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Master Thesis

Integrating thermal comfort into traffic calming objectives: a proposal for a street redesign strategy in the face of rising summer temperatures

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Abstract

Urban areas are particularly vulnerable to the effects of climate change, and they are experiencing increasingly frequent and intense extreme events, such as summer hot waves. The work focuses on the relationship between this phenomenon and the use of public spaces, with particular attention to urban streets. In order to allow suitable conditions for the use of such spaces, design strategies should address multiple issues such as safety and social functions, as well as thermal comfort. The thesis aims at studying an integrated approach of street design combining the goals of traffic calming strategies and thermal comfort solutions, and testing this strategy on a case study in the city of Turin. The theoretical framework is composed by four parts. The first part describes the role and functions of urban streets. An overview of the evolution of street design is proposed, from the approach characterising the second half of the last century, to the models aiming at an integration between the functions of "link" and "place". The second part of the theoretical framework focuses on the concept of traffic calming, as a tool to improve safety, allowing a better coexistence of social functions with mobility needs, with a focus on the Italian approach. The third part provides a definition and the main characteristics of urban microclimate, and the relationships with climate change. The section illustrates the concept of thermal comfort and the tools described by the literature to improve this condition for the users of urban spaces. The last part aims at finding a synergy between traffic calming strategies and thermal comfort solutions. An approach aiming at combining the goals of the two components is defined, by stressing its potential benefits and its limitations. The project component of the work proposes a scheme for redesigning a few streets, aiming at improving safety and at increasing the provision of space for multiple social and mobility functions. In the definition of the design strategies, the concept of thermal comfort is central, in order to favour the use of space in a context of rising temperatures. The application and the evaluation of the measures aiming at this objective are supported by the use of simulations conducted through the software "ENVI-met", with the analysis of a series of parameters affecting the conditions for a pedestrian using the space. Therefore, a first simulation was performed with the goal of analysing the perception of thermal comfort in the current state. The interpretation of its results highlighted the main critical elements and needs in terms of thermal comfort, in order to guide the design strategies with the goal of a synergy with the component of traffic calming. The project consisted in the elaboration of scenarios of transformation, integrating the multiple functions of the street with different degrees of priority, by applying in all cases solutions for the improvement of thermal comfort. The integration of the constraints related to different components, especially linked with dimensioning requirements according to the norms in force, highlighted the synergies and conflictual elements between the uses of space, and the necessity for trade-offs in the determination of a solution. Finally, the scenario allowing a maximisation of the needs for thermal comfort was selected for a second simulation, aimed at evaluating the effectiveness of the strategies adopted.

Contents

1. Introduction

In his book “Life between buildings”, Jan Gehl (2011) draws the attention to the importance that open spaces and streets have for the social life of an urban area, highlighting the relationship between the quality of outdoor spaces and the activities taking place within them. According to his theory, these activities can be categorised in “necessary”, which cannot be avoided due to the reasons at their origin, such as school or work, “optional”, which are not compulsory, and “social”, linked with the presence of other people or resulting from the other two categories. While the use of public spaces in the first case takes place regardless of outdoor conditions, in the two other cases it is strictly influenced by them, meaning that more intense activities can occur if a favourable setting is provided to users, while a use limited to the strictly essential needs characterises spaces of low quality. Therefore, the action of planners and designers becomes crucial in the provision of urban spaces of high quality, determining one of the conditions favouring the development of outdoor activities, as demonstrated by Gehl (2011), and contributing to the incremental process characterising the use of public spaces, according to which the presence of users works as an attracting element for an increase of activities and for additional users of the space.

A design action of public spaces, therefore, can be considered as a key element for a condition of comfort, which is determinant for the intensity and the modalities with which outdoor activities take place. The role of designers, hence, should take into account multiple factors influencing comfort, as well as the multiple uses of public spaces. In particular, if the attention is focused on urban streets, considering them as a typology of public space, a high level of complexity can be highlighted, given by its function of accommodating both uses linked with mobility, as well as functions related to the social sphere. Each of these functions can be analysed as a group of different interrelated activities, often coexisting on the same surface: while a clear difference can be observed between the characteristics of vehicular and pedestrian traffic, the behaviour of pedestrians on an urban street does not only consist in a movement to reach a destination, but it can consist of interactions as well as of actions such as sitting or standing, as analysed by Gehl (2011). Simultaneously, the interactions can be seen as an activity per se rather than a part of a displacement, constituting one of the optional or social activities described, but they are necessarily influenced by the presence of other functions characterising space. The action of the designer should therefore tackle this complexity, by addressing the conflicts which generate between functions due to the scarcity of space in urban area, with different solutions, ranging for example from a separation, allocating a specific portion of space to each function and ensuring that interactions are limited, to an integration, allowing therefore multiple uses on the same shared surface.

On top of the decisions on the strategies to divide and organise space between the functions, the action of the designer should aim at creating a space of high quality, which, as mentioned previously, provides good conditions for the intended activities, as well as constituting an attracting factor for potential additional uses and functions. In the context of this thesis, the concept of comfort is introduced for this purpose, encompassing a multiplicity of factors, from the perspective of a pedestrian. Already Gehl (2011) draws the attention on a range of technical elements determining suitable conditions for pedestrian uses, detailing specific elements of design. The present work focuses in particular on two aspects constituting part of the quality of a street from this perspective: the measures addressing the relationship with vehicular traffic, by studying and applying the concept of traffic calming, as well as the solutions for thermal comfort, allowing a continuity for the uses characterising the street even facing unfavourable climate conditions. These aspects have a particular importance in the contemporary context, as the theoretical framework describes: the effects of climate change are particularly important on urban areas, with specific attention to rising temperatures, and they affect therefore the conditions of use of their spaces. Simultaneously, the public spaces constituting current cities are often the result of a design approach which has characterised the second half of the last century, centred on the ease of vehicular traffic, with scarce attention to other modes of mobility as well as to other uses, and, most importantly, with an inefficient use of space, which, in urban areas, constitutes a scarce resource. Hence, the proposed design action provides opportunities to address both issues, by integrating, therefore, the objective of an improvement of thermal comfort in public spaces into a complex strategy for an efficient and more equitable redistribution of space between the uses of a street. The proposal of a design strategy allows to observe the interaction between its components, as well as between the functions of the street. Each need for an improvement of the quality of a street is related to specific requirements, allowing to achieve the intended objectives or to comply with sectorial regulations, in some cases conflicting with the standards characterizing other components of planning. The purpose of an integrated approach derives from the necessity to explore the relationships between these requirements, by maximizing the synergies and by finding suitable solutions to address the conflicts.

Hence, the research question of the present thesis is the following: “How can thermal comfort objectives be integrated into a traffic calming strategy on an urban street?”

The present work derives from the activity of internship at the Company Decisio s.r.l., which took place between April and July 2023. The internship was integrated in the activities of the company for the technical-economic feasibility study of the projects “Assi Ciclabili” and “Quartieri resilienti” for the Municipality of Turin. Part of the analysis and of the proposal are taken in consideration in this thesis, as a starting point for the development of the project phase.

2. Theoretical framework

2.1. The functions of street space

2.1.1. A space for motorised mobility

Public spaces are an essential feature of urban areas, characterising the urban fabric, but also with an importance in terms of social life, environmental issues, as well as constituting the context for multiple urban functions and characterising local identity. In this context, urban streets constitute a peculiar typology of public space, given a particularly high degree of coexistence of functions, which have to interact with the one of mobility (von Schönefeld and Bertolini, 2017). This interaction has evolved through time according to the changes in mobility technologies and behaviours, and often it has been conflictual, due to the limited availability of space in the urban context (von Schönefeld and Bertolini, 2017). The use and physical configuration of space in urban streets reflects the organisation which derives from the importance given to each function in a specific time context (Karndacharuk et al., 2014), allocating the amount and typology of space considered to be suitable for the different functions, limiting or regulating the possible conflicts between them. Considering the important and rapid changes in mobility through time, the design of urban streets has gone through phases of transformation according to the increased necessity of space to accommodate mobility needs, as well as to the aim of reducing conflicts between the function of connection and the other pre-existing functions characterising urban public spaces.

The current spatial configuration of urban streets often derives from the approach characterising design strategies for urban spaces starting from the second half of the XX century, with the increase of motorised mobility. In the previous centuries a specific regulated allocation of street space to different functions was not necessary, with the different users sharing the same surface (Jayakody et al., 2018). Due to a new condition of affordability, an increase in number of private cars began to characterise urban spaces starting from the 1940s in the UK and USA (Karndacharuk et al., 2014) and in some countries of western Europe since the 1950s (Jones et al., 2008), resulting in a necessity to adapt them to this phenomenon. The characterising approach was the design of urban spaces according to the needs of the increasing vehicular traffic, privileging fluidity and speed, providing to the function of connection the main priority, while the other social functions, as well as the other modes of transportation, resulted to have a secondary importance (Bertolini, 2020). Therefore, important transformations involved the redesign of urban streets, with the objective of channelling vehicular flows as a main priority, meaning that all the necessary space was allocated to this function, providing to the other functions the remaining portions of space, or moving them to secondary urban axes, where the mobility needs would not require increased space (Jones et al., 2008).

Considering the importance of traffic flows and the characteristics of motorised vehicles, the design had to address the conflicts with the other users of the street, as well as the necessity to provide an adequate space for the other urban functions, affected by the negative consequences of traffic on the urban arterials, in terms of safety, liveability and comfort. The principle which prevailed in this context was the one of segregation (Hamilton-Baillie, 2008), which consisted in a rational organisation of urban spaces, by strictly designating portions of the street space to specific users, in order to reduce negative conflicts and to eliminate obstacles to the free flow of traffic (von Schönefeld and Bertolini, 2017). The effects of this approach provoked important transformations on urban public spaces, as illustrated by Jones et al. (2008): while the newly planned areas according to the segregation principles increased urban sprawl, by enhancing the use of private car, the interventions to adapt the existing fabric and infrastructure to the needs of motorised traffic resulted in insufficient and low-quality space, as well as an increase of barriers for pedestrians, a general reduction in quality and safety of urban spaces, and an inadequate space for other urban functions. To these elements, the effects of an increase of traffic in urban areas can be cited, such as problems linked to air pollution and street safety (Hamilton-Baillie, 2008).

Figure 1. Segregation of space favouring vehicular traffic led to insufficient space for pedestrians (https://www.bikeitalia.it/2021/05/05/condividere-lo-spazio-pubblico-diamo-strada-alle-persone/)

The transformations of urban areas according to this principle were often extremely relevant, in terms of physical modification of space as well as in terms of cost, since they required the extension or the construction of imposing infrastructures through urban areas, often by erasing portions of the existing urban fabric and the complex of relations related to it (Socco, 2009). Moreover, the creation of additional space for traffic resulted to be counterproductive, due to the phenomenon of induced mobility, caused by the growth of traffic generated by the increased infrastructural offer, induced by the need to adapt to the growing demand (Socco, 2009).

Figure 2. Construction of urban highways in Boston, through the existing urban fabric (Socco, 2009)

2.1.2. The character of place and the safety goals

A model, which was strictly related to the logic of segregation but which aimed at limiting the impacts of motorised traffic by imposing limitations, is the logic of specialisation of urban axes through the assignment of a specific traffic function, by differentiating the streets with a function of access from those with a function of circulation, according to the influential Buchanan Report “Traffic in Towns”, the 1963 document by the British Ministry of Transport (Biddulph, 2003). The model is strictly linked with the concept of neighbourhood unit, which was first developed at the beginning of the XX century, by developing differently according to the contexts of application (Socco, 2009), and it is based on the definition of urban areas as a group of residential units, with some degrees of self-sufficiency, for example due to an adequate provision of services which allows local residents to remain in the neighbourhood for daily activities (Socco, 2009).

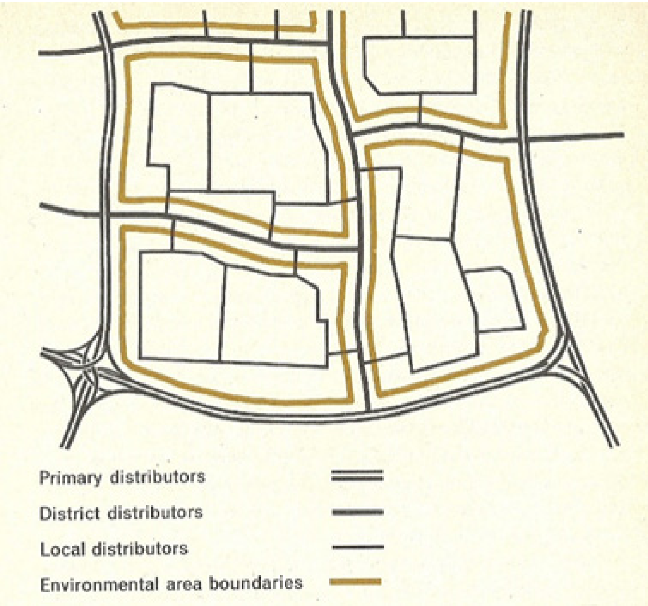


Figure 3. Example of a model of street hierarchy according to the Buchanan report. Between the primary axes for through traffic and the local access axes, an intermediate level is added as neighbourhood distributors (Buchanan, 1963)

From the point of view of mobility, the application of this concept reinforces the definition of the road systems in two levels, according to the principle that main axes are aimed at crossing urban areas, privileging speed and directedness, while local streets are reserved for displacements with its origin or destination in the neighbourhood unit, where through traffic is impeded (Socco, 2009). This model constituted a guide starting from the 60s for the planning of urban areas and for the adaptation of existing cities, not only with the aim of accommodating increasing traffic flows, but also with the goal of improving the environmental and social conditions of urban areas (Socco, 2009).

The distinction of different functional requirements mostly developed by the Buchanan report for the two typologies of street allowed to observe a first distinction of functions among streets, distinguishing axes with a "mobility" function and axes with an "access" function (Karndacharuk et al., 2014). Despite the introduction of a multifunctionality of the street system, this conception remains within the concept of segregation and maintains the focus on vehicular traffic. Criticisms to this approach have emerged through time (Bertolini, 2020), by challenging its focus on the objective of functionality, while attributing a minor importance to other functions of streets, such as the ones involving the social sphere, reducing the multifaceted importance of urban streets to the single function of allocation of traffic flows, characterising them as "links rather than a locus" (Biddulph, 2003, p. 218). This focus can be attributed to the professional category mostly involved in the field of street design, the one of traffic engineers, whose objective has been characterised by the functional requirements and standards of vehicular traffic (Jones et al., 2008), while an increased integration with other fields, such as planners, landscape architects or professionals involved in the social field would have highlighted other street uses (Hamilton-Baillie, 2004). The criticisms against the hegemony of traffic on urban streets mainly advocate for a different use of space, through an action of balancing which can take

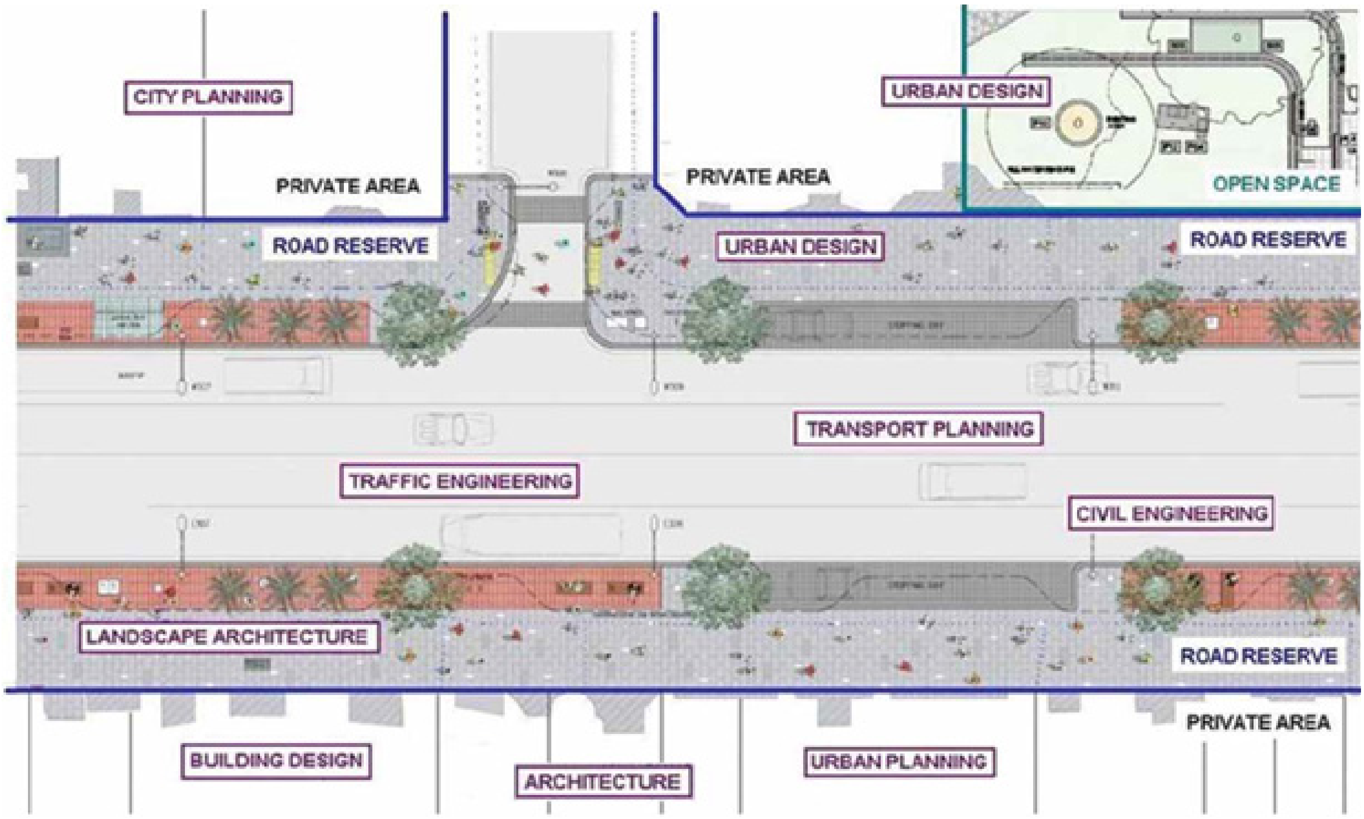


Figure 4. Relationship between street functions and professional competences related with street design (Karndacharuk et al., 2014)

into account two main issues: the necessity for a shift in mobility patterns from the private car towards alternative mobility modes and the recognition that other functions belong to the street and therefore they should be provided with a sufficient space, both in terms of quality and quantity (Jones et al., 2008). This approach allows to consider the street not only as a "link", a channel of mobility privileging rapidity and directedness of connections, but also as "place", a destination where multiple activities characterising urban space can happen (Jones et al., 2008), which leads to define a street as a «tree-function system» (Karndacharuk et al., 2013, p. 2). The recognition of these aspects, therefore, is linked to a different methodology in the planning and design of urban streets, taking into account multiple needs, and abandoning the hierarchical model based on the function of connection. According to Jones et al. (2008), the balance between the two components is a decision which should be taken from the first phase of planning to the design one, and it can be supported by a detailed method. Since the two aspects refer to different characteristics,

Figure 5. The tree-function system defining urban streets (Karndacharuk et al., 2013)

a measurement of the two functions follows different criteria and it refers to the field of different professional categories, the "link" function being prevalently measured through quantitative engineering aspects, and the "place" function being mostly characterised by qualitative aspects and the work of multiple disciplines (Jones et al., 2008), characterising the project for an urban street in the first place as a project of urban planning (Socco, 2009).

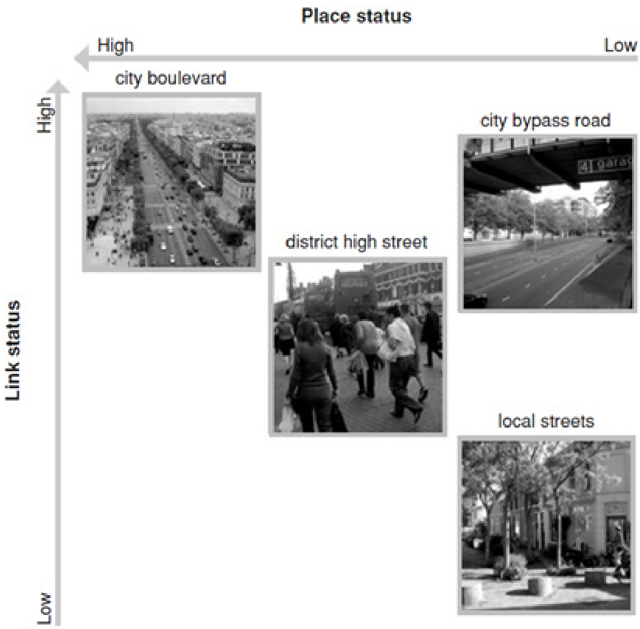


Figure 6. Degrees of interaction between Link and Place functions of urban streets (Jones et al., 2008)

Starting from the idea that the two aspects should not be complementary, meaning that a street can simultaneously have a high importance for both, the value that the plan aims at attributing to each of the two functions on a selected street should be evaluated based on an analysis regarding aspects such as the land use or higher-scale mobility decisions (Jones et al., 2008). The decision on the balance between the two functions supports the choices in terms of spatial configuration of the proposed design. In this context, a key requirement for the allocation of space of the street is the one of safety, considering how the multiple functions are often conflicting, measures should be taken in consideration in order to allow their coexistence, regulating the conflicts through different approaches: after the dominance of the segregation, alternative methods emerged, aiming at the opposite goal of integration between the different users and functions, ranging until the approach of sharing space, with limited delimitations between users (Karndacharuk et al., 2014).

2.2. Traffic calming for safety and social functions

2.2.1 Traffic calming

As mentioned, the dimension of street safety is fundamental in contributing to the goal of integration between the different functions of the street, allowing a peaceful coexistence between motorised vehicles and the other users of the space, through different techniques regulating their behaviour (Pharoah, 1993). This group of techniques can be included within the policies of traffic calming, comprehending tools with the main objective of improving street safety, reducing vehicular traffic speeds and therefore limiting the number of accidents (Department of Transport, 2007), but it emerged as a wider reaction to the increase of car traffic and its negative impacts on the urban condition (Zalewski et al., 2021). Literature links the origins of traffic calming to the context of the increase of motorisation of the second half of the XX century, in particular leading to an increase of vehicles on urban roads and traffic congestion

(Kjemtrup and Herrstedt, 1992): the difficult shortcuts through residential areas, resulting in disruptions for local life. While in some contexts actions of road closures were considered as obstructions for emergency vehicles, one of the first examples of traffic calming is recognised to be the woonerf experiment in Delft, in the Netherlands, in 1968. The action, led by local residents together with the planner Joost Vahl, aimed at reducing through traffic and external vehicles through a neighbourhood by rethinking the street space, by increasing its character of a space for living, where social activities could take place with the use of urban furniture and with a design allowing all users to share the same space, forcing drivers to change their behaviour or to avoid such streets.

Figure 7. Example of a modern woonerf in Delft (https://rue-avenir.ch/themes/quartiers-sans-voitures/pays-bas/delft/)

Following this example, starting from the 1970s, numerous measures started to spread throughout Europe, as applications of shared space, or through tools enforcing a speed reduction (Kjemtrup and Herrsted, 1992), also including measures which can be effective without requiring a complete and more expensive redesign of the street (Harvey, 1992). In particular, in Germany came the realisation that this kind of measures should be applied through a broader-scale planning phase applied to a specific area, in order to avoid that an intervention on a single street would divert traffic on other axes (Bunte, 2000). With German applications, moreover, the term "traffic calming" was coined, which is underlined by Brindle (1991) to express the concept of impose a change of behaviour to drivers rather than the complete elimination of vehicular traffic on an axis. With the evolutions of the concept, multiple terms have emerged, such as the common "Environmental traffic calming" (Brindle, 1991). The literature proposes multiple definitions of the concept of traffic calming, which vary according to the objective they focus on: aiming at encompassing most of them, Pharoah and Russel (1991, p. 80), define it as «the attempt to achieve calm, safe and environmentally improved conditions on streets», or, alternatively, it can be defined as «the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour, and improve conditions for non-motorized street users» (Pennsylvania Department of Transportation, 2012, p.3). As stated, the different definitions reflect a multiplicity of goals this group of policies is used to address, the improvement of street safety is often the main one, although some authors (Brindle, 1991) discuss the term not only in terms of means to achieve a goal, but as a goal itself. The tool can be used in order to improve different urban aspects (Ambros et al, 2023; Bunte, 2000; Juhász and Koren, 2016; Pharoah, 1993; Pharoah and Russel, 1991):

- Reduction of traffic speed
- Reduction of cut-through traffic
- Improvement of accessibility for non-motorised users
- Improvement of accessibility for non-motorised users
- Reduction of noise pollution
- Reduction of air pollution
- Promotion of alternative forms of mobility, such as cycling, walking or public transport
- Improvement of the accessibility to local activities
- Improvement of the attractivity of public spaces
- Promotion of local economy
- Promotion of social equity

Pharoah and Russel (1991) stress the relevance of the different objectives in each project. While speed reduction can be the main reason for the installation of traffic calming elements, induced improvements can be observed on other fields, for example due to the benefits on noise and air pollution resulting from slower traffic.

