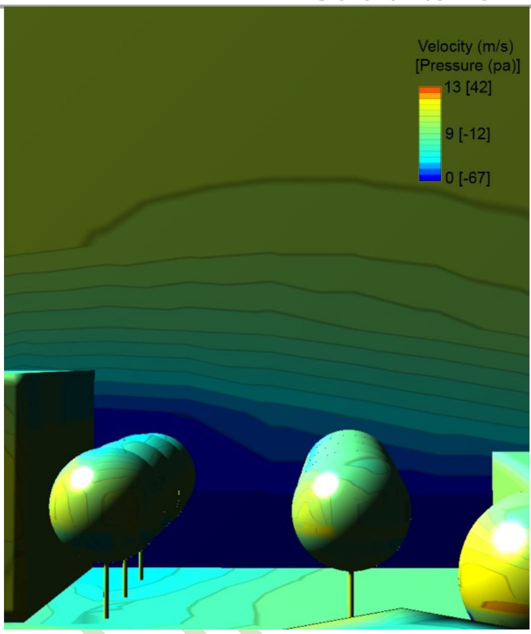


(c) Low-high buildings – On-Surface values

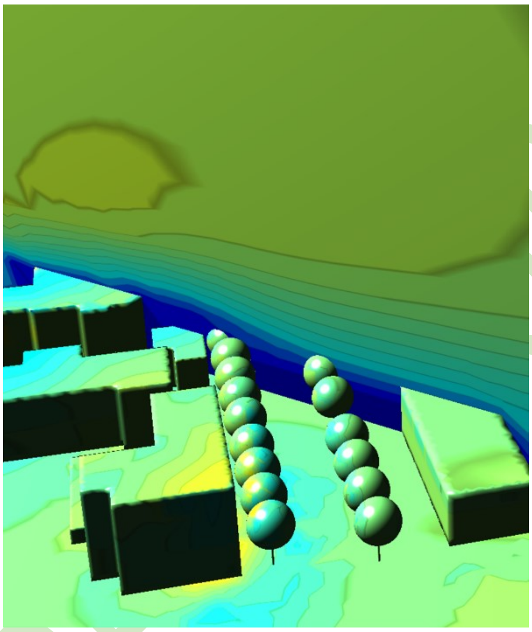


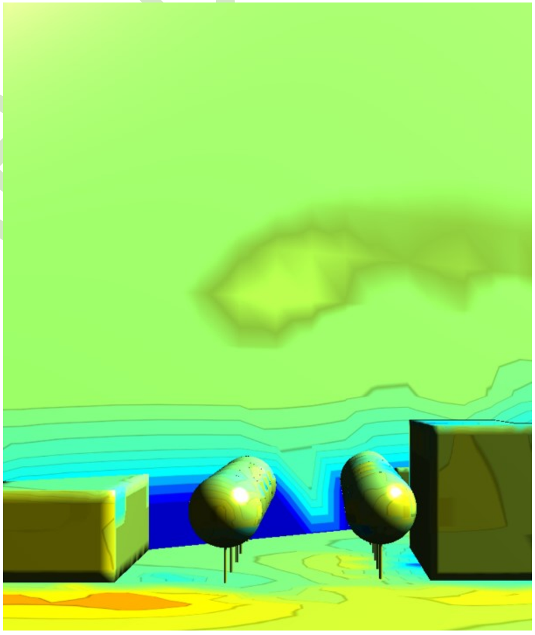
(d) Low-high buildings – Values at pedestrian level