Further distinction within the objectives abovementioned is provided by classifications of tools according to the typology of impact they have on traffic, resulting in a variety of instruments, considering also the long-lasting evolution in different geographical contexts of the concept: traffic calming is considered to be an «organizational, civil engineering, and legal solution» (Kempa, 2019, p. 2), therefore with a different type of action on the space and on the behaviour of drivers. Due to the differences related to the geographical contexts of application or research, there are multiple definitions and classification systems which may overlap or differ. First, Kjemtrup and Herrstedt (1992) define a distinction between "traffic calming", aiming at reducing the accessibility for vehicles, and "speed management", working on the regulation of vehicular speed, in order to reduce accidents. The first one, defined as "traffic management" by Pharoah and Russel (1991), or "volume control" by Bunte (2000) and Vanderschuren and Jobanputra (2009), rather than being specifically focused on the issue of safety, is related to the broader conception of the environment of the street and its set of functions. To these, the category of "safety enhancement" can be added, consisting in measures aiming at increasing visibility of space for weaker users (SCRCG, 2008). Bunte (2000) states how the tools can be differentiated between "passive or soft" and "active", the first ones being mostly constituted by non-physical measures aiming at encouraging or enforcing suitable behaviours, or actions such as traffic signs or road markings, the second ones consisting in physical redesign of the street space. Similarly, Chimba and Mbuya (2019) distinguish "physical measures", linked with transformation of the street design or the addition of elements, and "non-physical measures", with educational or regulation tool. Moreover, a grouping according to the scale of action is proposed by Brindle (1991), who distinguishes three "levels": the first one consisting in the single actions for speed reduction on an axis or neighbourhood, the second one consisting in the strategy proposed on a wider area or corridor, the third one in policies applying on the scale of the city.

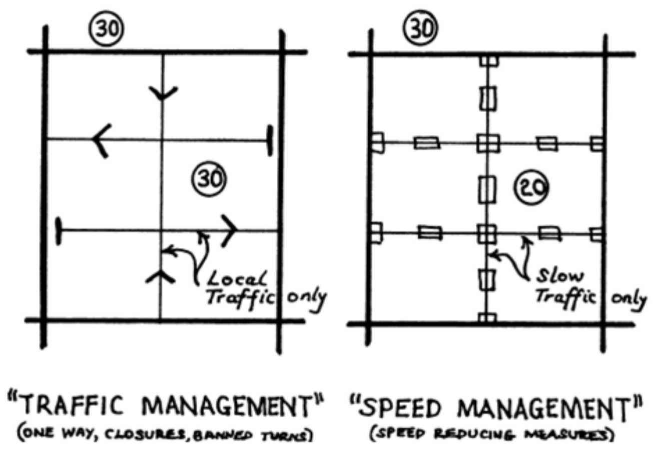


Figure 8. Distinction between Traffic management and Speed management (Pharoah and Russel, 1991)

As mentioned, after the first experiences, multiple strategies have been applied with differences according to the context of action. Pharoah and Russel (1991) collect the key successes in urban areas.

- Shared space schemes. They can be considered as one of the first ones due to the early experience of the Dutch woonerf, focusing on the redesign of local streets in residential areas, mostly through the removal of the distinction between carriageway and pavements, as well as a number of design elements, such as greenery, urban furniture or parking stalls, which allow pedestrians and cyclists to circulate on the whole surface and induce drivers to proceed at a lower speed, due to the presence of a higher number of elements of attention and to the absence of a linear direction. After its introduction in national legislation in the 1970s in the Netherlands, the model spread in other European countries.

- 30 km/h zones. They derive from the evidence of efficacity of shared space concepts, as well as their high costs of implementation: this solution resulted to be simpler but equally effective in the improvement of safety. The evidence that the reduction of speed is the key element in terms of safety is the base for this strategy, allowing design measures to focus first on this element, having as a result improved conditions on the whole axis, for example due to the reduction of space necessary for the carriageway, which can be allocated differently to other uses. Different approaches in the application of the strategy can be found: for example, while in the Netherlands the designation can be applied only where physical measures already induce behaviours to proceed at slow speeds, in Germany designation on wide areas are followed by selected physical measures on the most critical locations.

- Pedestrianisation. It is considered by the authors not to be completely included in the category of traffic calming, since the element of coexistence with motorised vehicles is lacking. However, it should be taken in consideration as part of the solutions for urban areas where it is suitable, for example in the cases where the coexistence between pedestrians and traffic is not possible.

- Actions on main axes. Actions of this type started in the 1980s as a way to manage conflicts appearing on main roads through areas with a high concentration of pedestrians, such as main axes in commercial areas. These strategies comprised a redistribution of space, including other users, as well as a reduction of vehicular speed.

Within these wide strategies, a list of single techniques and measures can be found especially in guidelines for the design of traffic calming, considering that several tools are used in multiple contexts, but they often must be adapted to the context and local regulations on design. The multiplicity of instruments can be also explained with the variety of aims interventions of redesign might have. The «narrow "accident reduction technique" interpretation of traffic calming» (Pharoah, 1993, p. 3) can be broadened to the interpretation as a strategy to a complete redesign of an urban axis: this shift of approach should be accompanied by a broadening of the group of actors involved in the planning and design processes, integrating multiple competences in a field which was historically dominated by engineers (Pharoah and Russel, 1991).

As previously mentioned, actions of traffic calming were initially put in place in order to improve safety conditions and reduce the number of vehicles on different categories of urban arteries. The evolutions of the strategy lead to a broader range of objectives and benefits, aiming at balancing and reconciliating the two functions of "link" and "place". Therefore, practical techniques varied during time also according to the context. Some authors provide a systematization of traffic calming tools (Bunte, 2000; Department of Transport, 2007; Pennsylvania Department of Transportation, 2012; Harvey, 1992; SCRCG, 2008; Vanderschuren and Jobanputra, 2009).

2.2.2. Residual spaces

As previously highlighted, the design of urban streets during the second half of the XX Century prioritized the provision of space for motorized vehicles, aiming at improving speed and facility of circulation, focusing on the achievement of design standards, often as a result of a political vision aiming at prioritizing car dominance (Nello-Deakin, 2019). One of the results of this approach is often evident on the repartition of space between users and functions on the streets of the current urban centres, which has been measured by multiple studies, in most cases with a social approach, considering the idea of equity, therefore seeking for an instrument of repartition of space which could be fair to all users of the street, and highlighting the current dominance of spaces devoted to cars in current cities (Nello-Deakin, 2019). A redistribution of the space of urban streets would determine a reduction of the space devoted to cars, both in terms of circulation and parking, in order to allocate it to other forms of mobility, such as pedestrians and cyclists, or to other functions typical of urban streets, in particular social and environmental uses. The blog "Copenhagenize" used for this dominant position the term "arrogance of space", through images highlighting this phenomenon (Nello-Deakin, 2019). It is particularly interesting to notice in these images the presence of spaces defined as "dead" (Nello-Deakin, 2019), or which could be named as "residual". Such spaces are constituted by portions of the carriageway which are not efficiently used. In some cases, they are formally not accessible to vehicles, being marked as traffic islands, but they are not provided with an alternative use, for example they do not constitute spaces usable for pedestrians.

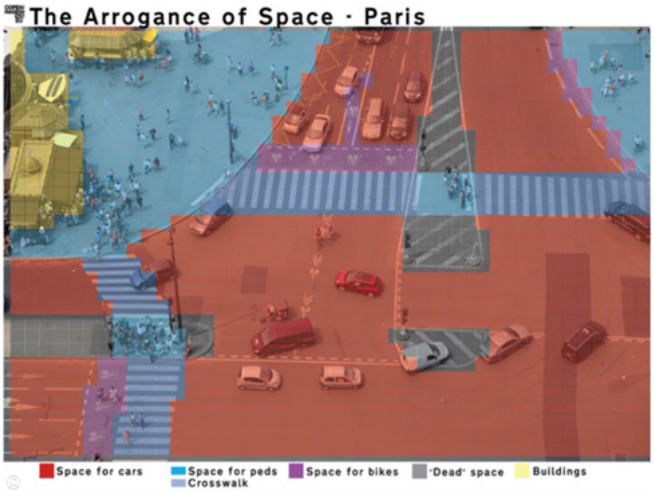


Figure 9. Representation of the prevalence of space devoted to cars, named as "arrogance of space" by Copenhagenhize (https://www.archdaily.com/800903/the-arrogance-of-space-mapping-the-unfair-distribution-of-public-space-at-urban-intersections)

Moreover, urban carriageways whose design results from the traditional aforementioned approach often contain spaces which are formally part of the surfaces where vehicles can circulate, but they are not effectively used by cars neither for circulation nor for parking. Examples can be cases in which traffic lanes are wider than necessary, wide carriageways where traffic lanes are not marked, street enlargements in correspondence to intersections with a lack of formal markings. To this category other elements can be associated, such as intersections where the radius of curvature is wider than the minimum requirements, with an effect not only on the efficiency of the use of space, but also on street safety. Considering the idea of a more appropriate redistribution of space, such spaces constitute key elements because of their availability, since their transferal to other uses would not constitute a limitation to the effectiveness of car spaces, without constituting therefore a source of conflict, which is typical in urban spaces due to the limited amount of space. Actions of redesign of the streets would therefore redistribute these spaces, by limiting the carriageway to the dimensions which are actually demanded by regulations. In some cases, even on-street parking places can be considered as part of this category, if reasonings concerning the expected character of the street would demand an increased necessity of space, and the large dimensions of the stalls would not constitute an efficient use. A practical example of this effect is shown by the phenomenon of the so-called "sneckdowns": as highlighted by activists (Pilsēta cilvēkiem, 2019; Tous à pied, 2021), during snowy days, considering also that driving behaviours tends to be more careful and slower due to the reduced safety conditions, the space of carriageways covered by snow showed how the portion of the street effectively used by vehicles is reduced, leaving a wide space untouched. This can be considered as an evidence of the possibility of reallocating this residual portion of space through actions of redesign, by limiting the space for cars to the minimum necessary standards.

Figure 10. Example of a sneckdown in Brussels. A redistribution of space could start from the idea that the space exceeding the minimum standards for car traffic could be redistributed (Tous à pied, 2021)

Figure 11. Multiple examples of residual spaces can be found in the city of Turin, on streets and intersections where an intervention of redesign has not taken place. Examples of residual spaces in Turin: corso Palermo, via Pianezza, largo Cardinal Massaia, via Millio, via Saorgio, via Asinari di Bernezzo (located in the area of study). These spaces are generated by wide carriageways, wide curb radiuses, traffic islands not accessible to pedestrians, vehicular shortcuts, parking stalls or other spaces without a specific function (Google Earth Pro)

2.2.3. Traffic calming in Italy: the strategy of 30km/h zones[1]

Despite the common design features used in multiple case studies, as mentioned before, traffic calming measures are strictly linked to the context of application, due to the different regulatory frameworks. In this case, an insight can be provided for the Italian case. The goal of this section is to define the framework for traffic calming measures in the context of the work on the case study.

As it was seen, the principle of the application of the model of residential units to the organisation of urban spaces implied a specialisation of the urban street network, according to the function of each street, in general terms divided between through axes and local streets. According to the context, a formal definition of such functions can be conducted by planning processes in order to regulate the physical characteristics of each street according to its function. This definition should be acted at a wider scale, in order to have a comprehensive view of the urban street network. In Italy, such process is defined by the "New highway code" (Nuovo codice della strada, d.lgs. 285/1992 s.m.i) and the "Directives for the writing, adoption and implementation of urban traffic plans" (Direttive per la redazione, adozione ed attuazione dei piani urbani del traffico, 1995), which define for urban areas a hierarchical system divided in four levels, each detailed with dimensional and functional characteristics, of which the main ones are listed below (Socco, 2009, p. 16):

- Highways (Type A according to the Highway Code). Characterised by separated carriageways, with the function of allowing through traffic crossing urban areas without origins or destinations in the neighbourhood, or to connect urban areas to the main extra-urban axes, with high degrees of separation from the rest of the network, they are characterised by high speeds and direct trips, and they are reserved to selected categories of motorised traffic.

- Through streets (Type D according to the Highway Code). With separated carriageways, they have the function of allowing through traffic avoiding the crossing of neighbourhoods with high levels of speed, the degree of separation is lower than highways and a larger group of users is allowed. Maximum speeds are of 50 km/h, which can be raised to 70 km/h with specific conditions.

- Neighbourhood streets (Type E according to the Highway Code). With a single carriageway, they link two neighbourhoods or different portions of a single neighbourhood, serving the main neighbourhood services, allowing all street users

- Local streets (Type F according to the Highway Code). Aimed at serving trips having their origin or destination along the axis, allowing all users except public transport.

To these, three additional levels are added by the directives, as well as the "service streets", to which the side streets named controviali can be associated.

1. *The chapter uses as a main source Socco (2009)*

This typology of classification received critiques: the rigid separation in seven hierarchical levels appears to be difficult to apply in consolidated urban fabrics, where a mix of uses exists on most of urban streets and where the physical characteristics of urban axes rarely meet the requirements foreseen by the law. Moreover, the criteria listed by the directives are strictly related to functional requirements, by concentrating exclusively on mobility aspects and without taking into account social and environmental functions of the street. Socco (2009) proposes a new approach in the regulations for urban street classification, aiming at strengthening the planning according to the model of the residential units, where through traffic would be excluded and where actions of requalification of public space following to the logics of environmental improvement could be concentrated, by strengthening the integration and coherence with urban planning instruments. According to this principle, a new classification of urban streets is proposed, integrating the goal of functionality with the principle of sustainability, taking into account social, environmental, cultural aspects. The classification foresees four typologies of streets, through streets, through streets with mixed traffic, neighbourhood streets and local streets; the first two are defined as “first level” streets, defining the boundaries of the residential units, while the other two, “second level” streets, constitute the internal network. The second typology formally corresponds to the neighbourhood streets according to the regulation, but it is distinguished by this classification by the mix of through and local access traffic, while neighbourhood streets should only be destined to internal traffic of the unit.

- Through streets. The traffic on these axes is only through traffic, with no destination or origin in the neighbourhood. They must be provided with service streets, allowing to serve the functions along the axis. They are possibly provided with public transport lanes. According to the typology foreseen highway code, speed limits can vary between 70 km/h and 50 km/h

- Through streets with mixed traffic. They are part of the main through traffic network, but they also have the function of serving the destinations along the axis, often commercial or tertiary functions. Different spatial configurations are possible, often with a central verge or wide lateral sidewalks. They host public transport lines and the speed limit is 50 km/h, except for reductions in some portions where necessary.

- Neighbourhood streets. They have the function of distributing local traffic within the area, or to give access to main local functions, but through traffic should be particularly reduced or avoided. They host public transport lines. Due to the residential character of these streets, traffic calming measures should be foreseen, and the speed limit can be of 50 km/h or 30 km/h.

- Local streets. Only traffic with origin or destination along the axis is admitted, and measures for traffic calming have their widest application on these contexts. Physical configurations depend on the high variability of existing urban streets, and the pedestrian character should be adequately managed with the function of parking.

The criteria for the design of urban streets in Italy are regulated by the "Functional and geometric norms for the construction of roads" (Norme funzionali e geometriche per la costruzione delle strade, 2001), in accordance to the highway code. The norms associate the street categories previously mentioned to four networks, divided in primary (highways, through streets), principal (through streets), secondary (neighbourhood streets), local (local streets), each of which is assigned a function, the categories of traffic allowed, and the geometric characteristics. Together with details regarding the functions and categories of users allowed on each category of street, the geometric characteristics are assigned by the Functional and geometric norms for the constructions of roads.

Public transport should be located on through streets and neighbourhood streets, with different characteristics on the function of the lines transiting and on the configuration of the space dedicated to them. Dedicated lanes should be provided, with different configurations according to the availability of space. Stops should be safe and accessible, they can be provided on spaces at the side of the street or on traffic islands. According to the norms, the minimum width of public transport lanes is of 3,5 m.

In addition to the criteria outlined for the spaces dedicated to motorised traffic, particular attention should be paid to the space allocated to other users, especially pedestrians and cyclists, including in all cases good quality infrastructures. Moreover, as mentioned previously, urban streets should not only be considered as spaces for movement, but they play a role as public spaces for a number of social functions, which benefit and are favoured by the quality of the design. In the context of the measures for traffic calming, and in general for a better use of space for pedestrians, Socco (2009) mentions the "spaces of pedestrian polarisation", with a relevant role due to the pedestrian functions they host, through different physical measures: the widening of sidewalks, in particular in crowded areas such as in front of school entrances, by reusing parking spaces or by reducing the vehicular carriageway, by freeing up space which can be improved with the insertion of urban furniture or vegetation. Stronger measures in this context are the partial or total closures of streets.

Regulations regarding cycling infrastructure were first introduced by the law of 19 October 1998, n. 366 "Norme per il finanziamento della mobilità ciclistica", and the guidelines for the characteristics of cycling paths were introduced by the ministerial decree of 30 November 1999, n.557, which defined four types of cycling infrastructures (Socco, 2009, p. 49):

- Mixed cycling and vehicular itineraries
- Mixed cycling and pedestrian itineraries
- Cycling paths on dedicated lane
- Separated cycling paths.

Itineraries with mixed bicycle and vehicular traffic are suitable only on local streets, where measures of traffic calming allow speed to be maintained low. Itineraries with mixed bicycle and pedestrian are accepted in parks and areas with prevailing pedestrian presence, or in the need to provide continuity to the cycling network, in case of a lack of space for a dedicated infrastructure, with suitable measures for protection from vehicular traffic. According to the ministerial decree, cycling paths can be divided into:

- Separated cycling paths, where there is a physical separation from the carriageway
- Cycling paths on a dedicated lane on the vehicular carriageway, where the separation is given by road markings, on a one-way lane
- Cycling paths on a dedicated lane on the sidewalk, on a one- or two-way lane, to be located on the side of the vehicular carriageway

The ministerial decree states a minimum width of all typologies of infrastructure of 1,5 m, which can be reduced to 1,25 m in case of two contiguous lanes, and to 1m in exceptional circumstances, for short portions and with sufficient signalling. A separating strip should be included between the cycling path and the carriageway, with a minimum width of 0,5 m, in order to avoid conflicts with car doors. Two-way cycling paths with contiguous lanes on one side of the streets are admitted in exceptional cases through a demonstration of the suitability and safety of the solution, especially at intersections. Visual recognizability of the cycling path should be provided through a dedicated colour, symbols and signalling of the status and direction of the itinerary, also extended and highlighted at intersections. The pavement surface should be regular and sufficiently maintained, with correct placing of leak pans in order to avoid danger for cyclists. At intersections, cycling crossings should be located next to pedestrian crossings, and they can be displaced in order to increase the distance from the contiguous carriageway, through a minimum curb radius of 3 m.

In the context of the pandemic emergency of 2020, modifications to the New Highway code were brought by including additional measures favouring cycling mobility (Circolare Ministero dell'Interno - 22/10/2020 - Prot. n. 7923 - Circolazione stradale, 2020):

- The bicycle street, defined as type E-bis in the New highway code, consists of an urban street aiming at favouring the use of bicycles. Cyclists have priority over other users, and they are allowed to occupy the whole carriageway, although motorised vehicles are allowed to overcome them, with particular attention. All users have priority to intersecting streets and the speed limit is of 30 km/h. However, in order to allow the validity of such measures, the street should be marked with specific signalling, which is not yet defined by national regulations
- The cycling lane, constituting a portion of the vehicular carriageway where cyclists have priority, characterised by a continuous or discontinuous marking on the surface of the street, which can be used by other vehicles to access parking stalls or in case of a lack of space on the carriageway.
- The possibility for municipalities to allow bicycle contraflow on selected one-

way streets with speed limit of 30 km/h by installing specific signalling and the marking of a cycling lane for bicycle contraflow, consisting of a lane identified by a discontinuous line located on the left side of a one-way street for motorised vehicles

- The possibility for municipalities to allow cyclists on public transport lanes, if they are characterised by a larger width than 4,30 m and if no tram tracks are present, identified by specific signalling

- The advanced space line, located at intersections regulated by traffic lights, designating a space for cyclists in front of motorised vehicles, with a width of 3 metres, accessible through a side cycling lane, and signalled by dedicated markings.

In the Italian context, on top of single measures for speed reduction, traffic calming actions are part of the broader strategy of 30 km/h zones. With the aim of prioritizing pedestrian uses, and with the model of residential units, the strategy identifies areas, surrounded by main axes, where measures of traffic calming and interventions of improvement of public space take place. Despite a lack of precise definition in the Italian regulations of such zones, through the application of different normative tools, municipalities can intervene on the street network according to the principles of this strategy. Starting from the definition of the functions of urban streets acted by the local SUMP, the identification of the areas for the application of the strategy is followed by a local plan where interventions are defined, distinguished between physical and educational. It is important to underline that the interventions can be different in their character, but they should be coherently comprised within the plan of the area, it is therefore not suitable to intervene on a single axis or intersection, although priority can be given in the implementation to the most critical areas. Socco (2009) defines four main objectives to be considered in the design of 30 km/h areas:

- Safety, using physical measures aimed at inducing drivers to proceed at a safe speed;

- Accessibility, providing continuity to cycling and pedestrian itineraries for all users;

- Multifunctionality, taking into account the street as a public space, with functions exceeding the one of mobility;

- Quality of the space, using the strategy to provide a unitary, coherent, and attractive design to the area.

To achieve these principles, some criteria for the design are defined:

- The exploitation of residual spaces, resulting from the reduction to minimal standards of parking provision and carriageway width, in order to gain space for soft mobility and social functions;

- The use of physical transformations of space in order to induce drivers to drive at safe speeds;

- The continuity of pedestrian and cycling paths, providing correct accessibility and safety

- Unity of design, including green spaces.

In order to achieve the goals of the strategy, through the application of the criteria, Socco (2009) identifies a number of tools, by stressing however the existence of a wide range of tools and the necessity to include them in the main strategy:

- Residential areas entrances. They mark the entrance to a traffic-calmed area from one of the main axes representing the boundaries. Measures such as rising of the surface, narrowing of the carriageway, or the insertion of signals, green or urban furniture aim at emphasizing the necessity to adapt driving behaviours to the conditions of the area (Figure 12).

- Raised intersections and pedestrian crossings. They consist in a rising of the surface of the whole area of the intersection, in some cases raising the level to the one of the sidewalks, allowing a complete continuity of pedestrian paths, as well as stating the primary importance of pedestrians, as well as inducing drivers to reduce their speed. They are often accompanied by narrowing of the carriageway, in order to increase visibility and prevent illegal parking, as well as to increase pedestrian space (Figure 13).

- Speed bumps. They aim at reducing driving speed, through visual discontinuity and by introducing an element of discomfort due to the elevation of the surface (Figure 14).

- Speed cushions. Similar to speed bumps, they are characterized by the selection of the targeted users, because of their reduced width, having a speed reduction effect on cars, allowing larger vehicles such as buses or emergency vehicles and cyclists to avoid their effect (Figure 15).

- Narrowings and traffic islands. They consist in a reduction of the width of the carriageway in order to induce a speed reduction, often simply caused by the visual effect when the dimensions are not largely reduced. Moreover, they can constitute a widening of the space allocated to pedestrians (Figure 16).

- Chicanes. They impose a change of direction for drivers, caused by the widening of sidewalks or by the insertion of greenery, urban furniture or parking spaces, inducing therefore a speed reduction, on top of mitigating the visual continuity of the axis (Figure 17).

- Neighbourhood traffic circles. They constitute roundabouts of reduced dimensions aimed at regulating critical intersections by improving fluidity and safety of pedestrians and cyclists (Figure 18).

- Street closures. Where possible, streets can be closed to vehicular traffic, totally or partially, by creating pedestrian areas or cul-de-sac, where selected categories of vehicles are allowed, and allowing a redesign of space favouring soft mobility and other uses of the space. At the scale of the street network, they can play an important role in limiting through traffic in residential areas (Figure 19).

Socco (2009) includes normative references and technical details regarding the design of these elements, which will be taken into account in the project phase of the present work.

Figure 12. Entrance to a "home zone", the model for residential shared spaces in the UK (https://street-design.com/cbristol.html)

Figure 13. Raised intersection (Socco, 2009)

Figure 14. Speed bump (Socco, 2009)

Figure 15. The first speed cushion in Turin (https://torino.repubblica.it/cronaca/2019/05/14/news/torino_arrivato_il_primo_cuscinetto_berlinese-226262657/#google_vignette)

Figure 16. Street narrowing (https://www.cerema.fr/fr/actualites/chicanes-ecluses-outils-moderer-vitesse)

Figure 17. Chicane (Socco, 2009)

Figure 18. Neighbourhood traffic circle (Socco, 2009)

Figure 19. Street closure with a modal filter, allowing access to bicycles (https://www.kingsheathltn.co.uk/what-is-happening/)

2.3. Climate change and thermal comfort

2.3.1. Microclimate

The study of climate is conditioned by the scale which is used to analyse the phenomena which are identified, and which are influenced by the characteristics of the territory. While the macro-scale, useful for areas of hundreds of kilometres, is useful to observe phenomena at the regional level, urban areas are involved in the analysis starting from the meso-scale, used for areas of tens of kilometres, where city-wide phenomena can be observed (Erell et al., 2011). Further detail is observed at the local level, with a scale of less than ten kilometres, where the effect of single elements of the urban fabric is relevant, and the micro-scale, with limits smaller than 1 kilometre, influenced by single architectonic elements such as components of a building or single trees, defining the concept of microclimate (Erell et al., 2011). The climate at this scale is the characterising element of the urban canopy-layer, consisting in the lowest sector of the urban boundary-layer, the part of the atmosphere closest to the surface of the earth: the urban canopy-layer's height corresponds to the height of elements such as buildings or vegetation (Erell et al., 2011). The study of microclimate is therefore fundamental in the context of urban and architectural design, considering that different choices regarding the forms and the materials for urban spaces can affect the comfort and the activities of the users (Erell et al., 2011), with impacts on human health (Ebi et al., 2021), meaning that solutions aiming at creating a comfortable microclimate contribute to the correct improvement of cities (Nikolopoulou et al., 2001). Oke (1987), in the definition of microclimate, strengthens the importance of the interaction of meteorological conditions and soil, allowing to define as boundaries of the scale for the study of microclimate not only the upper one in the atmosphere (consisting in its lower two metres), but also the lower one within the soil (consisting in its upper 0,5 m to 1 m layer). Moreover, Oke (1987) defines the ecoclimate, generated by the influence of vegetation, which extends the boundaries where a high presence of vegetation exists, and which is absent where no vegetation is present.

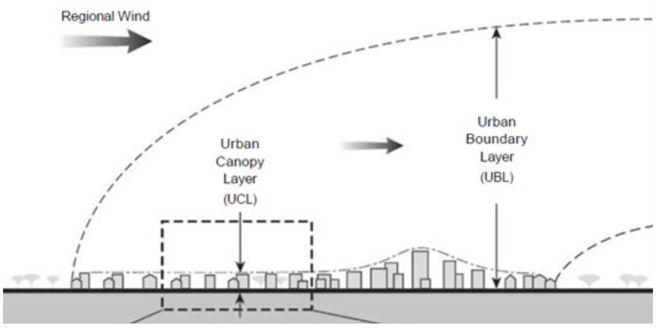


Figure 20. Representation of the urban boundary layer and urban canopy layer (Erell et al., 2011)

Within the urban canopy-layer, the microclimate is influenced by the shape of the urban fabric. Specific conformations of the built environment can be studied, such as the urban canyon, defined as «a semplified representation of the complex 3D urban surface in the form of a semi-infinite street whose cross-section is defined by two geometrical parameters: the average height of buildings along the street (H) and the street width (W)» (Erell et al., 2011, p.257). In order to analyse atmospheric phenomena and to allow comparison between different cases, three geometric factors can be identified to characterise the urban canyon:

- The height/width ratio (H/W), or aspect ratio, defined as the ratio between the height of the lateral boundaries, therefore the average height of the buildings along the street, and the width of the empty space, such as the average section of the street between the two facades (Erell et al., 2011). With a ratio value of 1, the canyon can be considered as uniform, with values lower than 0,5 the canyon is shallow, with values of 2 it is deep (Jamei et al., 2016).
- The axis orientation (θ), compared to the north-south direction (Erell et al., 2011).
- The sky view factor (SVF), corresponding to the angle of sky dome visible from the median line of the canyon width (Erell et al., 2011).

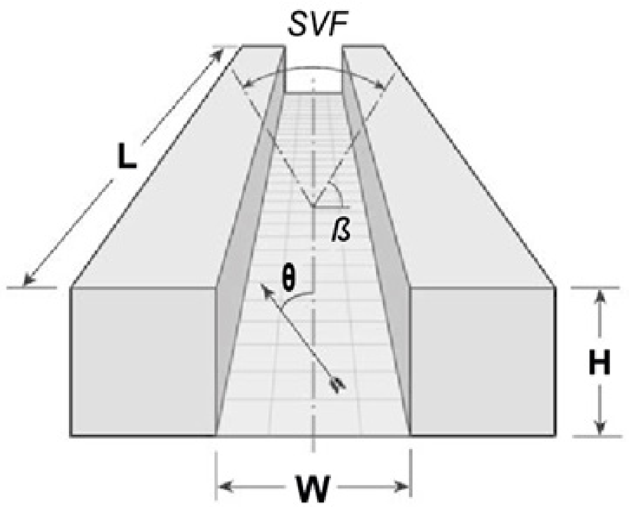


Figure 21. . Representation of the urban canyon (Erell et al., 2011)

Similarly, other urban spaces can be analysed using variations of the same factors, such as courtyards or plazas (Erell et al., 2011). As Erell et al. (2011) stress, these factors can be studied in order to evaluate the contribution of urban canyons to the effect of urban heat island (SVF and H/W ratio), to the behaviour of wind (the H/W ratio together with the orientation), and to the distribution of shading. The aspect ratio appears to have a role in influencing temperatures, with higher temperatures during nighttime with high values of aspect ratio, and opposite values during the day, especially because of shading (Jamei et al., 2016). The morphology of the canyon measured by the value of aspect ratio also influences the direction and speed of wind. In particular, high values of aspect ratio were found to be detrimental to wind flows, with important differences in the resulting temperature (Jamei et al., 2016). The aspect of canyon orientation is fundamental for air temperature, especially because of the shading function provided by the buildings, with important variations according to the geographical context, as well as because of the influence on wind (Jamei et al., 2016). Being influenced by the aspect ratio, the sky view factor has similar effects on air temperatures: it was observed that lower values of SVF correspond to lower temperatures during daytime, due to the reduced amount of radiation reaching the canyon, and higher temperatures during the night, due to the reduced possibility of long-wave radiation deriving from surfaces (Jamei et al., 2016). Similarly, higher values of sky view factor were found to increase wind speed (Jamei et al., 2016).

Finally, it must be noted that the urban canyon as described can be considered as a theoretical model of the reality, given the diversity of urban fabric, such as the different heights of the buildings along a street: in this context, while analysing a real case, simplifications or more complex adapted tools are necessary (Erell et al., 2011).

2.3.2. Climate change and urban areas

The effects of climate change are widely reported, both on ecosystems and biodiversity, as well as on human's health and socio-economic conditions (Kabish et al., 2017). One of the most important results of climate change is the increase in temperature, accompanied by an increase in extreme weather events, such as heat waves, droughts, floodings and wildfires (Emilsson and Ode Sang, 2017). Particularly important is the interaction between climate change with urban areas, which not only contribute to an increase of its effects, due to the ongoing urbanisation process (Kabish et al., 2017), but which are also the sites where the negative consequences are experienced the most (Emilsson and Ode Sang, 2017). The main effects of climate change on urban areas in Europe are grouped by Emilsson and Ode Sang (2017) between direct and indirect, the first ones visible on the change on weather phenomena, the second ones resulting from the first ones.

- The first effect is the increase in temperatures, resulting both from an overall global change and from the local phenomenon of urban heat island, due to the characteristics of the fabric and the materials of soil and buildings, the low presence of vegetation, and the heat emitted by human activities

- Another effect is the changes in hydrology phenomena and increase in extreme events, with the juxtaposition of periods of droughts and intense floods, with high impact on urban water management and on evapotranspiration, which is a key factor in urban cooling

- The indirect effects are related to the consequence on ecosystems and on single and group of species, due to the changes in climatic conditions which influence the availability of resources

One of the most important elements characterising urban microclimate is the phenomenon of the urban heat island (UHI). The main effect is verified in urban and metropolitan areas, where the temperatures measured in the urbanised area are considerably higher than the ones measured in the surrounding rural areas, due to the heat produced by human activities concentrated in cities, as well as to the scarcity of evapotranspiration due to the lack of vegetation and a high presence of impermeable surfaces (Zou and Zhang, 2021), although this effect is often difficult to evaluate, due to the problem related to the selection of locations for the measurements in metropolitan areas, where the distinction between rural and urban is often not clearly defined, as well as due to the influence of higher scale climatic conditions (Erell et al., 2011). Moreover, different dimensions of heat islands can be observed, ranging from the scale of a wide metropolitan area to the one of a building (Taha, 1997). The phenomenon is particularly relevant because of the multiple consequences it has not only on thermal comfort, but also in terms of energy consumption, quality of air and human health (Rizwan and Dennis, 2008). According to the typology of the effect of the urban heat island, three categories were defined (Erell et al., 2011):

- Surface heat island, whose effects are verified mostly during day hours, due to the different temperature between the urban and rural surfaces, often differing in their imperviousness and therefore their water retaining properties.

- Canopy-layer heat island, whose effect is perceivable during night hours, referred to the different temperature of the air of the canopy-layer, between the soil surface and the building height. The phenomenon is verified by the lower cooling rate in urban areas, leading to a slower decrease of temperatures during nighttime.
- Boundary-layer heat island, due to the effect of winds, consisting in a «dome of warmer air» (Erell et al., 2011, p. 69).

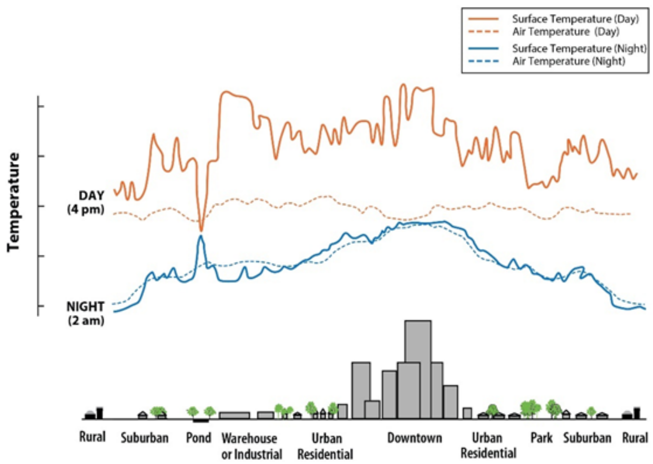


Figure 22. Schematic representation of the phenomenon of the urban heat island (https://www.usgs.gov/media/images/urban-heat-islands)

The phenomenon is known to be related to anthropogenic factors, but the factors generating urban heat islands are multiple. Rizwan and Dennis (2008) categorise them between controllable and uncontrollable variables, the first ones being related to human factors, such as the population of the urban area and the physical characteristics of urban space, the second ones being related to climatic factors. Some of these causes include:

- Urban form. The structure of urban areas is the main causing element. Heat in urban areas is resulting from human activities as well as from solar radiation which, due to reflection and absorption, is maintained within the urban area. The material characterised by high absorptive characteristics tends to release after the sunset the heat, which was stored during the day, by causing an increase of temperatures (Rizwan and Dennis, 2008). The difference in temperature during nighttime is derived from the different cooling rate linked to the surfaces, since urban areas are mostly characterised by surfaces and materials retaining heat, other than the heat produced by human activities (Erell et al., 2011).
- Building density. As one of the main factors characterising urban areas, the presence of buildings with reduced open space has important implications on heat: solar radiation is reflected multiple times by the surfaces of buildings, and it is easily absorbed by low-albedo surfaces (Erell et al., 2011). Urban areas as a whole can be considered to have a low albedo, due to the reduced capacity of the urban structure to reflect radiation, while absorption prevails (Rizwan and Dennis, 2008). Moreover, if the fabric is characterised by important building heights, ventilation and wind speed are limited, increasing the effect of heat (Erell et al., 2011).
- Surface characteristics. The phenomenon of water evaporation is important to the reduction of temperatures in proximity to the surfaces. While permeable surfaces

of rural areas allow water to be stored in the ground during precipitation events, and then they gradually release it through evaporation, allowing a constant process of temperature reduction, the impervious materials characterising urban areas maintain water on the surfaces, provoking a fast and immediate evaporation (Erell et al., 2011). Other than the characteristic of imperviousness, urban materials contribute to the urban heat island because of their albedo. Materials characterised by darker colours are characterised by lower albedo and are less able to reflect solar radiation, while their absorptive properties increase the phenomenon (Erell et al., 2011).

- Presence of vegetation. Vegetation contributes to the reduction of temperature thanks to its shading properties, as well as its evapotranspiration property, by increasing moisture (Erell et al., 2011). Such characteristics largely depend on the species and dimensions of the plants, but the role in contrasting the effect has been widely confirmed (Tan et al., 2021).

- Human activities. An important component of the heat is not linked to solar radiation, rather it is the result of human activities, which are concentrated mostly in urban areas, constituting an important factor for the urban heat island (Erell et al., 2011). The main sources of anthropogenic heat are reported to be heating and cooling of buildings, which provoke an increase of temperature in all seasons of the year, as well as industrial activities and emissions from vehicles (Zou and Zhang, 2021). Moreover, a role can be played by air pollution, limiting the reflection of radiation and therefore maintaining heat within the atmosphere (Rizwan and Dennis, 2008). Apart from the prevailing role of such effects, a correlation can be found with the population of a city (Rizwan and Dennis, 2008).

- Weather. The climatic conditions of the urban areas have an influence on the effect of urban heat island, due to the interaction with factors such as wind or cloud coverage (Erell et al., 2011).

Within urban areas, Erell et al. (2011) describe the opposite phenomenon of urban cool islands, mostly due to areas shaded by the effect of urban canyons, which cause that some portions of the ground might not receive solar radiation for most of the day, due to absorption and reflection of the buildings forming the canyon. However, the effects of the urban cool island are less known, also because of their reduced recognisability compared to the heat island and especially the anthropogenic heat (Erell et al., 2011).

The phenomenon of urban heat islands is particularly interrelated to the one of heat waves (He et al., 2021). Heatwaves lack a universally recognised definition: most of the existing attempts focus on the characteristics of intensity and duration of such events (Xu et al., 2016): Perkins et al. (2012, p. 1) define them as «a period of consecutive days where conditions are hotter than normal, thereby including seasonally extreme (i.e. summertime) events, or seasonally anomalous warm spells (i.e., annual)». To these elements in the definition, Robinson (2000) includes the effects on the human component, defining them as « an extended period of unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population» (Robinson, 2000, p. 763). Heatwaves are particularly relevant in the context of climate change, since the increase of temperature would affect the intensity, frequency and duration of such events (Meehl and Tebaldi, 2004). Considering the increase in extreme heat events during the last decades, the frequency of such events is expected to be determinant in the current century, taking into account for example that the most extreme events since 1871 happened after 2000, as well as their intensity and duration (Teskey et al., 2015).

According to Debbage and Shepherd (2015) there are multiple negative effects on urban areas resulting from the increase in temperatures, among which increases in energy consumption for human activities and reduction of air quality. One of the most dangerous consequences is related to human health, which stresses the importance of the study of climatic phenomena related with urban areas, and the necessity to provide adequate comfort conditions for the users of urban space (Koppe et al., 2004). The human body regulation system aims at containing body temperature within acceptable thresholds, maintaining a temperature of 37° at rest, and one or two degrees superior while exercising, by a mechanism balancing the heat coming from internal production or external sources with heat losses, mostly through the production of sweat and through the carrying of heat through blood to the skin (Ebi et al., 2021; Koppe et al., 2004). In order to maintain the ideal temperature, mechanisms of heat release take place, through convection, conduction, respiration or evaporation of sweat. If the difference between body temperature and external temperature is reduced, heat loss is diminished, to the point to cease when the difference corresponds to zero, when external temperatures reach higher levels than the body temperature, heat is gained by the body (Koppe et al., 2004). According to Koppe et al. (2004, p. 19) heat balance can be described as follows:

Heat storage = heat production – heat loss = (metabolic rate – external work) – (conduction + radiation + convection + evaporation + respiration).

These mechanisms are sensitive to extreme heat conditions, which can stress excessively the capacity of human body to adapt, such as cardiac demand or the production of sweat (Ebi et al., 2021): over certain thresholds human body is is exposed to risk of disease and health, with particular effects on vulnerable groups, such as elderly people or people with pre-existing health problems (Xu et al., 2016), with a verified correlation between heatwaves and mortality, as it was shown during the extreme event in Europe of 2003 (McMichael et al., 2006), and effects of single heatwave events were estimated, confirming the importance of such phenomenon on human health (Koppe et al., 2004). The relevance of heat as a cause of death is underlined by Ebi et al. (2021), reporting it as the main weather-related cause in high-income countries. Moreover, multiple illnesses are connected to heat exposure (Koppe et al., 2004), depending on the health conditions of the subject (Ebi et al., 2021). Due to the urgency of the phenomenon relating heat extremes and health, Jay et al., (2021) stress the importance of developing solutions, ranging from an adaptation of behaviours, to design measures in urban areas, to the elaboration of heat actions plans as a comprehensive tool encompassing measures of different typologies to protect from heat.

The interactions between human factors and climatic conditions can therefore be highlighted both through the effects of extreme heat events on human life, as well as through the impact of urban areas on microclimate. The study of urban bioclimates aims at analysing « the effects of anthropogenic changes in the thermal environment related to human health and wellbeing» (Koppe et al., 2004, p. 73). Therefore, attention to the effect of climatic elements on human health should be taken into account, considering different scales of intervention and the different disciplines linked to them, as stressed by the World Health Organization (2004). Considering the urban scale, planning activities should integrate considerations on the topic while operating at the larger scale of urban design, for example modifying the layout, the density and the orientation of streets according to climate conditions, but also at the smaller scale, through the design of open spaces, elements of vegetation or shelters, in order to improve the conditions of thermal comfort (Koppe et al., 2004). Considering the relevance of extreme weather conditions in urban areas, urban design becomes particularly relevant in the creation of spaces with suitable conditions for their use, by focusing the attention to the aspects of microclimate, highly determinant in the liveability of spaces (Chen and Ng, 2012).

2.3.3. Thermal comfort

Thermal comfort is a key factor of human life, being determinant on conditions of health, due to relationship between long exposures to thermal discomfort and diseases, but also the effects on emotional and cognitive conditions (Han et al., 2023). Thermal comfort can be defined as «the condition of mind which expresses satisfaction with the thermal environment» (Jamei et al., 2016, p. 1003), and it is the combination of three main factors:

- Psychological: related to the mind’s satisfaction with the external conditions
- Thermophysiological: related to the reactions of the body to the temperature
- Energetic: related to the heat flow of human body with the external environment

The importance of a simultaneous presence of different categories of factors is stressed by Middel et al. (2016), who state that the characteristics of the built environment and the climatic conditions only contribute with a proportion of a half to the overall condition of comfort, since an equally high contribution derives from personal characters (biological factors such as age and gender), psychological factors (such as the ability of adaptation, experience and expectation) and behavioural characters (such as the level of clothing, the characteristics of metabolism, the choice of activity and location).

Based on the studies related to the mechanisms of thermal energy balance of the human body, models of indoor thermal comfort have been developed since the beginning of the XX century by the field of ventilating and heating engineering (Erell et al., 2011). The thermal energy balance of the human body is based on exchanges of energy, gained or lost through different mechanisms, aiming at reaching an equilibrium: when the amount of gained energy is superior to the lost one, the person perceives thermal discomfort (Mazhar et al., 2015). These experimental models aimed at identifying thermal sensations, in some cases expressed through scales associating values to sensation ranging from "cold" to "hot", in order to identify the conditions under which comfort could be achieved, for example through the conception of a comfort zone, based on the recognition of a temperature at which a neutral sensation was perceived by a majority of people, or the creation of a "Effective Temperature Scale", based on an index of perception of warmth based on temperature and humidity (Erell et al., 2011). Victor and Aladar Olgyay located a comfort zone on a "Bioclimatic Chart", composed by two axes, humidity and temperature, aimed at providing to architects the range of external conditions under which comfort could be achieved, and the possible measures in order to reach comfort, by increasing ventilation or evaporative cooling (Erell et al., 2011). In his book "Design with climate", Olgyay (1963) defined his model for outdoor thermal comfort. The development of indexes for thermal comfort evolved until the proposal of the PET, which will be treated later.

The research on outdoor thermal comfort is more recent than the indoor experiments, and it developed since the 2000s by an adaptation of the concepts used for indoor comfort (Johansson et al., 2014), as, for example the use of the PET index also for outdoor conditions. The evaluation of outdoor thermal comfort appears to be more complex, especially since outdoor thermal and, in general, microclimatic conditions are not as stable as inside buildings, and the characteristics of urban space are largely variable, with effects on microclimate which can strongly vary according to the context (Middel et al., 2016). Similarly, differences exist due to social and cultural factors, such as the different ways in which the space is used, which can influence the perception of comfort (Johansson et al., 2014).

Mazhar et al. (2015) identify seven parameters influencing outdoor thermal comfort: air temperature, humidity, air movement, solar radiation, terrestrial radiation, clothing insulation and metabolic heat, considering that the first five depend on external conditions, while the other two depend on the choices and characteristics of the person. Instead of the two components of radiation, Atmaca et al. (2007) include the factor of mean radiant temperature, referring to the influence on thermal comfort of the materials located around the person regardless of air temperature (Atmaca et al., 2007), due to the radiative exchange of heat (Butera, 1998). Radiant temperature can be calculated starting from the temperature of the surfaces and their location with respect to the observer, expressed through a view factor (Atmaca et al., 2007). The component of radiant temperature is particularly important, since it was shown that it has a great influence on thermal sensation, and it is strictly influenced by the characteristics of the space, for example by the surfaces (Tan et al., 2013). This factor is taken into account by thermal comfort indexes such as the PET (Tan et al., 2013).

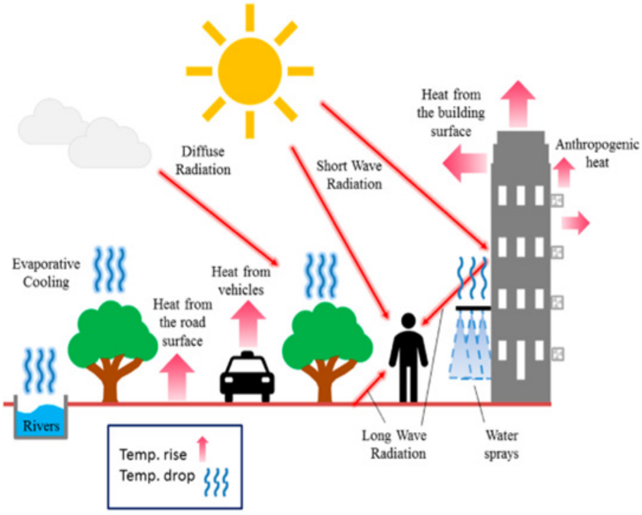


Figure 23. Factors influencing thermal comfort (Wai et al., 2021)

Alongside these elements, Erell et al. (2011) introduce additional considerations on the elements influencing thermal sensation, by defining the concept of thermal preferences, which combine six physical elements which would be preferred by a person, taking into account influencing elements such as socio-economic or cultural factors. Such preferences can be categorised in three groups, the ones regarding climatic conditions, the ones regarding the characteristics of the built environment, and the ones regarding social or personal aspects (Erell et al., 2011).

2.3.4. Design tools for thermal comfort

Taken in consideration the effect of climate change on cities, it is in urban areas that contrasting actions are the most important (Sharifi, 2020) and, in this context, planners and designers have a key role (Erell et al., 2011). Such contrasting actions are mainly divided in the two groups of adaptation and mitigation measures. Although they used to be seen as independent, they both are human actions aimed at contrasting the effects of climate change, however, they differ in the approach. Adaptation measures act on the ability of the system to react to climate change, by working on its vulnerability, while mitigation acts on the sources of climate change, in order to prevent or reduce its effects, for example by reducing greenhouse gas emissions (Sharifi, 2020). While adaptation has a short or medium term and a spatially localised focus, mitigation works on the long-term and its effects are visible at large scales (Sharifi, 2020). Both typologies of measures are necessary in the action of contrasting climate change, considering that achievement in mitigation actions would still require the action of adaptation measures (Pollo and Trane, 2021).

The measures of transformation of public spaces in order to improve their liveability, for example through the improvement of thermal comfort, can therefore be recognised as part of the actions for adaptation to climate change. Based on the study of literature, multiple measures can be identified as solutions to increase thermal comfort in urban areas. Considered the context of the work, the solutions searched are mostly focused on thermal comfort in summer, aimed therefore at reducing the effect of high temperatures, however, the solutions identified might not constitute a suitable solution for winter periods.

According to the strategy of the Rue Commune (Richez Associés et al., 2022), five main factors can be identified as design strategies in order to improve thermal comfort on urban streets:

- Increase of shading, constituting the main factor of action. Different degrees in shading can be identified, according to the typology of shading device
- Reducing surface temperature, decreasing the temperature of materials, allowing to reduce the heat which they can radiate once stored
- Reducing surface reflection, by increasing the capacity of surfaces to absorb radiation in order to prevent its reflection to the users of space
- Increase ventilation, allowing free flow of air by reducing obstacles
- Increase humidification, corresponding to evaporation effects, which can be difficult to reach, unless water surfaces are introduced on the street

Given the importance of solar radiation as one of the main factors influencing thermal comfort, shading is one of the key solutions, considered as the most important by Nasrollahi (2020): the heat load on human body is increased if the individual is directly irradiated by the sun (Koppe et al., 2004). As mentioned previously, shading in urban areas is firstly influenced by the geometries of urban canyons, for example, despite the different contextual characteristics, it was shown that higher aspect ratio corresponds to improved shading (Nasrollahi, 2020). However, these factors result to be less relevant while working on consolidated urban areas, since acting on these elements would require a modification of the morphology of the canyon, acting on the height or location of the buildings: by limiting the action on the transformation of the space between the buildings, interventions on greening are often favoured (Li et al., 2018). Trees were proven to be particularly effective in increasing shading and therefore improve outdoor thermal comfort, especially in open spaces, due to their role in preventing direct solar radiation to reach the users of space (Coutts et al., 2016; Li et al., 2018; Massetti et al., 2019; Nasir et al., 2014), with an impact especially on mean radiant temperature, as well as reducing the amount of radiation reaching the surfaces, which therefore store and release less heat (Armson et al., 2012; Klemm et al., 2015; Rahman et al., 2015). Sun et al. (2017) stressed how a high correlation was found between the decrease of PET values and the presence of high trees, underlining how the introduction of a dense coverage of trees is one of the most important measures to be taken. An appropriate location of street trees should be studied, considering also the effect they might have in reducing ventilation (Jamei et al., 2016), according to the characteristics of the context and of the geometry of the urban canyon, since in deep canyons the shading effect of the buildings generally prevails on the one of trees (Jamei et al., 2016); in general, trees should be planted on the side of streets exposed to the sun, in order to maximise the shading effect with low values of aspect ratio (Coutts et al., 2016). The complementarity with the shading effect of the geometry of the canyon is stressed by Morakinyo et al. (2017). The ability to provide shading operated by trees is measured based on the amount of light transmitted by the canopy and it depends on the species and characteristics of the elements, in particular on the size and shape of the canopy, the characteristics of leaves and their density, and the height and shape of the tree (Jamei et al., 2016). The “Leaf Area Index” (LAI) was developed, in order to compare the shading function of different species, expressed as the leaf area per unit of ground area (Jamei et al., 2016, p. 1008).

In order to improve shading, Shashua-Bar et al. (2012) recommend a combination of measures, taking into account not only planting of trees with dense canopies, but also alternative shading measures. Despite the primary importance of vegetation, certain contexts do not allow trees to be planted, due to lack of space, or conditions of soil or water for irrigation, because of this, shading devices can be used, as cost-effective solutions replacing vegetation shade (Lam et al., 2023). In addition to built structures, such as overhangs or concrete shelters, other materials can be used, such as nylon sun sail, PVC, glass, aluminium, as well as elements such as pergolas or photovoltaic canopies (Lam et al., 2023).