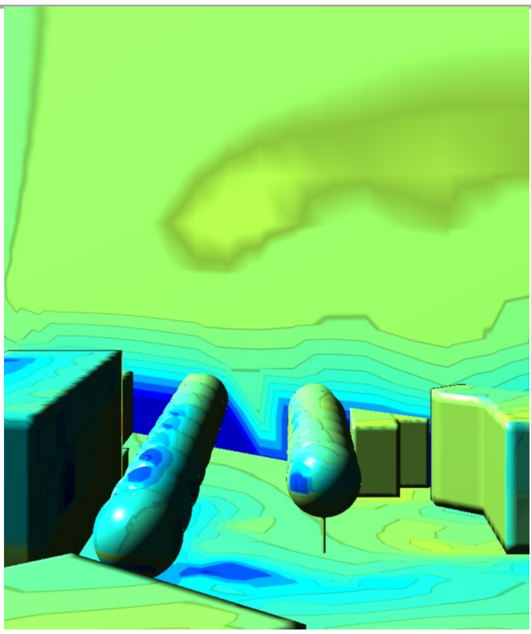

(e) Low-high buildings – wind profile transversal flow



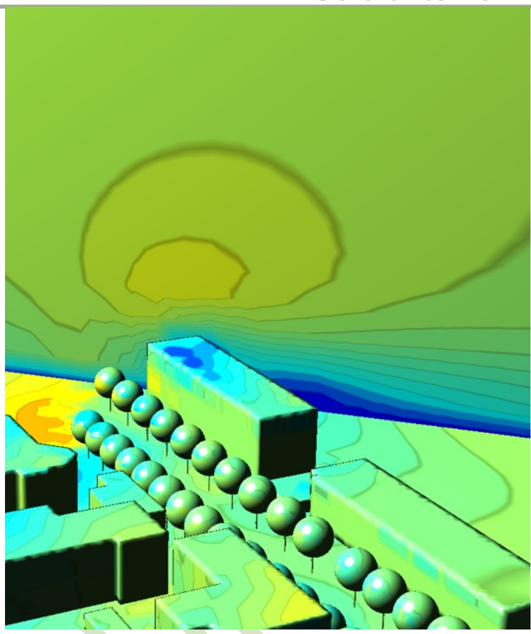
(f) High-low buildings – wind profile transversal flow


(g) High-low buildings – wind profile 45° flow


(h) Low-high buildings – wind profile 45° flow



(i) High-high buildings – wind profile 45° flow



(j) High-high buildings – wind profile 45° flow

Figure 27 - Urban canyon wind behavior, with 10 m/s wind speed blowing from left to right.

6. Conclusions

There has been substantial proof of the effect of the urban fabric on the development of SLODs and their harmful effects on the people that live within, and on those ones which frequently interact within. The best way to assess this issue is to identify the SLODs which can generate the largest impact and the parameters and variables that govern the mechanisms generating the poor environmental conditions within the BE, as it has been performed in this work.
After these parameters have been identified, it is possible to estimate the potential risk of SLODs for the inhabitants in a certain portion of the city by collecting information on these parameters along the city space. In particular, the identification of the scenarios for facing the highest severity conditions, highlighted in Section **Errore. L'origine riferimento non è stata trovata.** should be a priority.

Hence, the following remarks can be highlighted:

- From what has been described in Section 3 and Table 2, progressive *increasing temperatures* and degeneration of *air quality and air pollution* increase were identified as the most critical SLODs.
- The main actors which are involved within these SLODs risk are (Figure 28):
  - The population and its susceptibility.
  - The environmental and inherent conditions or features of the context.
  - The characteristics defining the built environment.
- The parameters governing the problem can be grouped in different macro-categories depending on the scale in which the risk-assessment analysis is performed. Nevertheless, the most representative groups, and differentiated by the 3 elements that compose risk are:
  - **Exposure**
    - Frequency of exposure.
    - Built environment density, coverage of green areas and water bodies.
  - **Hazard**
    - Environmental conditions.
    - Heat and pollution concentration.