Apart from its shading function, vegetation can contribute to the improvement of outdoor thermal comfort in other ways. Vegetated surfaces such as grass have lower albedo than other artificial surfaces, such as concrete: this increases the heat absorption and reduces the radiation reflected, improving the condition for the users of space (Erell et al., 2011). Differently than other artificial surfaces with low albedo such as asphalt, however, vegetation maintains low surface temperature, due to the cooling process of evapotranspiration (Erell et al., 2011), which allows a reduction of surface and air temperature (Massetti et al., 2019; Koppe et al., 2004), by vaporising the water contained in the leaves and in the soil (Sun et al., 2017), as a mechanism of plants to reduce the heat absorbed by radiation. Evapotranspiration is a factor characterising the importance of green areas in urban spaces, since it is a contribution to the reduction of air temperature which cannot be achieved by artificial surfaces (Jamei et al., 2016). Although, as mentioned before, vegetation might be an obstacle for ventilation, leading to a reduction of the cooling effect, the action of evapotranspiration can be combined to the one of wind, by spreading the lower temperature through the movement of air (Santamouris et al., 2018). The effects of vegetation are not only linked to the benefits of single trees, but also on the combined effects of larger areas, such as urban parks, where temperatures were observed to be significantly lower than other urban areas (Jamei et al., 2016), constituting examples of the effect of cool islands (Erell et al., 2011), although the effectiveness of urban parks in reducing air temperatures depends on multiple factors, such as the dimensions, the presence of trees and their typology, the characteristics of the surrounding environment, the availability of irrigation (Jamei et al., 2016). While the presence of parks was verified to have a cooling impact even at distances of hundreds of metres, the influence of smaller green areas is debated: the literature in some cases indicate them as cool islands, but other elements suggest that they might have the opposite effect of increasing temperatures (Santamouris et al., 2018). Moreover, vegetation is reported to have impacts due to the improvement of landscape conditions, with effects due to the aesthetic perception of space, given the reported influence on thermal comfort both of physical and psychological aspects (Klemm et al., 2018; Sun et al., 2017), on top of the numerous benefits on human health and well-being of vegetation, even if not strictly related to thermal comfort (Santamouris et al., 2018).

Another strategy for the improvement of thermal comfort involves the use of water (Nasrollahi et al., 2020). Water in urban areas was proven to have an important role in reducing air temperature (Syafii et al., 2017). According to Broadbent et al. (2018) the main effect of water is a downwind cooling effect, because of the reduced temperature compared to other materials, as well as because of evaporation, in particular if combined with solutions for shading or canalisation of wind. However, its effects on air temperature should be studied in relation to the context, since some cases showed an opposite effect during night hours (Broadbent et al., 2018). Given its role in reducing air temperature and radiant temperature, solutions to include water bodies in urban areas appear to be particularly suitable (Reza et al., 2021), however, due to the difficulty of designing such elements in urban areas because of reduced space, Broadbent et al. (2018) stress the possibilities offered by irrigation as a sustainable way to reduce temperature, especially if reusing stormwater. Alternatively, Wai et al. (2021) have shown the effectiveness in reducing air temperatures brought by spray cooling through evaporation. However, these techniques have to be evaluated in order to avoid excessive consumption of water, especially in periods of drought (Richez Associés et al., 2022).

As mentioned, ventilation plays a role in outdoor thermal comfort (Jamei et al., 2016). Rijal (2012) studied the effect of wind velocity on indoor and thermal comfort, observing how, in indoor situations, wind velocity increases the comfort temperature, and estimating that, since in outdoor situations velocity is often higher, the presence of wind allows to achieve thermal comfort even with high temperatures. Confirming the importance of ventilation for thermal sensation, Roshan et al. (2020) stress the need for planners to take into account this aspect in the design of urban areas. As highlighted by Richez Associés et al. (2022), the action on wind is reduced in consolidated urban fabric, due to the impossibility of modifying built elements. However, attention to this factor should be paid in the integration to open spaces of elements which could constitute obstacles to wind flow, such as trees (Roshan et al., 2020).

One of the key aspects influencing thermal comfort is related to the characteristics of the materials, in particular the materials used for paving, due to their interaction with solar radiation, emitted by the sun as shortwave radiation and directed to the surfaces, which heat-up and emit again longwave radiation, as infrared (Djekić et al., 2018). In this context, two main characteristics are fundamental, the albedo, characterizing the ability of surfaces to reflect light (ranging from 0 for surfaces absorbing all radiation to 1 for surfaces reflecting all radiation) and the emissivity, characterizing the ability of the surface to emit longwave radiation (Djekić et al., 2018). Each material has different characteristics and therefore has different effects on thermal comfort, two of the main characteristics affecting a different performance are the colour and the texture. Darker colours generally result in low albedo values, while light colours characterize surfaces with higher reflective capacity, similarly, rough surfaces tend to reduce the albedo (Djekić et al., 2018). In the context of the measures aimed at mitigating urban heat island, considered that pavements are among the most important sources of urban heat islands (Santamouris et al., 2013), one of the strategies is to increase the use of materials with reduced heating storage capacity, in order to reduce the heat which is released by the materials through convection, by increasing air temperature (Santamouris and Yun, 2020). With this purpose, the group of "cool materials" was developed, characterized by high solar reflectance and high infrared emittance, resulting in a low surface temperature and low air temperature in the lower layers of the atmosphere (Santamouris et al., 2011). The increased reflectance can be obtained both through materials with higher albedo or through the application of lighter layers on the existing material, for example by adding a white or coloured layer on asphalt (Santamouris et al., 2011). The advantages of materials with high albedo on urban microclimate were proven to be linked to multiple aspects (Gachkar et al., 2021): the reduction of urban heat island (Lontorfos et al., 2018; Mohammad et al., 2021; Taleghani and Berardi, 2018), air temperature (Doulos et al., 2004), surface temperature (Djekić et al., 2018), and air pollution (Gachkar et al., 2021).

Literature shows that while most of the measures presented can have a synergic contribution in reducing the effect of urban heat island as well as improving outdoor thermal comfort, such as the use of vegetation for evapotranspiration and shading or the use of water (Rizwan and Dennis, 2008), there is only limited agreement on the effects of high-albedo materials, which might have a counterproductive effect for pedestrian thermal comfort (Gachkar et al., 2021). According to Doulos et al. (2004) cool materials can contribute to thermal comfort. The research by Rosso et al. (2016) explored the perception of urban paving materials, through the distribution of questionnaires, which highlighted, apart from a general preference of grass, that low-albedo surfaces like asphalt were perceived as less comfortable than materials characterized by higher albedo from the thermal point of view. However, most of the authors highlighted that the increase of albedo in urban surfaces results in lower thermal comfort, as measured by a reduction of PET in different case studies (Gachkar et al., 2021; Mohammad et al., 2021; Taleghani and Berardi, 2018). This is due to the high reflective properties of the materials: while a contribution to thermal comfort is given by the reduced surface temperature due to reduced absorption, the effect is contrasted by the prevalence of mean radiant temperature, resulting from the reflection on the material, which as seen previously, is one of the main factors affecting thermal comfort (Mohammad et al., 2021). Moreover, on top of the effects on thermal comfort, high-albedo materials resulted to be critical for pedestrian areas paving due to their effect on visual comfort due to their brightness (Falasca et al., 2019; Rosso et al, 2016; Santamouris and Yun, 2020).

It was found, therefore, that literature shows contrasting results regarding the efficacity of high-albedo materials on PET, since some of the authors privilege low-albedo materials for urban pavements. According to Erell et al. (2014), this contrasting effect should not be considered as an indication of the unsuitability of high-albedo materials in urban areas, but rather as an element of attention: for example, such materials would not be recommended for paved areas used by pedestrians, but they are encouraged on other surfaces, such as roofs. Moreover, this results in the necessity to carefully study the conditions of the study area as well as the priorities expected (Richez Associés et al., 2022). Santamouris et al. (2011) mention the use of permeable artificial surfaces, which would contrast the effect of radiation through the evaporation of water. In general, however, in order to avoid conflicting effects, a preference is stated for green areas, which combine absorption and cooling due to evapotranspiration, as well as shading solution, which reduce radiation incoming to the ground (Mohammad et al., 2021).

2.4. Street redesign for thermal comfort

2.4.1. Pedestrian comfort

Among the different criteria required for the design of quality urban places, comfort is a recurring and one of the most important themes, although it is not sufficiently researched, as expressed by Jan Gehl (Djekić et al., 2018). In the previous section, particular attention was devoted to the aspect of thermal comfort. However, this constitutes just one of the components of the broader topic of pedestrian comfort. This is defined as «a positive emotional reaction to external surroundings (the walking environment) in different situations, including physiological, physical, social and psychological reactions» (Øvstedal et al., 2002, p. 2). As it can be noticed, the definition is similar to the one of thermal comfort, but it takes into account a wider set of elements influencing the perception of a person in space. According to Øvstedal et al. (2022), multiple factors can influence comfort:

- Feeling of safety
- Conditions of pavement
- Conditions of lighting
- Appealing surroundings
- Thermal comfort
- Acoustic comfort
- Traffic conditions
- Air quality
- Ease in finding the way
- Ease to rest
- Visual comfort
- Ease to move

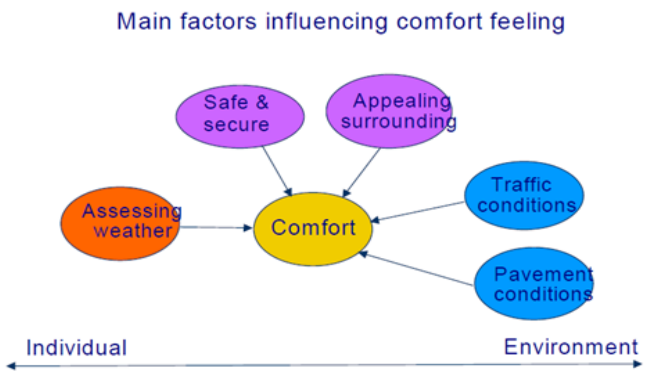


Figure 24. Factors influencing thermal comfort (Wai et al., 2021)

Moreover, according to Øvstedal et al. (2002), pedestrian comfort depends on:

- The individual: it is a subjective feeling which consists in a personal assessment of the factors composing, to which different values can be attributed, according to personal characteristics

- The situation: the perception of comfort can vary according to the conditions under which the person uses the space, for example depending on the available time, the presence of other people or the reason of the displacement

- The surroundings: the evaluation might be different for different geographical contexts or different portions of the city with different characteristics

Moreover, comfort is considered as hierarchical, since an individual establishes priorities in their needs, aiming at meeting at first the most urgent (Øvstedal et al., 2002). In the results of their research, some of the factors appeared to be particularly important, as shown in the image.

2.4.2. Pedestrian comfort and street redesign

The previous section showed how multiple aspects can be considered in order to provide public spaces providing good levels of pedestrian comfort and it can be observed how many of the listed factors can be modified through an action of design of space. For example, the levels of traffic, the ease to move and to rest, air pollution and acoustic comfort are all directly or indirectly connected to the component of mobility. In this context, it was observed before how strategies and measures of traffic calming have been applied in order to improve the conditions of urban streets, with the main objectives of improving street safety and liveability. Through actions of redesign of the infrastructures designed for motorised traffic in the second half of the XX century, the space of urban streets can be redistributed in order to provide a more equitable use. On the other hand, it was seen how climate change is strictly connected to urban areas, where extreme weather events are expected to be more frequent. Particular attention was focused on phenomena such as urban heat island and heatwaves, and thermal comfort was defined. These elements show the necessity of integrating the aspect of thermal comfort in the design of public spaces. The hegemonic application of functional criteria in infrastructure design led to a street network heritage lacking permeable and green areas, scarcely performing in terms of adaptation to climate change (Richez Associés et al., 2022). Moreover, as previously mentioned, actions of traffic calming often lack consideration of environmental or thermal comfort aspects, as it can be seen from the four main objectives of the strategy of 30 km/h areas cited by Socco (2009). Therefore, a need for an integrated design taking into account not only traffic calming objectives, but also thermal comfort considerations is rendered evident. In this context, the model of the Rue Commune (Richez Associés et al., 2022) proposes a methodology for a rethinking of urban streets in the French metropolitan areas. The model is based on an integrated action on urban spaces based on three objectives:

- Transition towards sustainable mobility, through a distribution of space and the introduction of measures favouring soft mobility and street safety
- Soil liberation for ecological purposes, aiming at strengthening thermal comfort, water management and improvement of biodiversity
- Liveability of urban space, with the objective of integrating the different uses and social functions of the street

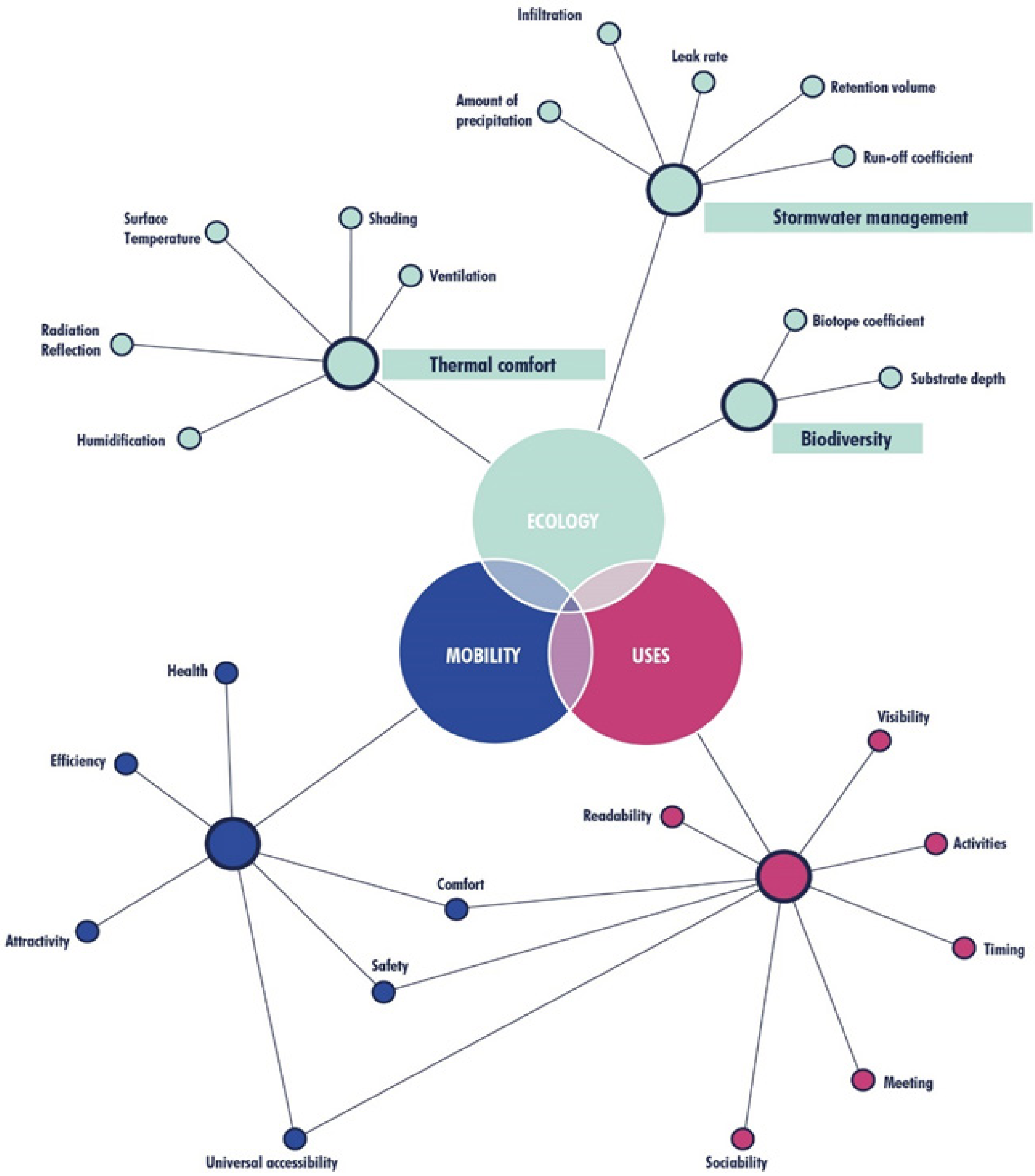


Figure 25. Schematisation of the approach of the Rue Commune (Elaboration of Richez Associés et al., 2021)

An example of integration of mobility and environmental aspects in a complex design of urban streets is the Green Axes of Barcelona. After the superblock model, internationally recognised and exported to other urban areas (Eggimann, 2022), the strategy of the municipality focused on the action on axes rather than areas, due to an easier implementation (Nello-Deakin, 2022) starting from 2021, by maintaining “Superilla Barcelona” as the name of the strategy, shifting from an area-based approach transforming dispersed superblocks throughout the city, to a comprehensive network of linear elements, corresponding to every third street of the most dense urban area (Magrinyà et al., 2023). The strategy conjugates objectives related to mobility, environment and community aspects (Magrinyà et al., 2023):

- Integration of mobility systems
- Increase of vegetation in the most dense and compact area of the city and connection to the existing green areas
- Fostering of communities around the squares created through transformation of the intersections

The design criteria of the new axes aim at reinforcing soft mobility and social relations with the preference of the shared space as the model of organisation of the street, integrated with measures for the increase of green elements, with the preservation of the existing trees and the addition of new vegetation, improving thermal comfort, biodiversity and absorption of CO_2, as well as the improvement of soil condition, increasing fertility and drainage (Magrinyà et al., 2023). Considering the goal of maximising green spaces on this

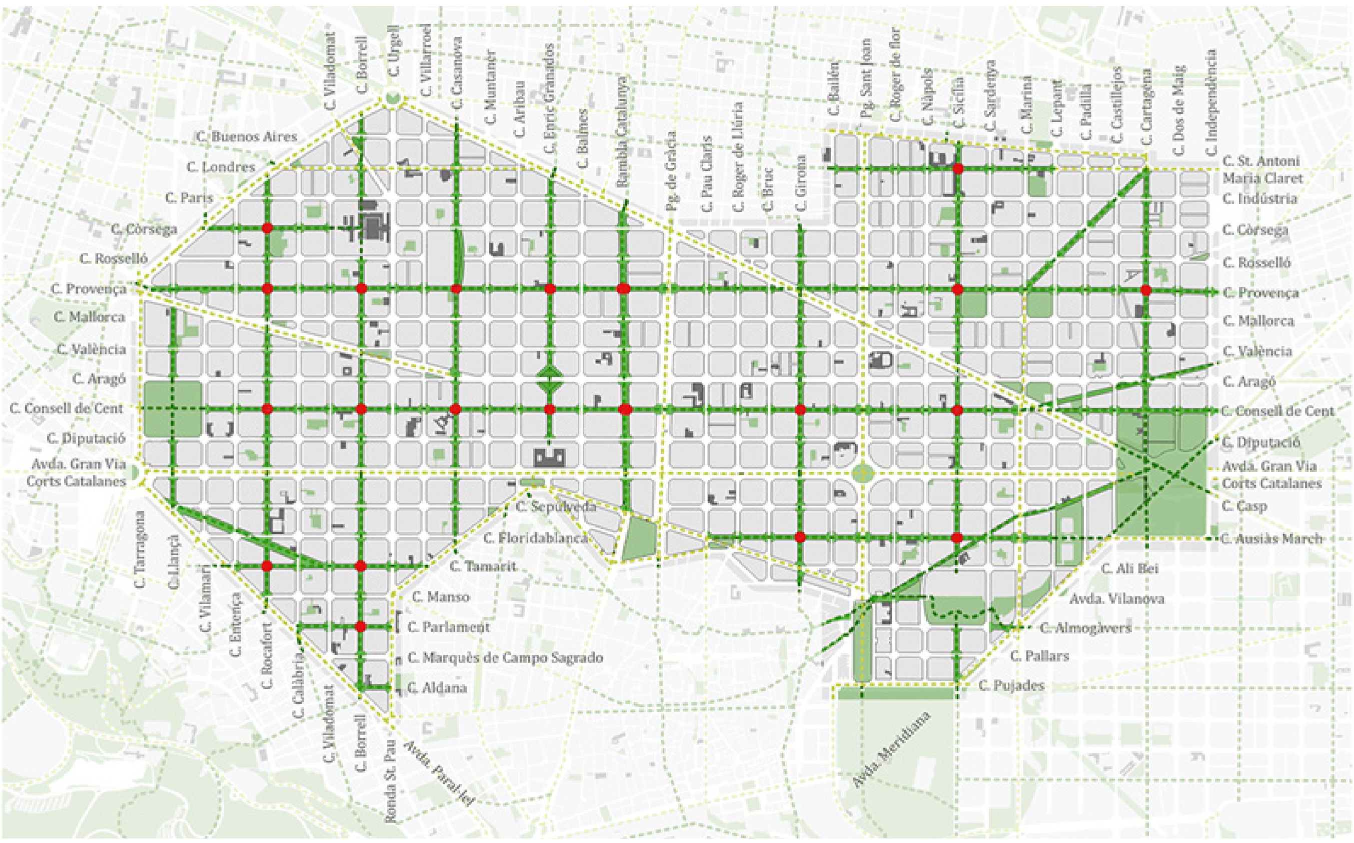


Figure 26. The first green axes to be implemented in the "Eixample" of Barcelona (https://ajuntament.barcelona.cat/superilles/en/superilla/eixample)

typology of streets, which should increase from 1% of the current surface to 12% (Ajuntament de Barcelona, 2022a), Magrinyà et al. (2023) highlight a set of elements influencing the ability to reach it, such as the availability of space and the necessity of coexistence with the uses of the street, the presence of infrastructure in the soil. As a result, a section of a green axis appears as follows (Magrinyà et al., 2023):

- A 3.5 m strip next to the buildings with restricted access to pedestrians, where planting is not possible due to the soil conditions;
- A 2 m to 5.8 m strip, where planting is possible;
- A 5.2 m surface accessible to all users according to the model of shared space;
- A 2 to 4 m strip, where planting is possible;
- A 3.5 m pedestrian strip next to the buildings, without planting.

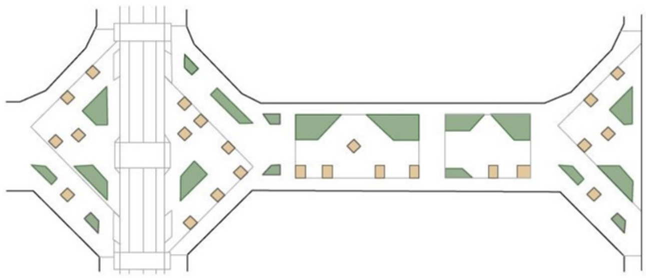


Figure 27. Representation of the spaces for green areas along the axes (Ajuntament de Barcelona, 2022a)

The design is adapted to the uses of the street, therefore, interruptions to the planted areas can be foreseen in order to provide vehicular access to buildings or to maintain paved spaces for specific uses, moreover, the higher availability of planted surface on one of the two sides is related to the need of privileging the use of vegetation on the side exposed to the sun (Magrinyà et al., 2023). In addition to this, new elements for social activities are planned, such as playgrounds and urban furniture, as well as a new system of lighting. On the shared platform asphalt is completely removed and replaced by "panots", typical paving blocks, which were reinvented in order to increase permeability (Garcia, 2021). The intersections between axes create large urban squares, treated with similar measures increasing vegetation (Ajuntament de Barcelona, 2022a).

Figure 28. An example of an implemented green axis. The central portion of the street is shared among all users, while the two lateral strips, at the same level, are reserved to pedestrians. New planted areas are added and the asphalt is replaced with permeable paving (https://www.urbidermis.com/es/blog/los-ejes-verdes-evolucionan-el-imaginario-urbano-de-barcelona/)

Figure 29. The shared surface of the green axes and the planted areas alternated with spaces for commercial activities (https://www.elperiodico.cat/ca/eixample/20230907/reforma-consell-cent-cost-26-91825394)

On top of the measures for the green spaces, regarding mobility, the strategy of green axes maintains a similar approach to the one of superblocks, by reinforcing the shared space character of the streets. A key principle is the reduction of through traffic, obtained in the previous strategy with street closures allowing vehicular access but redirecting traffic to the main axes (Palenzuela, 2021), and maintained along axes with the interruption of the free flow along the street with closures forcing cars to turn on perpendicular streets (Ajuntament de Barcelona, 2022b). Moreover, the platform of green axes is designed according to the principles of shared space, allowing pedestrians to circulate freely on all portions of the street at the same level, while vehicles, considered as guests, can circulate with a maximum speed of 10 km/h only to access functions along the axis, following a non-linear path (Ajuntament de Barcelona, 2021).

Figure 30. The circulation scheme along the green axis diverts through traffic on alternative streets, through street closures at intersections (Ajuntament de Barcelona, 2022b)

2.4.3. Scales of action

It was highlighted how a design approach bringing a requalification of space integrating traffic calming and measures to improve thermal comfort can improve liveability of spaces. An important factor to consider in this context is related to the scale of application of the two components. Especially with the strategy of 30 km/h zones, it was seen that the application of traffic calming measures should not be limited to a single intervention on a street or an intersection, but it should be part of the actions of a coherent plan involving the whole area. On top of this, the definition of the residential unit is the result of a planning action of higher level, conducted at the metropolitan scale by the SUMP. It is evident, therefore, that the actions of traffic calming are the result of a wider planning process, and they cannot be taken in consideration singularly, if not in the process of establishment of the priorities of intervention, for example by identifying critical elements of the street network from the point of view of street safety (Socco 2009). On the other hand, it was seen how thermal comfort can be influenced by multiple factors. Some of them are the result of mesoclimate conditions, they are therefore related to the whole urban area, similarly to effects such as the urban heat island or heat waves. However, other influencing elements are strictly related the characteristics of small portions of space, for example the presence of single elements of shading or the reflectivity of the surface used for one sidewalk. These elements show the necessity of a multi-scalar approach integrating single interventions resulting from planning decisions at a wider scale, taking into account the needs at a local level, by maintaining the objectives of unity and coherence of the design. In the perspective of an application of this double-aimed approach, particular attention is therefore conveyed to the planning process, in particular because it involves different competences, as mentioned by Karndacharuk et al. (2014), which should therefore have the capacity to integrate their methodology and needs, as well as the different scales characterising the design choices. This element constitutes an additional element of complexity, considering that this necessity of integration already emerges in the context of traffic calming strategies, due to the characteristic of multifunctionality of the street (Socco, 2009).

3. Case study: via Carrera/ via Asinari di Bernezzo

3.1. Presentation of the context

The project area of the present work is constituted by two axes located in the western part of Turin, in the neighbourhood of Parella.

The neighbourhood is comprised between the main axis of Corso Francia to the south and Corso Regina Margherita to the north, Corso Lecce to the east and the boundary with the municipality of Collegno to the west. Until the years 1920s the area was mainly rural. The first allotment plans appeared in the 1910, following a regular pattern for the street network defining an urban fabric mostly composed by wide rectangular blocks (Davico et al., 2014). An exception is constituted by the historical axis, appearing already on cartography of the beginning of the XIX century (Davico et al., 2014), corresponding to the current via Asinari di Bernezzo and strada Antica di Collegno, linking through an irregular path the historical nucleus of Turin to the town of Collegno, which mostly remains in the current fabric, and which constitutes one of the two axes of analysis.

The neighbourhood, in its eastern portion, between Corso Telesio and Corso Lecce, is characterised by a high building density, resulting from the urbanisation of the XX century, with a prevalence of residential blocks and few historical buildings resulting from the rural past or historical architectural exceptions. In the direction of Collegno the density diminishes, with a higher presence of lower buildings resulting from the first urbanisations and the presence of unbuilt blocks. With a main east-west orientation between the park Pellerina and Corso Francia, the neighbourhood is crossed by a number of wide north-south axes, two of which characterised by a more important connecting function, via Cossa and Corso Lecce, while the other two, Corso Telesio and Corso Monte Grappa, are characterised by a more important presence of a recreational function, with a central green portion with planted trees. Together with these axes and the park located at the northern boundary, the provision of open and green spaces is affected by the dense urban fabric, with the exception of the park Tesoriera, surrounding the historical building.

The two streeets on which the present work focuses are via Asinari di Bernezzo and via Carrera, the two central east-west axes of the neighbourhood, linking piazza Bernini with the western boundary of the municipality and Collegno, with a complementary function in terms of mobility. Via Asinari di Bernezzo, as mentioned, results from the irregular path of the historical axis of strada Antica di Collegno, and it maintains its name in its western portion. Via Carrera, despite having a rectilinear path, runs almost parallelly: the two axes intersect and diverge between via Cossa and Corso Telesio, and they merge into a larger street from piazza Chironi until piazza Bernini, with the name of via Medici (Figure 32).

The two streets constitute central axes in the neighbourhood, forming an east-west connection, parallel to Corso Francia, from which via Medici derives in piazza Bernini. At the western boundary, strada Antica di Collegno is extended into the neighbouring municipality as viale Certosa, constituting another parallel main axis to corso Francia. Despite the complementarity with corso Francia, their function and physical characteristics differ. The axes serve a number of points of interest in the neighbourhood. Particularly relevant is the concentration of schools of different level along the street (Figure 33).

According to the SUMP of the municipality of Torino of 2010 (Città di Torino, 2010), the axes are classified as follows:

- Strada Antica di Collegno: neighbourhood street
- Via Carrera (between via Franzoj and via Bellardi): local street
- Via Asinari di Bernezzo (between via Pietro Cossa and via Bellardi): neighbourhood street
- Via Carrera (between via Bellardi and corso Monte Grappa): neighbourhood street
- Via Asinari di Bernezzo (between via Bellardi and piazza Chironi): local street
- Via Medici (between corso Monte Grappa and piazza Bernini): neighbourhood street

(Figure 34).

Despite the similar character of the two streets, it can be seen how the southern axis is identified with a lower hierarchic level, in this context, the role of the two streets should be seen in the context of the neighbourhood, where the parallel via Bianchi is also classified as neighbourhood street.

Although the classification system used by the plan is different, the SUMP approved by the Metropolitan city of Turin (Città metropolitana di Torino, 2022) partially maintains this classification for the two axes, since the northern axis is classified as “complementary street”, while the other is a “local street”. However, in the cartography related to the project phase, the plan identifies 30 km/h zones for the neighbourhood, separated by the axes of via Bianchi and via Servais, and the axis of via Cossa, regardless of the classification presented (Figure 35).

Between via Franzoj and piazza Chironi, the two axes are one-way streets, the northern one allowing circulation towards the west, the southern one towards the west. Between Corso Marche and via Franzoj, and between piazza Chironi and piazza Bernini, the axis is a two-way street. Car parking stalls are located along both sides of the street on the one-way sections, while they are located exclusively on the southern side in the eastern portion (Figure 36).

The axes are served by the public transport line 65, with the exception of the portion between Corso Svizzera and piazza Bernini, serving the neighbourhood and providing a connection to the underground line (Figure 37).

Between the municipal boundary and corso Telesio, a bicycle itinerary provides a connection with the municipality of Collegno. The infrastructure is mostly constituted by a two-way path identified by horizontal markings and separated from the traffic lane by parking stalls. Between via Bellardi and corso Telesio, two one-way paths are located on the right side of the two axes. The axes intersect cycling paths in corso Telesio, corso Monte Grappa, and corso Lecce, as well as in piazza Bernini. An important cycling axis, parallel to via Asinari di Bernezzo and Carrera, is constituted by corso Francia. Currently in the section between the municipal boudnary and piazza Bernini, the side streets, known as "controviali", are identified with horizontal and vertical markings as "shared street", with the goal of strenghtening the recognisability of these axes as main cycling itineraries, as well as of inducing drivers to adapt their behaviour consequently, considering that the speed limit is set at 30 km/h. The markings consist in vertical panels and horizontal markings reminding the speed limit and the presence of bicycles, as well as advanced stop lines at some intersections (Figure 38).

The regulatory framework regarding cycling infrastructures can be analysed through the SUMP, approved in 2022, starting from which the new cycling plan is being developed (Torino Metropoli, n.d.). The cartography regarding the current state highlights the existing portion of bicycle infrastructure, moreover, it identifies this portion, as well as its extension along via Asinari di Bernezzo and via Medici, as part of the axis n. 3 (Via Francigena della Val di Susa – Via Francigena della Val d'Aosta) of the national cycling network. Similarly, this is highlighted in the cartography related to the project phase.

As it was previously highlighted, climate change has important implications on urban areas, and the specific characteristics of each context influencing mesoclimate and microclimate are related to the phenomenon. Starting from the evidence of the verification of the consequences of climate change on its urban area, the City of Turin approved in 2020 the "Climate resilience plan", developing a strategy aiming at improving the capacity of adaptation of the city, maintaining the provision of services and of a good quality of life in front of the changes, with special attention to the vulnerable groups of its population, through an approach based on the interaction with best practices and the integration of the competence of multiple technical sectors of the municipality (Città di Torino, 2020). One of the most important outcomes of the analysis conducted in during the production of the plan is that the two main issues related to the effects of climate change in Turin are related to an increase of flooding events due to extreme precipitation events and an increase in intensity and duration of heatwaves (Città di Torino, 2020).

Since the half of the last century, temperatures are reported to have raised both in their maximum and mean values: maximum temperatures increased of 0,6°C every 10 years, with a raising importance of heat waves, which started to happen more regularly during the last years, with the perspective of becoming longer and more frequent in the next 30 years (Città di Torino, 2020). An analysis was conducted during the development of the plan in order to assess the phenomenon of the urban heat island in Turin, which highlighted the contribution of green areas to the reduction of this effect, and the higher exposure to this risk of areas characterized by large presence of impermeable surfaces, such as industrial areas (Città di Torino, 2020).

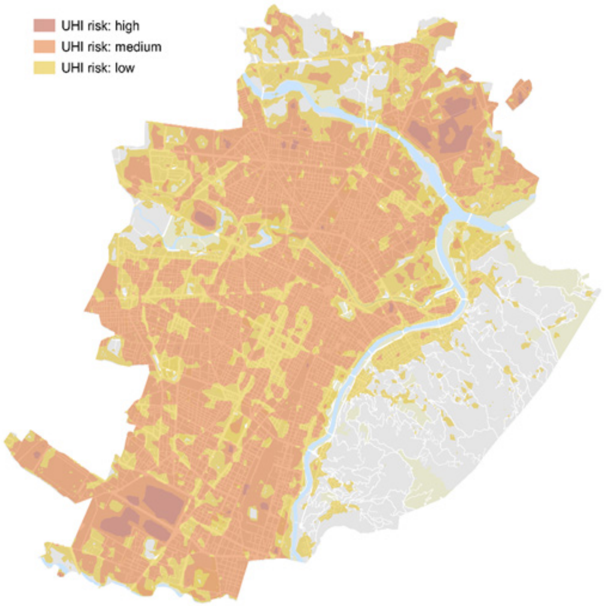


Figure 31. UHI phenomenon in the neighbourhood (Personal elaboration based on data by Città di Torino)

The selected neighbourhood can be identified in the analysis presented in the document. Most of the neighbourhood shows a medium risk, in particular corresponding to the densely built areas. The risk is low in correspondence to the green areas of the neighbourhood, comprising the planted axes of Corso Telesio, corso Monte Grappa and Corso Lecce (Figure 39).

As previously mentioned, the phenomenon of UHI constitutes only one of the processes connected to climate change having an impact on urban areas. The characteristics of the urbanized area as well as the observation of phenomena at the scale of the city stress the importance of an action for thermal comfort facing the climatic conditions.

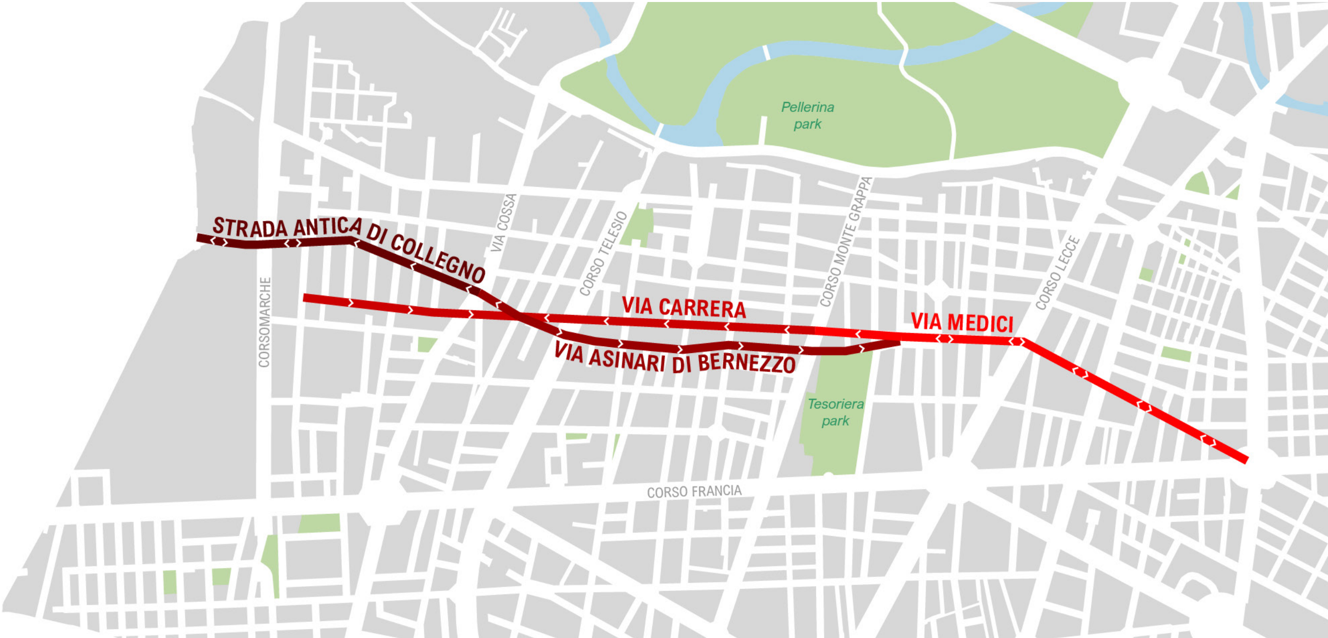


Figure 32. Selected axes (Personal elaboration)

Figure 33. Elements of interest in the neighbourhood (Personal elaboration).

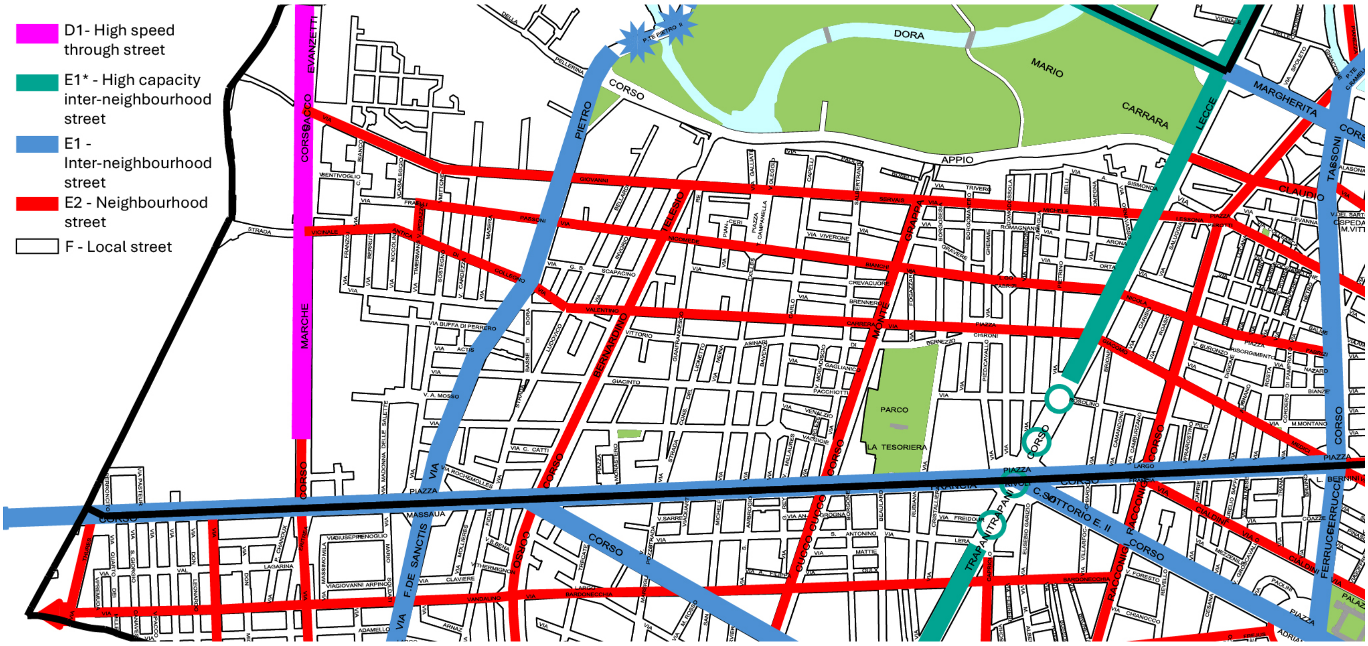


Figure 34. Street hierarchy according to the SUMP of 2010 (Personal elaboration based on Città di Torino, 2010)

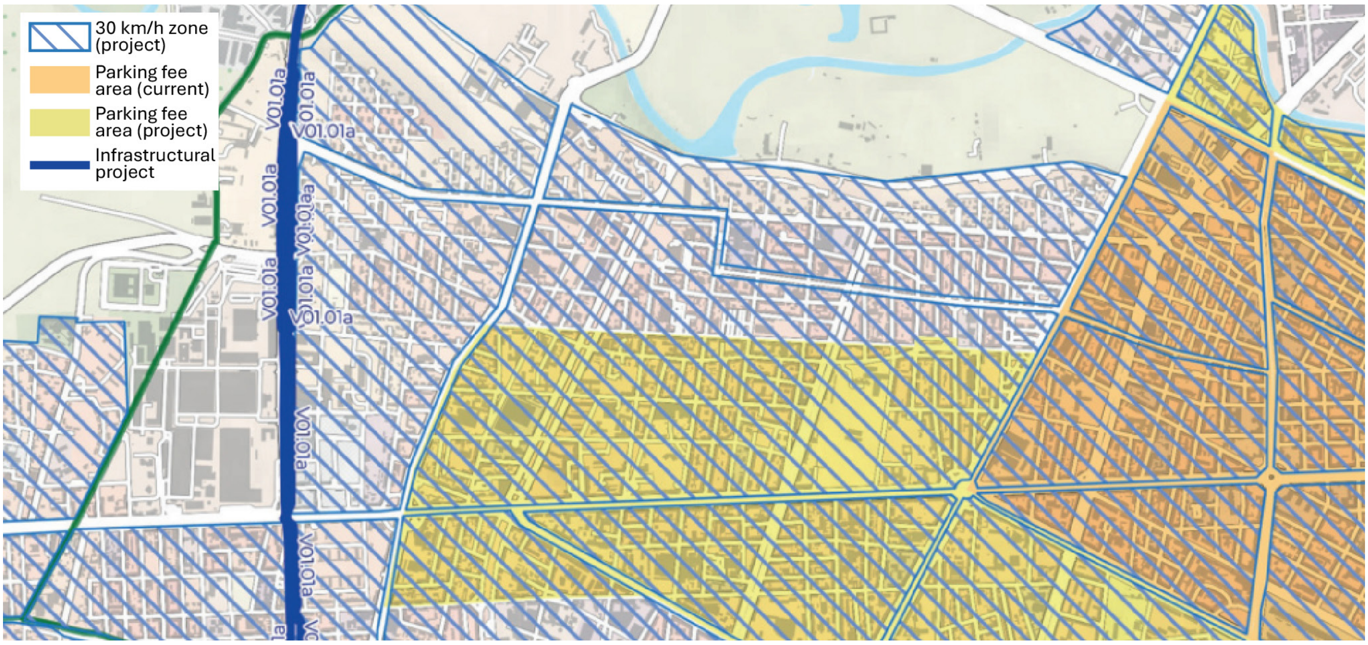


Figure 35. 30 km/h zones identified by the SUMP of 2022 (Personal elaboration based on Città Metropolitana di Torino, 2022).

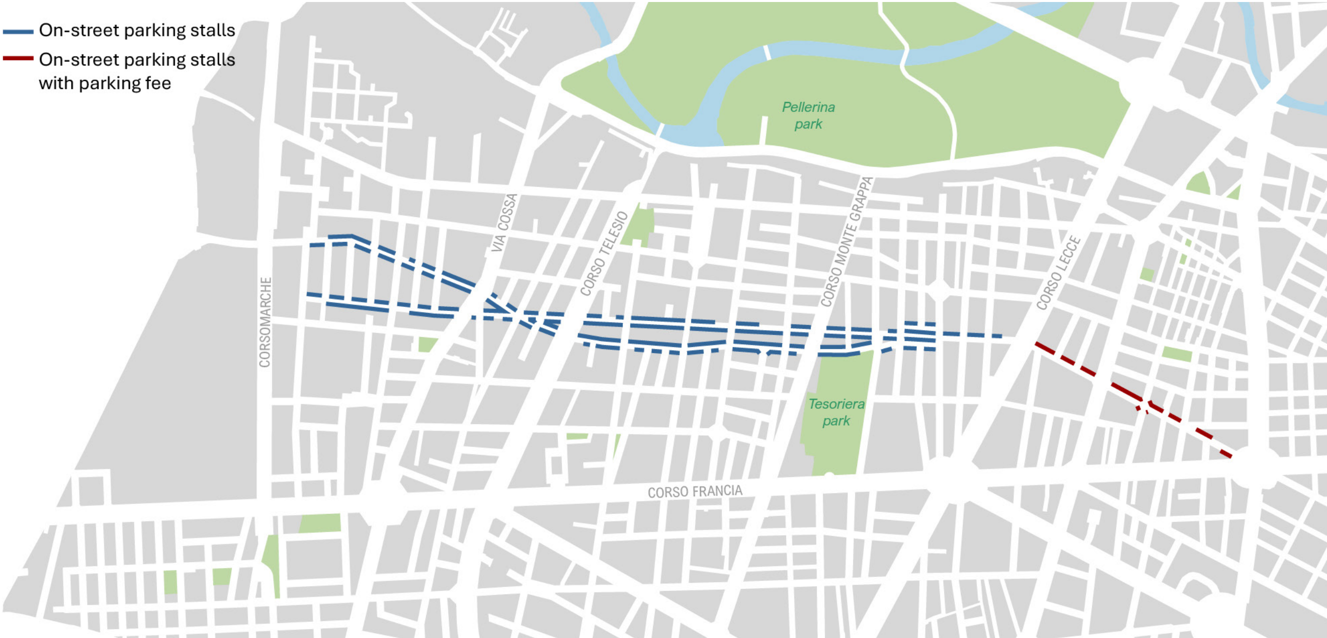


Figure 36. Street parking of the area (Personal elaboration).

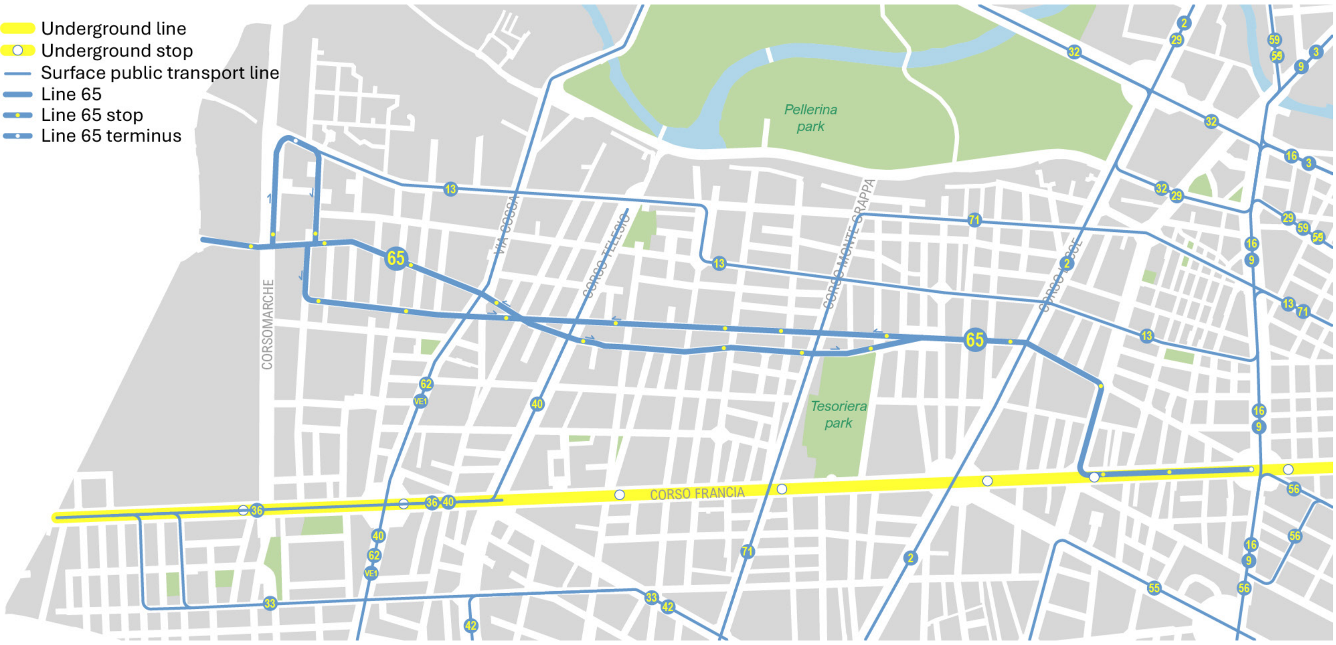


Figure 37. Public transport system (Personal elaboration).

Figure 38. Cycling infrastructure system (Personal elaboration).

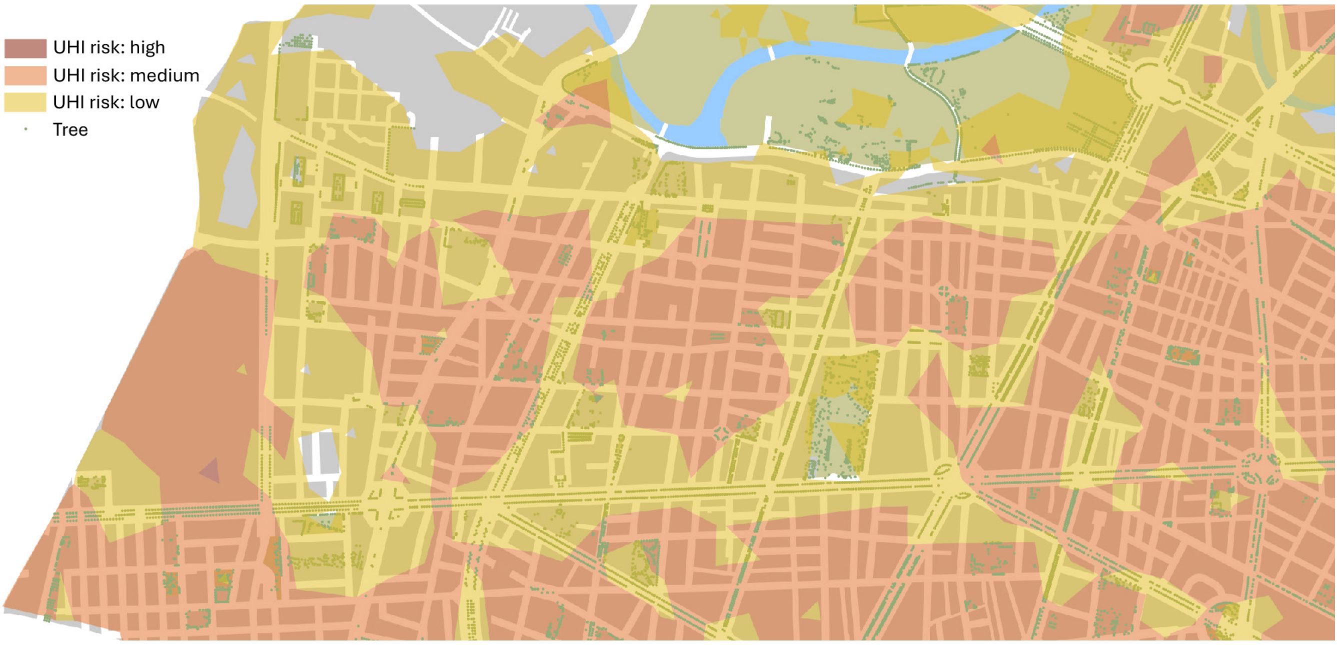


Figure 39. UHI phenomenon in the neighbourhood (Personal elaboration based on data by Città di Torino)

The selected neighbourhood can be identified in the analysis presented in the document. Most of the neighbourhood shows a medium risk, in particular corresponding to the densely built areas. The risk is low in correspondence to the green areas of the neighbourhood, comprising the planted axes of Corso Telesio, corso Monte Grappa and Corso Lecce (Figure 39).