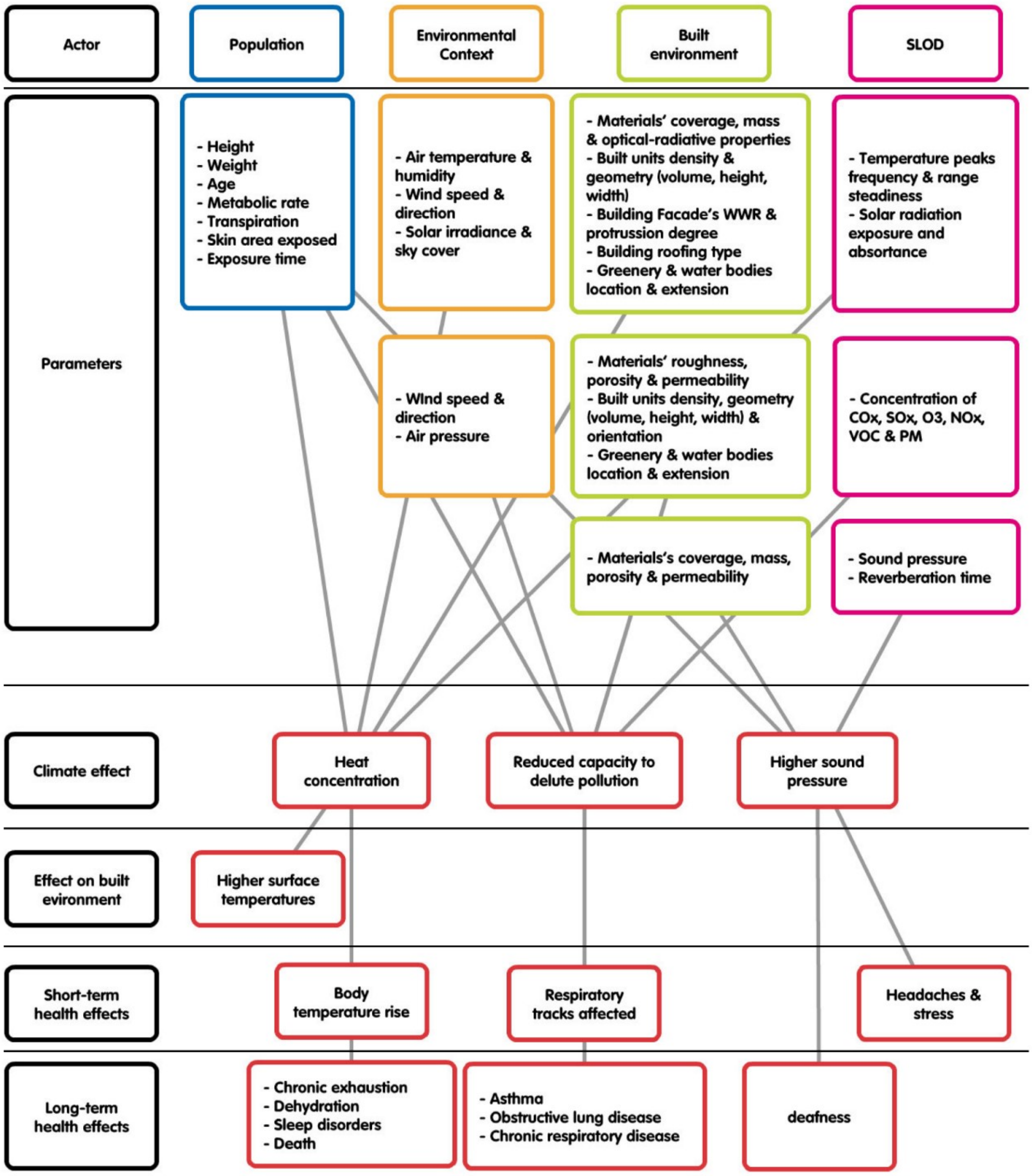


Figure 28 – Schematic description of the force's relationship involved in SLODs development, which might favor their risk, including the potential effects on the climate, the BE and the health of the BE's population.

- **Vulnerability**
  - Susceptible population.
  - Severity of built environment scenario.

- The built environment scenarios which are more prone to expose their hosts (people) to SLODs risk are those which promote Heat and pollution concentration; due to their low capacity to deal with heat absorption and rejection, in addition to a poor performance on pollutant absorption or dilution. Scenarios such as *(a) and (c)* in *Piazza and Piazzale,* or most of the *urban canyons* can reach severity 3 (Section **Errore. L'origine riferimento non è stata trovata.**). Therefore, these will be the archetypes of scope for the following steps of the project.

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