As previously mentioned, the phenomenon of UHI constitutes only one of the processes connected to climate change having an impact on urban areas. The characteristics of the urbanized area as well as the observation of phenomena at the scale of the city stress the importance of an action for thermal comfort facing the climatic conditions.

1. Strada Antica di Collegno: neighbourhood street
2. Via Carrera (between via Franzoj and via Bellardi): local street
3. Via Asinari di Bernezzo (between via Pietro Cossa and via Bellardi): neighbourhood street
4. Via Carrera (between via Bellardi and corso Monte Grappa): neighbourhood street
5. Via Asinari di Bernezzo (between via Bellardi and piazza Chironi): local street
6. Via Medici (between corso Monte Grappa and piazza Bernini): neighbourhood street
7. The bowls court located on via Salbertrand

Figure 40. Elements of interest in the study area (Personal elaboration).

Each of these elements should be taken into account because of their social importance for the neighbourhood, which generates implications on the use of public space, revealing needs in term of redesign, such as the possibility to extend space destined to pedestrians in correspondence with the entrances of the buildings, or the necessity to improve street safety at intersections.

The following map shows the distribution of commercial activities along the two axes, concentrated especially along via Asinari di Bernezzo, at the ground floor of residential buildings. It should be noted the presence of a pastry shop which is provided with a structure for an outdoor terrace, occupying the space of parking stalls on the northern side of via Asinari di Bernezzo.

Another characterizing element of the area is the urban fabric: the section of the two streets is rather uniform, with the exception of the intersection of via Asinari di Bernezzo with via Mogadiscio, where a wider open space is present, currently used partially for parking spaces, but with a large portion of space which could be associated to the "residual spaces" mentioned previously.

Figure 41. Buildings with commercial activities along the selected axes (Personal elaboration).

3.2. Context and objectives of the project, initial proposals

The present work derives from the work conducted at the company Decisio s.r.l. in the context of the commission by the Municipality of Turin for the projects “Assi Ciclabili” and “Quartieri resilienti”. The commission consisted in the technical-economic feasibility study for the two projects. The two projects are complementary, and they foresee actions of redesign of public spaces in the territory of the municipality of Turin, with a different focus:

- The “Quartieri resilienti” aims at selecting specific areas where to implement actions of redesign throughout the neighbourhood, by improving street safety and liveability of public spaces, together with actions to improve climate adaptation: the areas have to be identified through a participative process with the local urban districts n. 3 and 4.
- The “Assi ciclabili” aims at redesigning the space of 4 axes, which constitute primary itineraries for cycling mobility in the city, with a role in providing connections with the neighbouring municipalities: the axes selected by the municipality are:

  1. The completion of Corso Francia, where dedicated infrastructures only exist between piazza Statuto and piazza Bernini, with an action involving the whole length of the axis in connection with its extension in the municipality in Collegno;
  2. The axis of via Medici/via Asinari di Bernezzo/via Carrera, as an extension towards the city centre of the link between Turin and Collegno;
  3. The axis linking Turin with the municipality of San Mauro, running along strada San Mauro and the bridge connecting to strada di Settimo
  4. The connection between the urban core and the nucleus of Villaretto, lacking pedestrian and cycling infrastructure in an extra-urban context.

Figure 42. Location of the four “Assi ciclabili” (Personal elaboration)

The second axis is the focus of this work. The goal of the project committed by the municipality is the extension of the infrastructure, which is already existing, the two-way bicycle path linking Collegno, which is split into two one-way cycling paths until corso Telesio, where a bicycle path intersects the streets and connects to Corso Francia to the south or the park Pellerina to the north. An extension of the two itineraries is pertinent along via Carrera and via Asinari di

Bernezzo, since it is a more direct connection towards piazza Bernini and the city centre, allowing to avoid a detour on corso Telesio and corso Francia, on top of being coherent with the metropolitan SUMP, as previously highlighted. The feasibility study was aimed at analysing the characteristics of the area and identifying possible scenarios of redesign to address the transformation foreseen.

In the context of the feasibility study, at the date of production of this work, the first phases have already taken place. The analysis of the context foresaw the production of documents regarding the reading of the current state of the axes, ranging among multiple themes. The analysis highlighted especially some key points:

- The location in a context with a high density of schools: this strengthens the importance of the provision of accessible spaces for all users, given the central connecting role of the axes, with attention to the objective of street safety, considering in particular that four schools have their main access on one of the selected streets, constituting points where specific measures to improve safety can be relevant. Apart from the presence of a raised pedestrian crossing in correspondence with the access to the school Manzi in via Medici, no specific interventions were registered.

- The prevalence of space destined to cars, both for circulation and parking, with the presence of wide lanes, compared to an absence of cycling infrastructure and reduced green spaces, which are concentrated only in piazza Chironi. Sidewalks result to have adequate dimensions, mostly ranging between 2,5 and 3,5 metres.

- The relevance of parking stalls, and the phenomenon of unauthorized parking, for example in correspondence with bus stops, which are not provided with design measures to discourage such behaviour.

- The concentration of car accidents in correspondence with the intersections with Corso Monte Grappa and Corso Lecce

Following the analysis, the phases of the project foresaw the production of proposals for a redesign of the axes, through the use of sections. The proposals involved sections referred to different portions of the axes, in this context, the focus is on the portion comprised between Corso Telesio and piazza Chironi. The proposal consisted in a redesign of space, in order to improve the quality, starting from a redistribution of the space between users guided by the introduction of an infrastructure for cyclists, by maintaing the sidewalks, which resulted to be adequate, and by increasing green areas as a tool to improve liveability and attractivity. The schemes presented constitute a first phase of the proposals, and they will be subject to adjustments and integrations with the evolution of the project. Given the complementarity of the two axes, characterized by opposite circulation directions, different proposals were presented, based on the section of via Asinari di Bernezzo:

1. A separated cycling path in the same direction of vehicular circulation, located on the right side of the street, maintaining parking stalls on the opposite side and adding a green strip replacing parking stalls on the side of the cycling path.

2. A separated cycling path in the opposite direction of vehicular circulation, located on the left side of the street, maintaining parking stalls on the opposite side and adding a green strip replacing parking stalls on the side of the cycling path.

3. The introduction of markings, the use of a coloured surface and the use of different materials for the lateral strips of the street in order to reinforce the association to a cycling street, where bicycles and cars share the same surface, by maintaing parking stalls, alternated with green areas for planting.

4. A combination of scenarios 2 and 3, by maintaining the shared scenario in the direction of circulation, and allowing cycling contraflow on a separated bicycle path, by maintaining parking stalls on one side of the street and adding greenery on the side of the bicycle path.

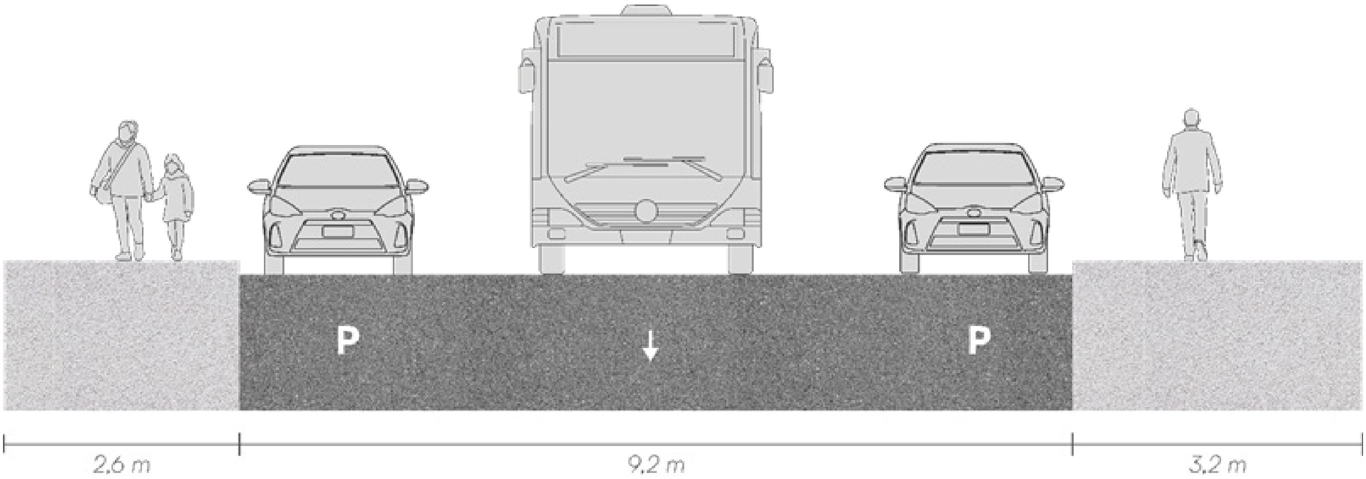


Figure 43. Decisio proposal: current state (Decisio s.r.l.)

Figure 44. Decisio proposal: scenario 1 (Decisio s.r.l.)

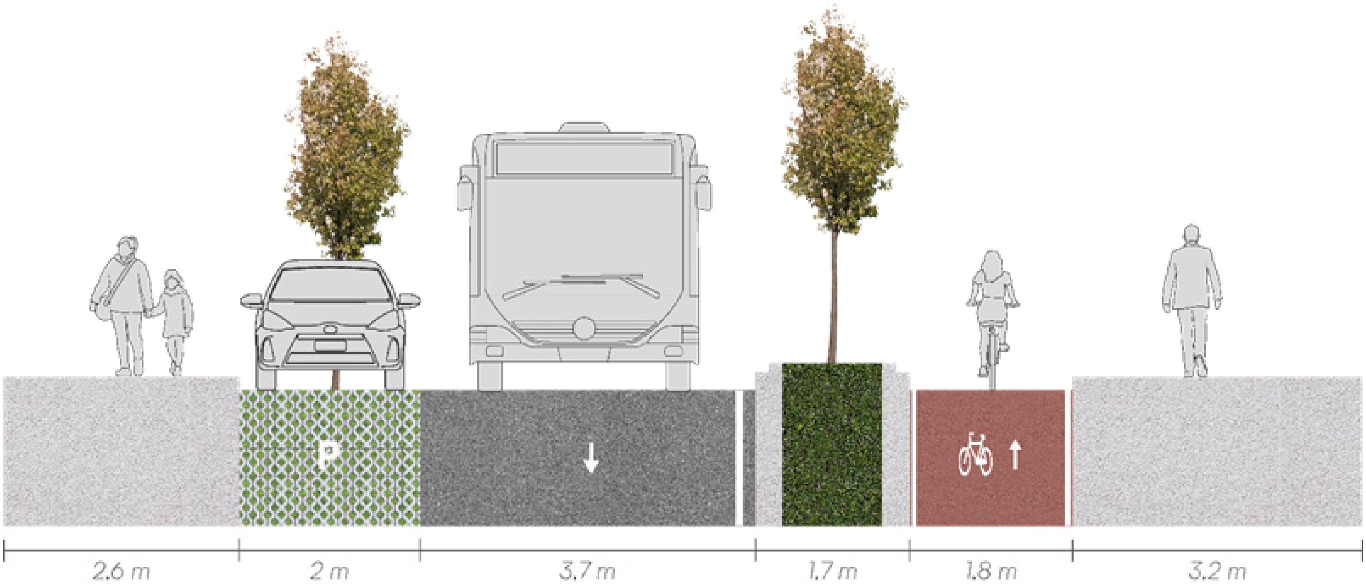


Figure 45. Decisio proposal: scenario 2 (Decisio s.r.l.)

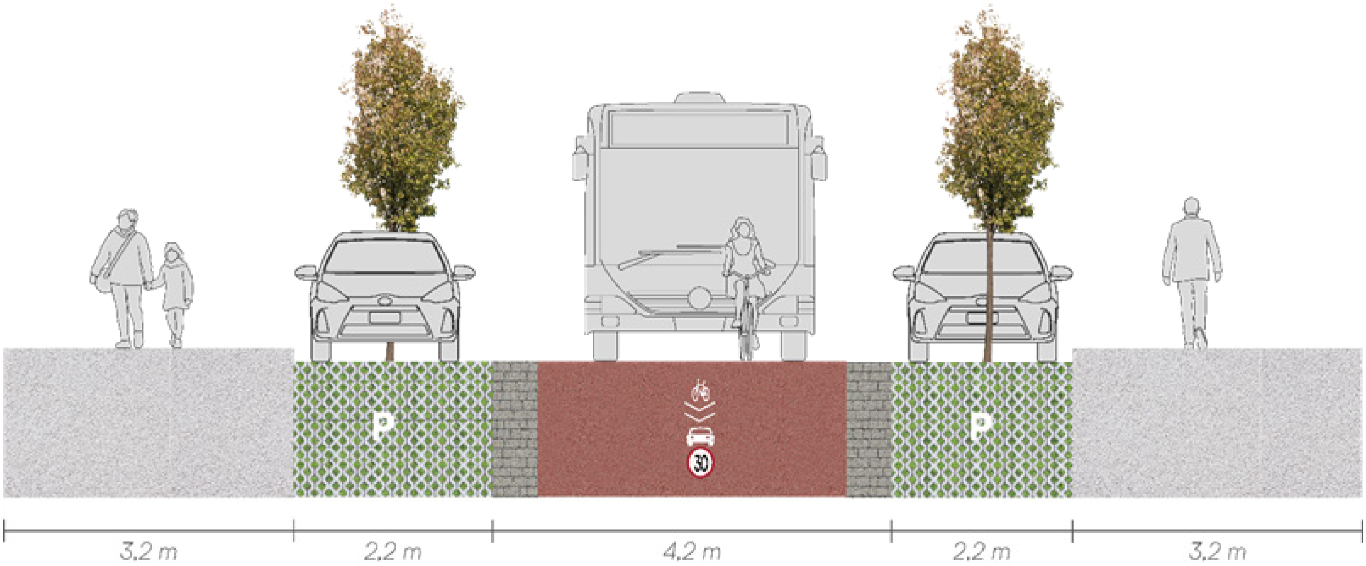


Figure 46. Decisio proposal: scenario 3 (Decisio s.r.l.)

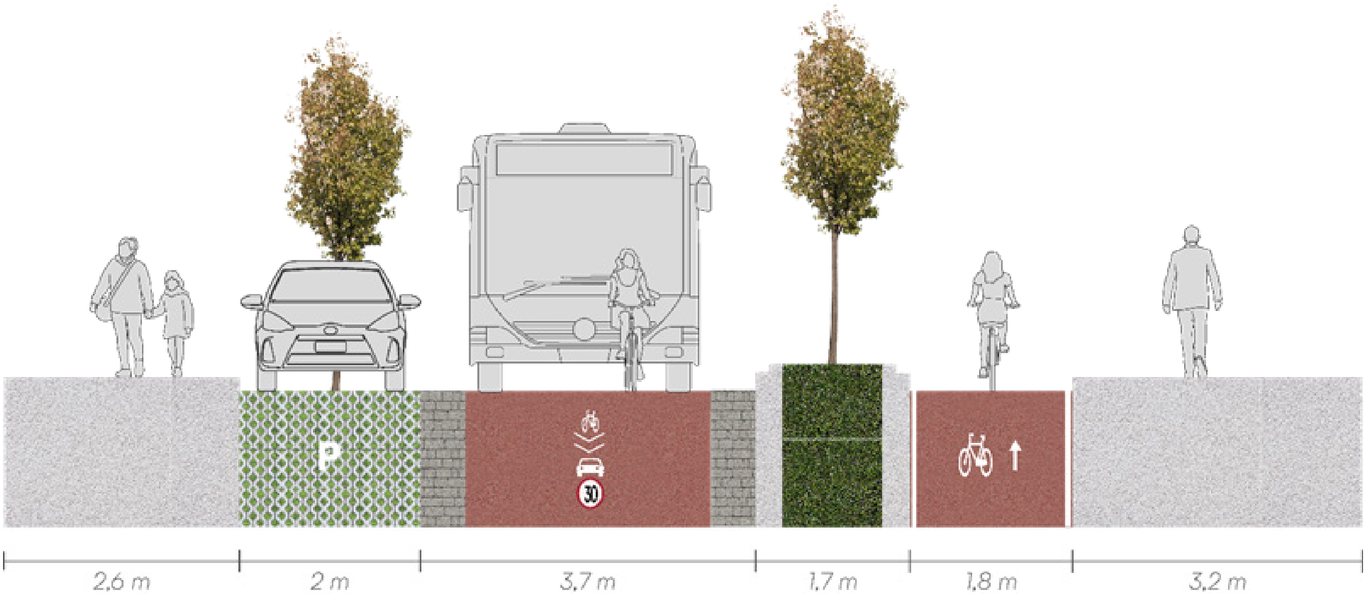


Figure 47. Decisio proposal: scenario 4 (Decisio s.r.l.).

Some remarks can be highlighted for the different scenarios.

- The scenarios introducing a separated bicycle path appear to provide increased safety and recognizability for the cycling itinerary, compared to the shared scenario, which requires particular attention where the axis is characterized by relevant traffic flows. However, the scenario 3 allows a less transformative approach, maintaining a higher number of parking spaces, which constitutes an important element in the area, and which resulted to be important for the municipality.

- The scenarios 2 and 4 might appear unusual, due to the bicycle contraflow which is not common in Turin, and they might result less logical compared to scenario 1 for cyclists, especially for the users which are not aware of the circulation scheme of both axes. However, drivers turning left might be facilitated in identifying cyclists coming from the opposite direction, while scenario 1 requires attention in the right turns, especially if insufficient space is designed for cars to give priority.

- In all cases, the lane width is reduced, considering however that a minimum width of 3,5 should be maintained for neighbourhood streets, taking into account also the presence of the bus line. It was decided to maintain or, in some cases, increase the existing sidewalks width, keeping as a principle the idea of avoiding reductions of space for pedestrians. The necessity to meet the minimum requirements, as well as to have sufficient space for the bicycle infrastructure and for the green strip may induce to reduce the width of sidewalks.

- In the cases proposed, the green strip works as a separating element between the bicycle path and the circulation lane, while parking spaces are located contiguously to the sidewalks. However, as it will be seen later, attention should be provided to the shading function of trees, which can lead to move the strip to other locations, requiring attention to the necessary separation of the cycling path.

- Changes to this organization of space can be made in order to reduce speed, for example by introducing changes of level (such as raised intersections, speed bumps) and changes of direction (such as chicanes), as well as to solve particular needs, such as extensions of the sidewalks at the entrances of public buildings and schools.

The proposal of design of this work will start from these proposals, by selecting the most suitable configurations for the entire portions of the streets selected and by adapting the needs related to the component of mobility to the ones of thermal comfort.

4. Methodology

4.1. PET index and ENVI-met

The objective of this work is the integration of a project of requalification of two urban axes with measures aiming at improving thermal comfort. In order to achieve an evaluation of the current climate conditions as well as an observation of the result of the interventions undertaken, thermal comfort tools are used as an objective instrument to assess the main critical points and strengths of the current urban space in order to provide an indication of possible interventions. As mentioned, models have been developed for the evaluation of outdoor thermal comfort based on the existing ones for indoor conditions. The present work is based on the use of the PET index, measured through the software ENVI-met. The model on which the comfort index is based is a "two-node model", based on the comparison of the studied environment with a reference environment: the index corresponds to the «temperature of a reference environment that would provoke the same physiological response as the studied environment» (Walther and Goestchel, 2018, p. 1). First developed by Höppe, the PET index is defined as «the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed» (Höppe, 1999, p. 73). The values for clothing and activity are assumed as stable, in order to allow comparisons between indexes without considering different human behaviours (Höppe, 1999). Through the PET index, therefore, thermal comfort is expressed starting from the use of skin and core temperature (ENVI-met, n.d.). The constitution of the index coincides with the following procedure (ENVI-met, n.d.):

- Definition of incoming and outgoing fluxes of the body;
- Definition of a skin and core temperature coherently with the fluxes;
- Definition of a condition in which the person is in an indoor environment, instead of outdoor
- Elimination of the data referred to outdoor conditions, such as radiation and wind
- Definition of an indoor temperature which would cause the same skin and core temperature of the outdoor environment, corresponding to the PET

Höppe (1999) stresses how the PET can be used to evaluate external temperature based on human experience, allowing to have a single index for an overall comparison of climate conditions, considering the effect of multiple parameters, such as air temperature, air velocity, air humidity. Because of this, the index is used in this work as a tool to perform a comparison between two statuses, before and after a projected intervention on the area, in order to evaluate the effectiveness of the measures aimed at improving thermal comfort, although the observation of the single parameters will be taken into account.

The PET index was evaluated in this context through the software ENVI-met. This tool simulates the interactions between climatic parameters with elements such as vegetation, built environment, soil, and surfaces, allowing to observe the effects on microclimate of small transformations, through the input of mesoscale climate conditions (Bruse and Fleer, 1998; Sharmin et al., 2017).

For this work, ENVI-met was used as a tool allowing an objective evaluation of the performance of two scenarios in comparison. The modelling of the study area was first conducted considering the current state, and secondly considering the spatial configuration of a scenario of transformation, characterized by a requalification of the public space aiming at integrating the objectives related to the component of traffic calming and the one of thermal comfort. Each of the two scenarios, therefore, was evaluated through a simulation conducted using the software, of which the results were analysed through the production of cartographies and the comparison of absolute values referred to selected climatic parameters.

4.2. Phases and settings of the simulation

The operations related to the software ENVI-met can be divided in three phases:

1. Modelling
2. Simulation
3. Outputs

The first phase consists in the provision to the software of the different input data necessary to perform the simulation. One of the main input data to be provided consists in the information regarding the elements constituting the space, including the characteristics of the built environment, of soil, of vegetation, of water bodies. A modelling of space must be operated by the user. To do so, the section “Spaces” of the module “Edit” of the software provides a tool through which each of these elements can be defined. The modelling of space in the software is operated with the support of grid cells, to which the user assigns the characteristics of the portion of space they are referred to. According to the expected level of detail, the cells can have different dimensions. Given the necessity to operate on a small portion of a neighbourhood, and especially with the intention of observing the impact of decisions related to street design interventions, the dimension of cells was set to 2x2x2 metres, considering that a furtherly smaller dimension of cells could lead to an excessive simulation time. Based on this, the dimension of the model was set, considering a height corresponding to the double of the maximum building height observed in the area. As a base for the modelling, a basemap can be loaded to the software. In this case, it was decided to use the technical cartography of the City of Turin, with a scale of 1:1000, allowing to have correct details regarding space. The area is constituted by a rectangle with dimensions 400m and 300m, corresponding to 200 × 150 grids. 40 grids are considered for the height, the lowest cell of the vertical grid is divided by 5, allowing a higher degree of precision in correspondence to the portion closer to the users of space.

Figure 48. Basemap used for the modeling phase (Carta Tecnica Comunale, Comune di Torino, 2023)

The modelling procedure consisted in the assignment of a set of characteristics to each cell of the model, according to the element of space they corresponded to, based on a comparison with the basemap. The modelled elements were:

- Buildings
- Surfaces
- Vegetation

Regarding buildings, the software allows the definition of specific characteristics for each element. Given the focus of the study, which aims at observing changes on public space rather than on built elements, an evaluation of the prevalent character of the buildings of the area was used as a base for the settings of the model. The two main aspects to be set are the roofing and the façade materials. In this case, it was observed that the prevalent roofing material were tiles (set as “Roofing: Tile” in the software), while façade materials were more various, although a prevalence of bricks (set as “Brick Wall: burned”) was registered. Considering once again the lower necessity for details regarding buildings, roofs were modelled as flat, taking into account the building height registered in the layer of the GIS technical cartography of the city of Turin. Based on the correspondence to the basemap, each grid cell belonging to a building was assigned a height with the pre-set material, for the entire area.

Regarding surfaces, the default soil material was pre-set by the software as “Default Sandy Loam”. A surface material was assigned to all soil not covered by buildings or grass. Different typologies were registered in the area. The main one consisted of asphalt, used on carriageways, characterised by an albedo of 0,12 in the ENVI-met database. Despite smaller differences in colour appearing on urban streets, a specific material with an associated single albedo was chosen for the area, considering the variability in time of the state of the asphalt layer due to periodic interventions of restoration. The whole network of sidewalks of the area is composed by asphalt, despite appearing slightly different in texture than the one used for the carriageways, it was chosen to use the same material in the modelling in the software. A third material chosen for the area corresponds to “Concrete Pavement Gray”, which was observed to be present especially in some of the internal courtyards of the blocks of the area. Despite a variability in texture and colour of the surfaces, this material is generally characterised by a lighter colour and therefore a higher albedo (pre-set as 0,3 in the software). Only one of the courtyards, through a satellite observation, appeared to be composed of a different material, which was associated with “Brick Road (yellow stones)”, with albedo 0,4. Given the peculiar characteristics of the bowls court located on via Salbetrand, it was chosen to assign to this area the material “Pavement (Concrete) used/dirty”. The football pitch located next to the garden of via Carrera is mostly composed by a dirt patch, since the material was not existing in the ENVI-met database, the definition of a new material was necessary with the creation of a database, through the “DB Manager” tool of the software. The material, named “Dry clay soil”, was obtained by cloning and editing the ENVI-met database material “Loamy soil” by editing the albedo as 0,2, as a value coherent to the ones contained in Dobos (2003).

Two typologies of vegetation can be added through the software. The first, called “Simple plants” in the software, concerns in the case of this work grass surfaces. Such surfaces are located prevalently in the public green area located next to via Carrera. Smaller grass surfaces are also located inside the courtyards, and small green strips are located around the school “Dante Alighieri”. Although every green area might have different characteristics in terms of species of vegetation as well as maintenance conditions, a single typology of grass was selected for the whole area. In particular, the grass which was selected resulted from an edit of the default grass existing in the software, by modifying the height from 10 cm to 25 cm, through the use of the “DB Manager Tool”. Moreover, hedges belong to the same typology of vegetation, and they can be selected according to their height. In the area, they are mainly located around some private courtyards and the area belonging to the school “Duca d’Aosta”. The other typology of vegetation inserted is “3D Plants”, which corresponds in the area to trees. In the area, trees are located both in privately- and publicly-owned areas. While the information regarding height and species of the trees on public areas is accessible through the data of the municipality, the characteristics of the trees located on private areas were obtained through direct observation and comparison with the other type. The software allows to insert trees according to different criteria, in the context of this work the selection was done through a comparison with the characteristics of the elements: the selection was done between Conifers, Deciduous Trees and Palm Trees. Three categories of height are foreseen by the software (5m, 15m, 25m), as well as two different typologies of canopy (sparse or dense), and different shapes (conic or cylindric for conifers, cylindric, heart-shaped or spherical for deciduous trees). The highest trees are located in the public green area next to via Carrera and around the bowling green, and in the courtyard of the school "Duca d'Aosta". Smaller trees are located in the green public area, as well as in the back courtyard of the school "Cavaglià", and in private areas.

After the definition of the characteristics of space, and the definition of additional aspects regarding the area of the model, additional input concerning climatic data should be provided, through the "ENVI-guide" section of the "Simulate" module. Due to time constraints, the simulation is performed considering one day, to which the climate data are referred. In the case of the present work, the selected day was 27/06/2019, the hottest day of 2019, in order to have comparability of the results of the simulation on the area with other similar works analysing climate conditions on the same date. The software requires to provide data regarding the speed and direction of the wind at the beginning of the simulation, while the data regarding relative humidity and temperature should be provided hourly. The file generated with the addition of this information was used to launch the simulation through the "ENVI-core" section of the software. The data were obtained from ARPA databases, considering the station "Giardini Reali" for air temperature, relative humidity and solar radiation, and the station "Reiss Romoli" for wind speed and direction. The data used for the simulation are inserted in the following page.

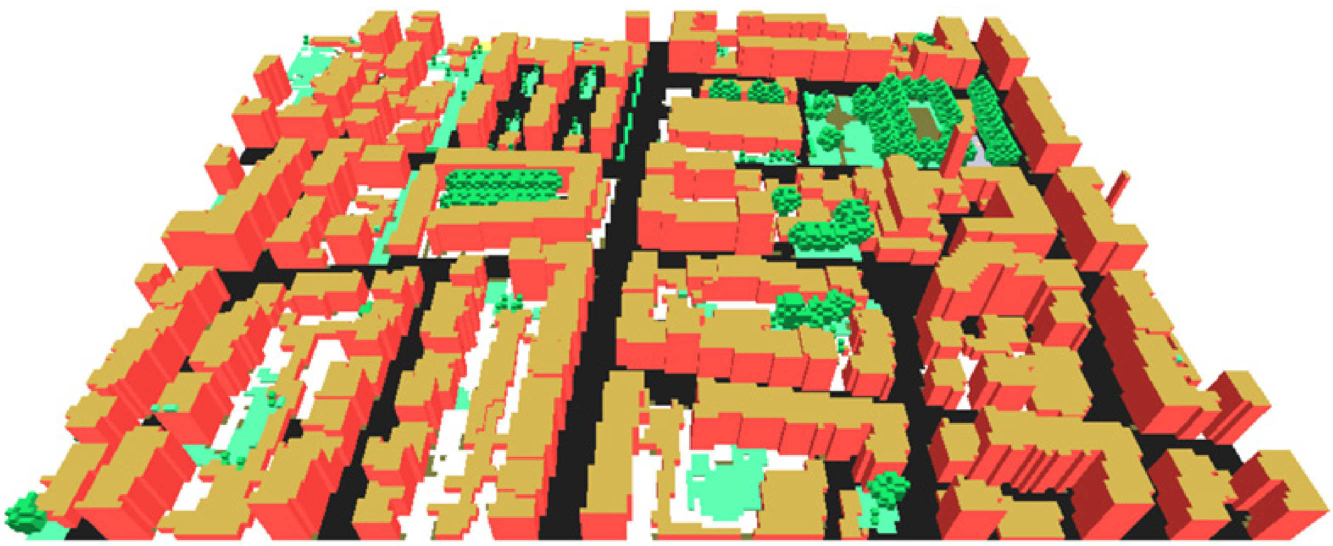


Figure 49. 3D representation of the selected area in the model of ENVI-met

Hour	T air °C	R.H. %	Wind speed (m/s)	Wind direction °
0:00:00	25,2	82	0,0	-
1:00:00	24,6	84	1,0	308
2:00:00	24,2	87	0,9	276
3:00:00	23,7	90	0,3	272
4:00:00	23,5	92	0,7	323
5:00:00	24,0	90	1,5	271
6:00:00	27,0	75	1,2	247
7:00:00	30,1	54	2,2	227
8:00:00	31,1	57	1,2	254
9:00:00	32,4	53	2,6	181
10:00:00	32,9	54	2,0	200
11:00:00	34,1	52	2,9	173
12:00:00	35,3	47	1,4	188
13:00:00	36,3	40	2,5	184
14:00:00	37,1	39	3,0	186
15:00:00	37,6	35	4,0	199
16:00:00	38,2	27	4,3	201
17:00:00	37,4	34	2,6	214
18:00:00	34,9	43	1,9	245
19:00:00	31,1	59	1,7	327
20:00:00	29,4	66	2,6	319
21:00:00	27,6	69	1,6	309
22:00:00	26,6	75	1,8	267
23:00:00	25,6	80	1,7	323

For the simulation, the “simple forcing” method was used. Compared to the “full forcing” method, it is less accurate and it requires less input data. Moreover, it is less precise on the simulation of the movements of air, since it requires as an input only the values at the first hour of wind speed and direction (ENVI-met GmbH, 2024). The outputs of the simulation can be obtained through the visualisation of cartographies, generated by selecting one variable and the time of the day, through the section “Leonardo” of the “Visualise” module. For the purpose of this work, cartographies were generated for the climatic variables of interest (Solar radiation, Potential air temperature, Surface temperature, Relative Humidity, Wind speed) as well as for the representation of the PET index. While requesting the results of the simulation, given the three-dimensional character of the software, it is necessary to select a height at which the variable should be analysed. Among the available options of the software, the height of 1,80m was chosen, as it is the closest to the average human height.

4.3. Integration with the project

The elaboration of cartographies allowing to visualise the results of the simulation corresponds to the beginning of the analysis of the characteristics of space and the climate conditions of the area of analysis before the intervention. Through a comparative reading of the cartographies, the interaction of different variables can be observed, in order to highlight specific elements of attention, especially critical areas or phenomena in terms of thermal comfort, which will be taken in consideration during the elaboration of strategies for the area. Specific interactions of particular critical values for single variables can be analysed in order to identify needs to be addressed in terms of thermal comfort, for example through the adoption of measures in order to increase shading or favour ventilation.

Parallelly, the work studies possible scenarios for the design of the space of the two selected streets, through a requalification which includes a redistribution of space, with the objective of allocating suitable space to each of the functions of the street, with attention to the element of street safety.

The key point of the work consists in the elaboration of solutions which allow to integrate these needs in terms of thermal comfort to the fundamental elements in terms of mobility of the requalification of the space. The presentation of the context allowed to observe the characteristics and the needs in the area in terms of mobility and in terms of climate conditions. The objective is the elaboration of a design of space which can take into account the two aspects and provide synergic solutions, by trying to provide correct solutions aimed at meeting the needs of each component. It must be considered that this approach might lead to trade-offs, considering the reduced amount of space characterising a dense urban fabric, and taking into account that conflicts might emerge in the allocation of space to a specific function. This constitutes a further element of complexity, considering that conflicts rise even in the definition of solutions aiming at working on single aspects. Examples might be the need to increase space for pedestrians and cyclists by limiting the impact on the provision of parking spaces, which in the selected context cannot be ignored. Similarly, it was seen how an appropriate selection of materials for the mitigation of the phenomenon of urban heat island, in certain conditions, might not be the most suitable choice in terms of improvement of thermal comfort. Therefore, the production of scenarios of space design is aimed at illustrating solutions providing an integrated scheme for the selected area.

5. Simulation

5.1. Results of the first simulation

The results of the simulation can be analysed through maps generated by the "Leonardo" component of the software. A graphical representation of the area analysed is provided according to a high number of parameters which can be taken into account. For the purpose of this work, the variables were selected according to their relationship with the thermal comfort of pedestrian and cyclist street users, as well as their relationship with the open public spaces. The focus being on the characteristics and the potentials for transformation of the different elements of the street, the parameters allowing to analyse its surface and its relation to thermal comfort were selected. A further analysis could focus on the other components of the urban fabric, such as the built environment, its morphology and its materials, since they can have an impact not only on the climate condition of the urban area as a whole, but also on the microclimate of the street. However, since the present work is not intended to intervene on the built environment, its characteristics are considered as invariable before and after the proposal of this work. As mentioned, however, the effect of the other components of urban space should be kept into account, and the performance of each variable should not be only attributed to the characteristics of the public space.

Given the settings of the simulation, it is possible to observe the results related to each variable for each hour of the selected day, through the generation of maps.

The variables considered are:

- Solar radiation
- Potential air temperature
- Surface temperature
- Relative Humidity
- Wind speed
- The PET index

The analysis of the results is conducted in two ways: first, by analysing each value throughout the day, in order to focus on the variations and distribution of its values, secondly, by focusing on 4 specific hours of the day, in order to focus on the interaction of the variables in their contribution to thermal comfort. Due to the high number of images and in order to avoid redundancy, in this text are inserted the outputs referred to the hourly analysis.

Single variable analysis

Solar radiation. The analysis of solar radiation is fundamental because it allows to observe the direct impact of the sun on the temperature of the air and the surfaces. In particular, the component of direct solar radiation is strictly influenced by the characteristics of the urban fabric and elements such as vegetation: the analysis of direct radiation clearly provides an overview, at each time, of the areas radiated and the ones which are shaded, allowing a comparison between the two and therefore observing the impact of shading on the temperature. It was already shown that one key element for thermal comfort is shading.

On the selected day (26/06/2019), solar radiation is first registered in the area on the image referred to 5:00. The two axes of via Carrera and via Asinari being oriented along the east-west direction, they are immediately radiated starting from 6:00 to 7:00, a period of time at which almost the whole surface of the two streets is receiving direct solar radiation. Starting from 8:00, shadow appears on the southern side of the axes, at 12:00 the shadows reach the longest extension, covering therefore a broader portion of the surface of the two selected axes. The shadow's width along the axes reduces progressively until 15:00, when the streets are again almost completely radiated. Shadows on the northern side of the streets appear starting from 17:00, especially on via Asinari di Bernezzo due to the orientation and the height of the buildings, while at 18:00 the streets are almost completely shaded.

The morphology of the blocks located on the southern side of the streets obviously reflects the presence of shadow along the two streets, with an important effect on comfort especially in the warmest period of the day. The blocks along via Carrera are characterised by a more continuous profile, mostly given by the presence of large buildings such as the schools and the religious complex, providing better shadowing capacity than the discontinuous morphology of the blocks on the northern side. On via Asinari di Bernezzo, while the blocks are characterised by an east-west orientation of buildings between via Capelli and via Salbertrand, allowing a better shading, the north-south orientation of the buildings located in the blocks between via Exilles and via Capelli is not particularly favourable for a continuous presence of shadow. The numerous intersections, especially the one via Mogadiscio, furthermore, increase this effect.

Furthermore, it is possible to observe the shading effect of vegetation, especially where trees are characterised by larger sizes and density. An important shaded area is the public garden of via Carrera, as well as the courtyard of the school "Duca d'Aosta", where the combined effect of vegetation and buildings can be verified.

Surface temperature. An element which is strictly related to solar radiation is the surface temperature, both because of the presence of shading devices which reduce the temperature of the surface, but also because the characteristics of the surfaces react differently to radiation. The first element which can be observed is the relation with direct solar radiation, with an increase of surface temperatures in areas which coincide with the ones mentioned above. The hourly analysis will highlight how, especially in the morning, shaded surfaces are cooler than the radiated ones. During afternoon the distinction between them is less visible. During night hours the temperature is rather uniform, ranging between 26° and 28° until 23:00, and then lowering until 19° to 23° at 05:00, before the sunrise. This may be an indication of the behaviour of surfaces, which maintain the higher temperature even after the direct radiation has finished, especially for asphalt surfaces: between 02:00 and 05:00 the concrete courtyards appear to be 1° to 2° degrees cooler. A comparison between the asphalt surfaces of the street and other areas shows that concrete areas are slightly cooler during the day, while a higher difference can be observed with the grass of the garden on via Carrera: at 13:00, while the street shows a temperature of 50° to 54°, the unshaded portions of grass show temperatures of 43° to 46°: Most importantly, however, the vegetation plays an important role in the reduction of surface temperatures, as it can be observed in the courtyard of the school "Duca d'Aosta", which, despite being mostly covered in asphalt, shows temperatures below 24° at 13:00, even on the portion not shaded by the building, or in the small vegetated area between the kindergarten and the church on via Asinari di Bernezzo, with temperatures of 24° to 28°, or in the garden on via Carrera, where the temperatures range between 24° and 35°.

Potential air temperature. In general, during daytime, the highest temperatures are experienced on asphalt streets. The relation with direct radiation can be seen especially after the sunrise and before the sunset, when the two east-west axes show higher temperatures, while in the central period of the day it is more difficult to observe a strict relation. A detailed description of air temperature will be included in the hourly analysis. During daytime, it is useful to observe how the internal areas of the blocks are generally cooler than the streets, probably due to the combined effect of the shadow provided by the buildings, the higher albedo of the pavement and the sporadic presence of vegetation. The impact of vegetation on air temperature is particularly visible: the trees allow the highest reduction in temperature, at least of 1° in comparison to the adjacent street for the case of via Carrera, while the courtyard of the school "Duca d'Aosta" is affected by the combined effect of vegetation and shading. While observing the maps it should be noted that the focus should be placed on the central portion, while the high temperature of the edges are the result of the simulation operated by the software, which does not take into account the characteristics of the fabric located outside the area.

Wind. The analysis of wind allows to observe the effect of the characteristics of the fabric. The wind comes from north-west, as it can be observed in the widest open spaces. An effect of urban canyon can be partially seen along the two selected axes, where higher wind speeds are concentrated along the streets from west to east. Given the direction of wind, higher speeds are mostly observed on the southern sides of the streets, and the flows are diverted in correspondence of intersection with north-south axes. The long blocks along via Carrera allow to form a more continuous flow, while the morphology of the blocks along via Asinari di Bernezzo does not have the same effect. Wind speed is mostly similar throughout the day.

Humidity. The analysis of relative humidity highlights a partial interaction with solar radiation. Especially during the morning, higher values of relative humidity are associated with the shaded areas, taking into account especially the shadow provided by buildings. On the two selected streets, in the afternoon, the distribution appears to be more uniform. A key role in the context of relative humidity is played by vegetation, as it can be observed on the two areas with a high presence of trees, where high values of humidity are observed throughout the day. By comparing humidity with radiation, it can be observed that this effect is related with the shading effect of trees, however, given the prolongation of the effect on humidity after 18:00, when direct radiation stops on the area, as well as the slightly higher values on the grass exposed to sun in the garden of via Carrera, it can be noted that a role is played by vegetation regardless of its shading function.

PET. As mentioned before, the PET takes into account multiple variables and human characteristics and provides an index which can be used to evaluate thermal comfort. As in the other cases, the PET index is evaluated hourly at a height of 1,8m. For the index, maps were generated both by maintaining the standard classification of the software, which generates different classes according to the maximum and minimum value of the selected time, and by setting a standard classification with identical classes for every time selection, which allows better visual comparison, but lower detail due to the necessary amplitude of the classes. One of the main outcomes of the analysis is the confirmation of the relationship between thermal comfort and solar radiation. The differences in values of the PET during daytime coincide in most cases with the differences between shaded and radiated areas, stressing therefore the importance of providing shade as a strategy to increase thermal comfort on public spaces. Excluding shaded areas, during daytime, it can be observed that higher values of PET are reported in courtyards, characterized by surfaces with high values of albedo: although it can be considered that this may be the result of lower ventilation, this finding can constitute a confirmation of the unsuitability of high-albedo materials in terms of pedestrian thermal comfort, showing that low-albedo materials, despite increasing air and surface temperature, have better performances in terms of thermal comfort. As with the analysis of the other variables, the representations show the importance of shadow provided by vegetation, highly reducing PET values on public and private spaces. The area covered with grass, considering PET values, does not appear to particularly influence thermal comfort, showing similar values to the nearby streets, without considering the shaded areas. During daytime, and particularly the central hours of the day, some areas appear particularly exposed to higher PET values, corresponding to intersections or wider open spaces: an important example is the wider space corresponding to the intersection between via Asinari di Bernezzo and via Mogadiscio which, during the afternoon, shows values higher than 57° on its eastern portion. Similarly, higher values are observed at the intersection between via Carrera and via Capelli. Overall, the hour showing the highest maximum PET value is 15:00. It must be said that at this time, the values range between 48° and 54°, with some particularly hot areas, as mentioned before. Few are the portions of the street with lower values along the street, since the shadows are mostly oriented towards east.

Given the settings of the simulation, it is possible to observe the results related to each variable for each hour of the selected day, through the generation of maps.

Hourly analysis

In order to observe the interaction between the different parameters, the analysis can be conducted based on specific moments of the day, considered as significant. The selected hours are:

- 07:00, due to the relation between the orientation of the streets and the direction of the sunlight. It was observed that on the selected day at this time, sunlight from the east radiates almost completely the surface of the two axes, with a lack of shaded areas along via Asinari di Bernezzo and via Carrera, with the exception of the small surfaces deriving from the inclination of via Asinari di Bernezzo

- 12:00 since the sun radiates the streets perpendicularly, resulting in shadows located on the southern sides of the streets, and with their minimum length.

- 15:00, since the output of the simulation referred to this time showed the highest maximum value, and particularly high values along the two axes

- 18:00, when the sun does not radiate the streets directly. Solar radiation comes from north-west, and the buildings provide shading almost to the whole surface of the streets. The difference conditions in shading highly influence the conditions of thermal comfort.

07:00. As mentioned, the streets are almost completely directly radiated. A high value of reflected radiation is also registered along the streets, with peaks in correspondence with the facades oriented towards the east. Due to the influence of the radiation, the surface temperature is also particularly high on the radiated surfaces, especially on the surfaces covered with asphalt, since the garden in via Carrera shows lower temperatures. Although different variations exist, shaded surfaces are about 10° colder than the radiated ones. The surface of the courtyard of the primary school "Duca D'Aosta" is particularly cold, due to the shadow provided by the building and the vegetation. The surfaces which are radiated mostly reach temperatures comprised between 32° and 34°, while the shaded perpendicular streets show a prevalent temperature between 26° and 28°. The influence of solar radiation appears also on potential air temperature, which has higher values along the two axes. Via Asinari di Bernezzo appears to be slightly cooler, with temperatures ranging between 28° and 29° along the eastern blocks, and between 28° and 30° along the western blocks. Via Carrera shows similar temperatures, but a warmer area is observed on the southern portion along the church, closer to 30°, and a cool area (27° to 28°) results from the influence of the garden covered with vegetation, probably due to the effect of shading and evapotranspiration, influencing also the values of humidity.

The direction of the wind is constant throughout the day, higher wind speeds are registered where facades forming the urban canyon along the east-west are not interrupted, and on the intersections where flows coming from the north intersect the ones coming from the west. The values of PET are mostly influenced by direct radiation: radiated areas along the two axes show values between 40° and 43°, peaks are registered next to the facades oriented towards the east. A difference of around 10° is verified between the radiated and the shaded surfaces, and a lower PET is registered on the areas covered with trees, where lower temperature and higher humidity was verified.

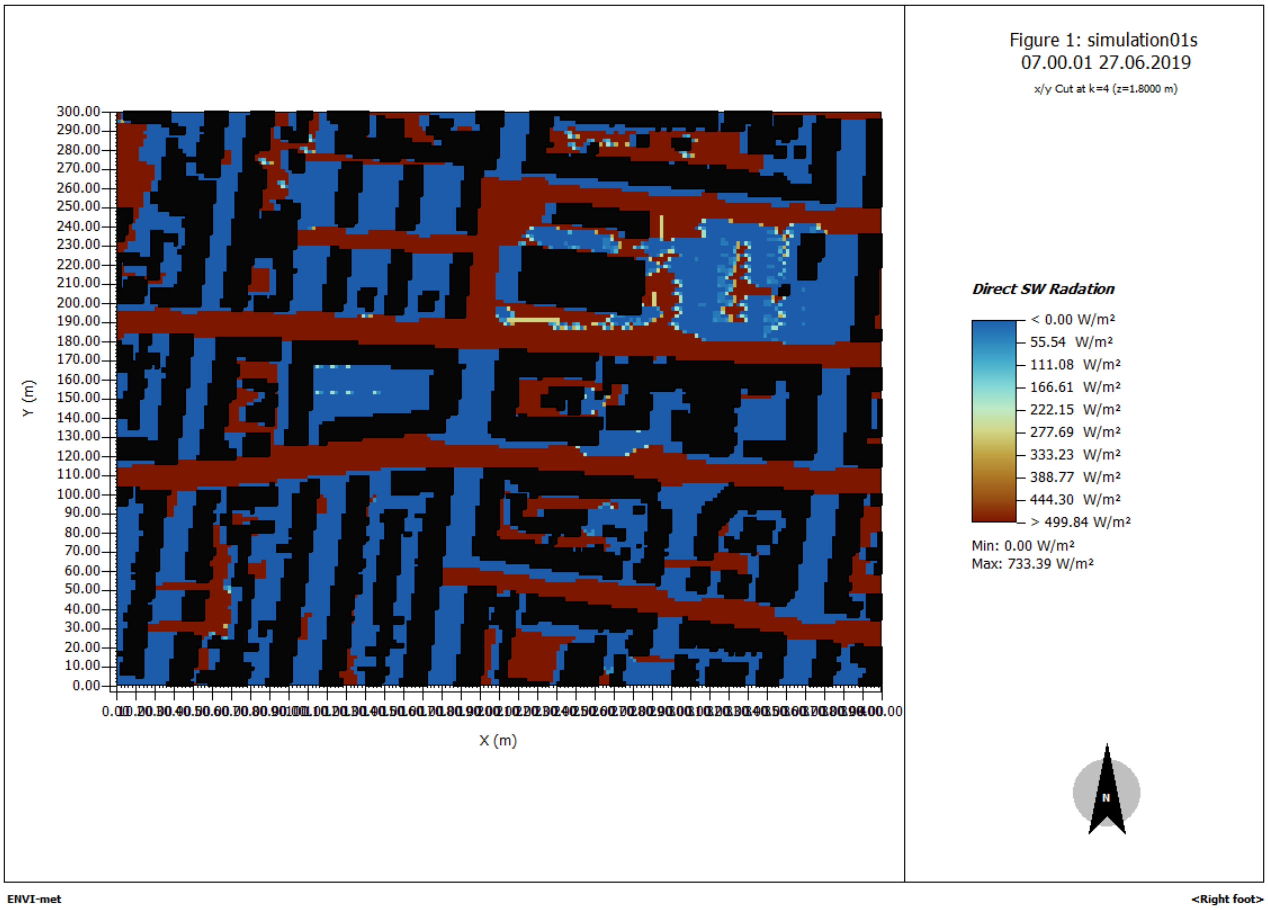


Figure 50. Direct radiation, current state, 07:00

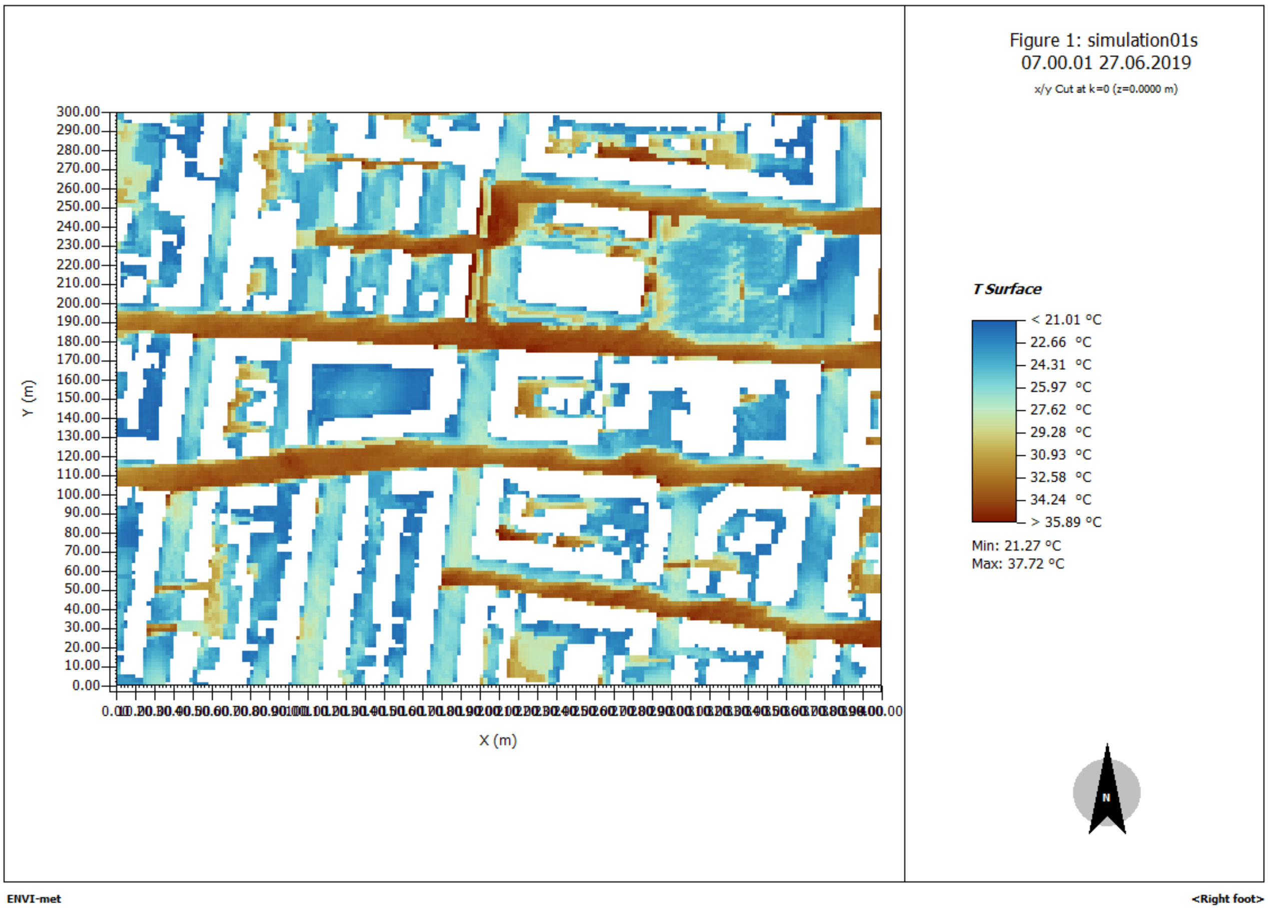


Figure 51. Surface temperature, current state, 07:00

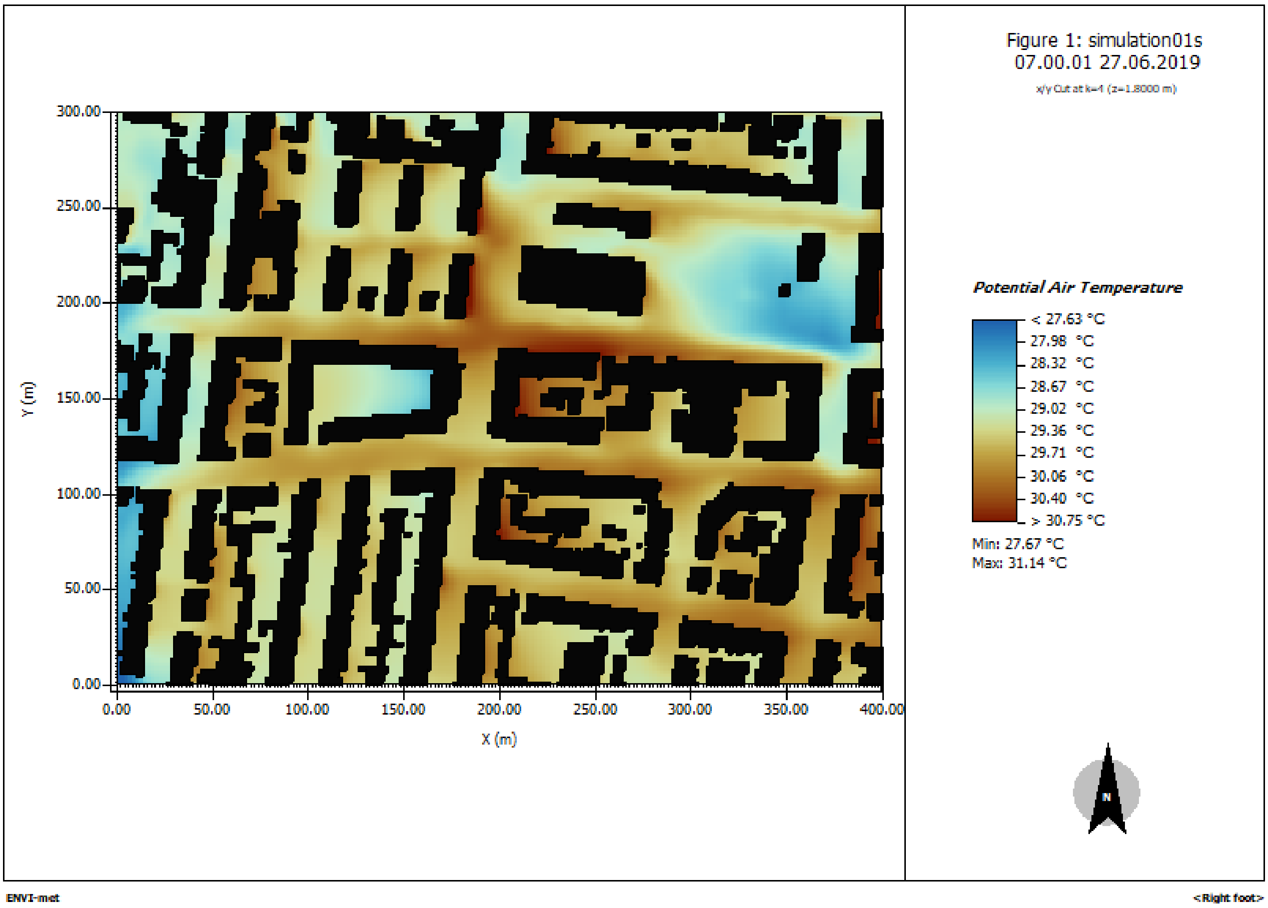


Figure 52. Potential air temperature, current state, 07:00

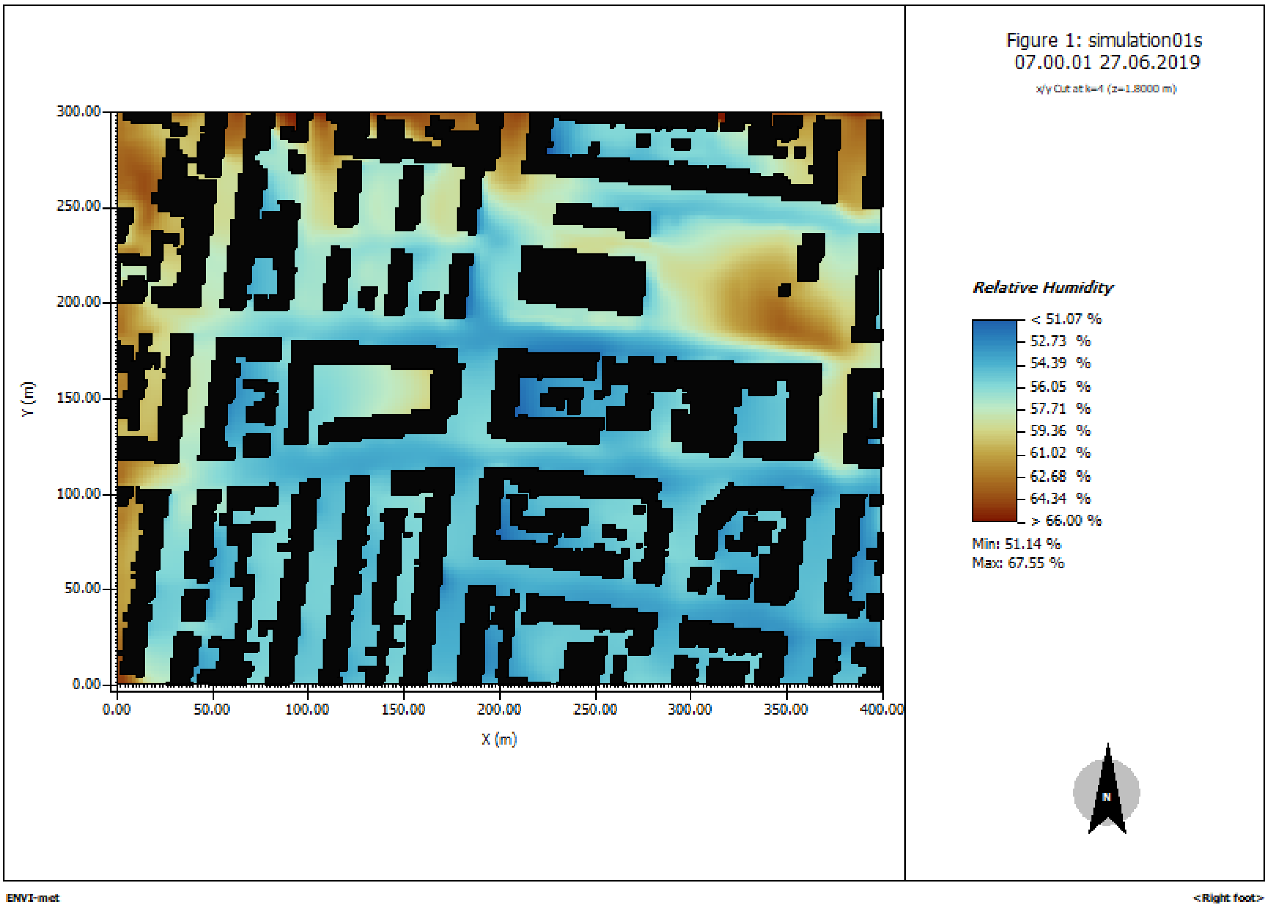


Figure 53. Relative humidity, current state, 07:00

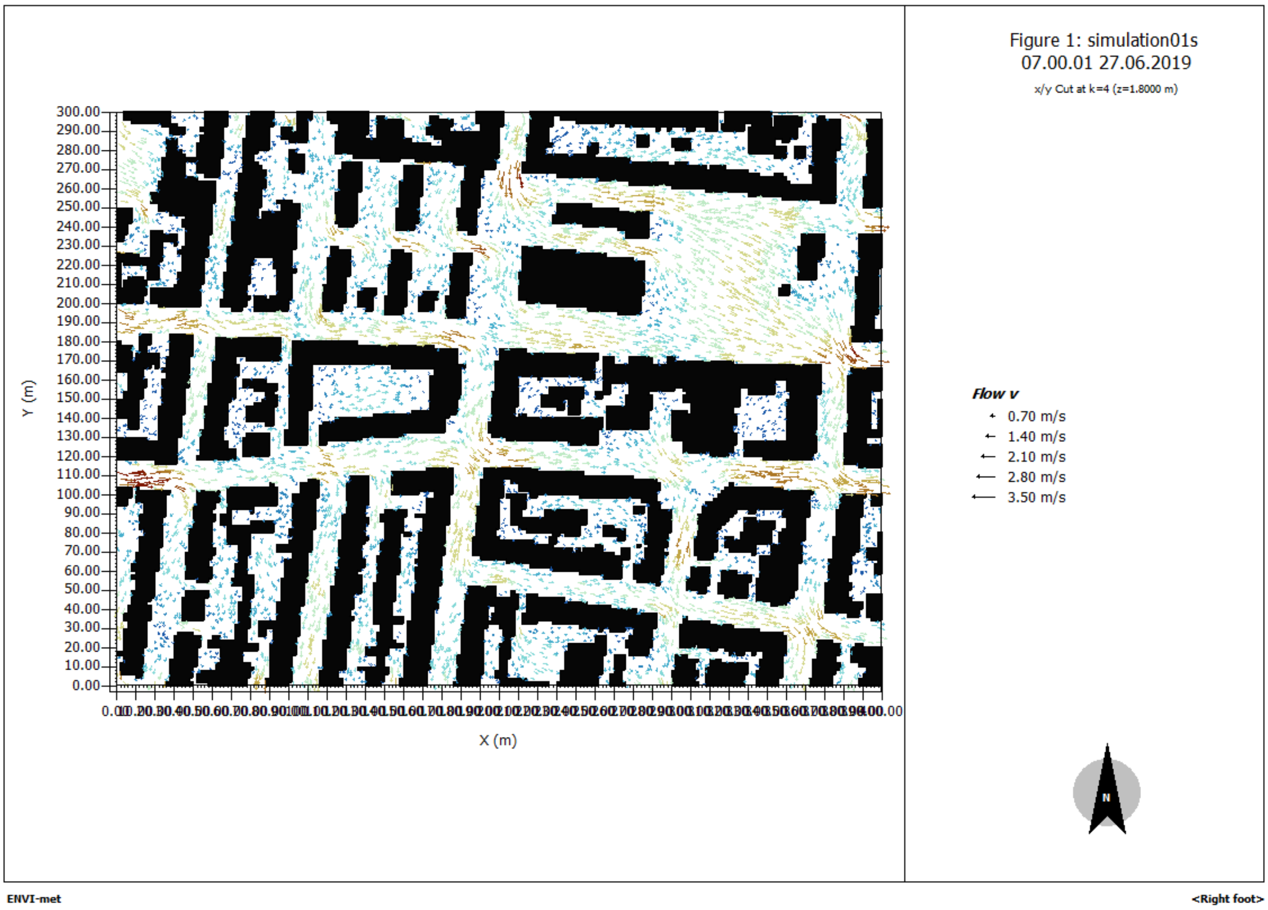


Figure 54. Wind speed and direction, current state, 07:00

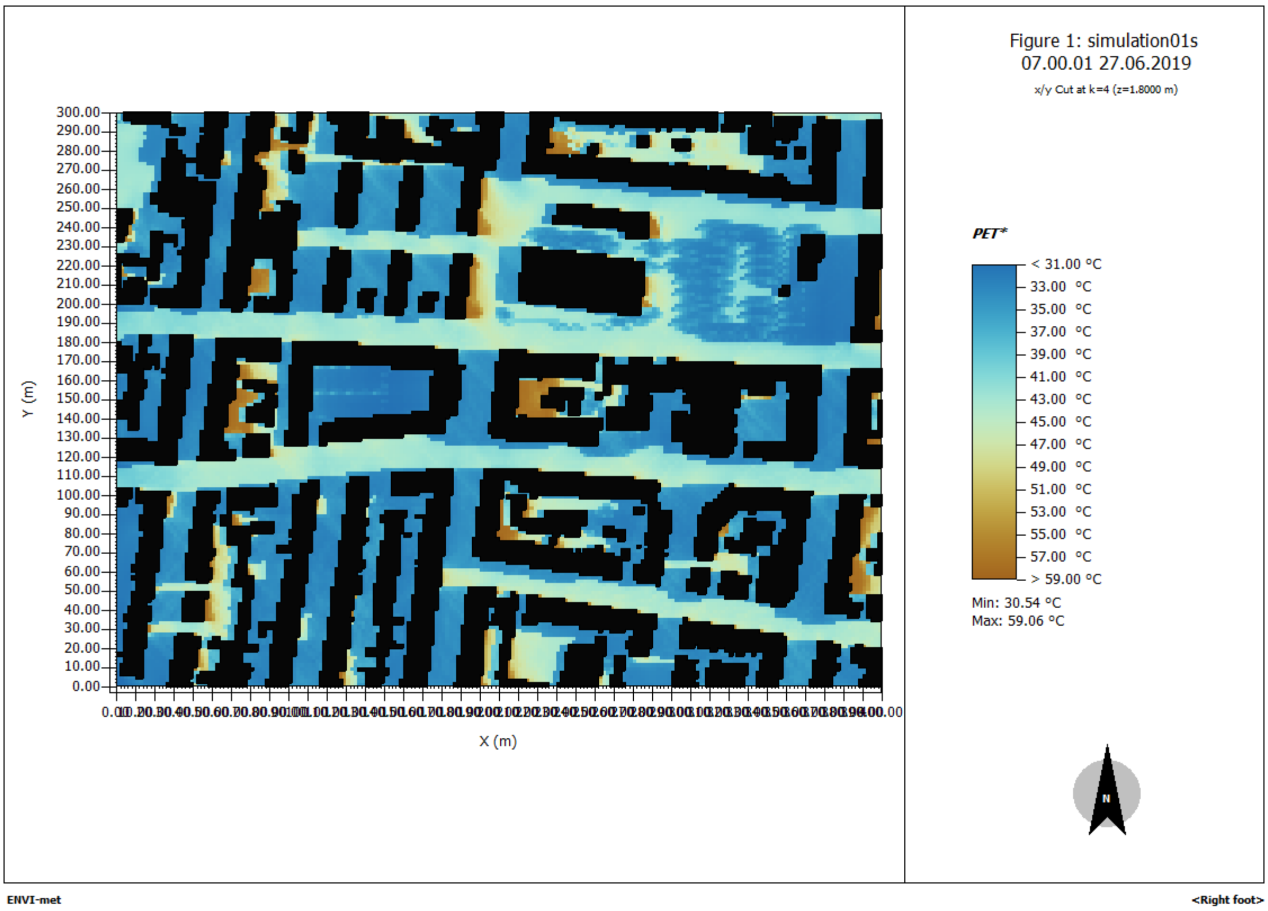


Figure 55. PET, current state, 07:00

12:00. Sun radiation is perpendicular to the two axes, therefore the shadows have a north-south direction along the southern sides. The sidewalks located on this side are shaded, except from the portions where the buildings are interrupted. The shadows of the trees are also evident. The component of reflected radiation shows mainly three zones: the lowest values are registered on the shaded surfaces. The radiated portions of the surfaces covered with asphalt show a medium value, with peaks in front of the facades oriented towards the south. The radiated portions covered with grass or concrete show the highest values. This might be the result of the different albedo. The relationship with shadow and albedo can be observed also with the analysis of surface temperature, which is higher on the asphalt surfaces of the radiated portions of the streets (45° to 53°), while it is lower on the shaded portions of the streets (31° to 38°), the shaded portions of the courtyards or of the garden (24° to 35°) the concrete surfaces (34° to 42°) and the grass area (34° to 42°). As in the previous case, potential air temperature and relative humidity show a similar distribution, with low temperatures and high humidity next to the concentration of trees. Along the two streets, the temperature varies around 35°. The same observations of the morning hour can be made about the wind speed and direction. Similarly, the PET is strictly dependent to the shading: along the two streets, the shaded areas, corresponding to the southern sidewalks, show an index comprised between 36° and 39°, while the radiated portions show indexes between 47° and 50°, with higher values along the northern edges and with peaks over 50°. The effect of the shadow is verified also in the garden of via Carrera and in the courtyards of the schools “Duca d’Aosta” and “Cavaglià”.

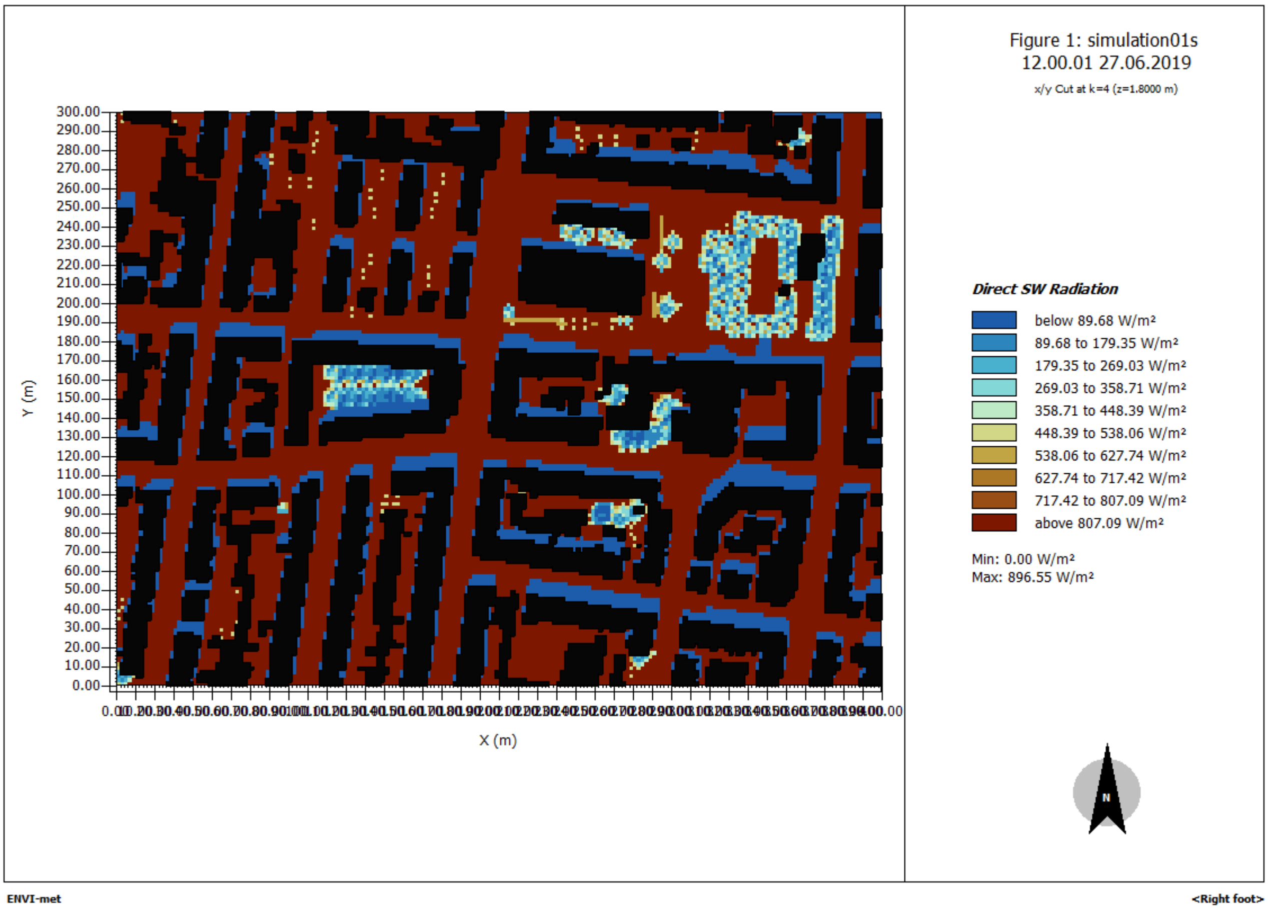


Figure 56. Direct radiation, current state, 12:00

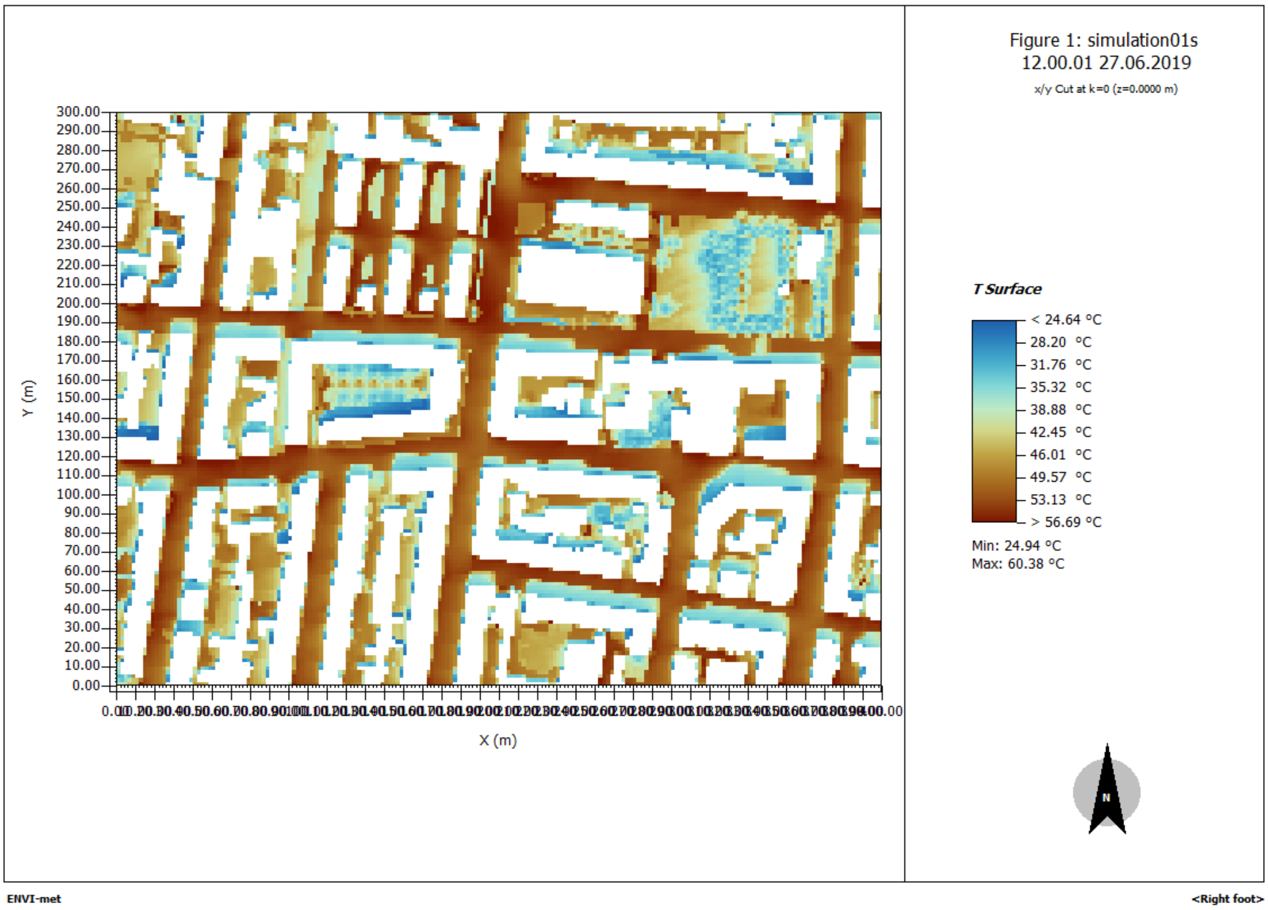


Figure 57. Surface temperature, current state, 12:00

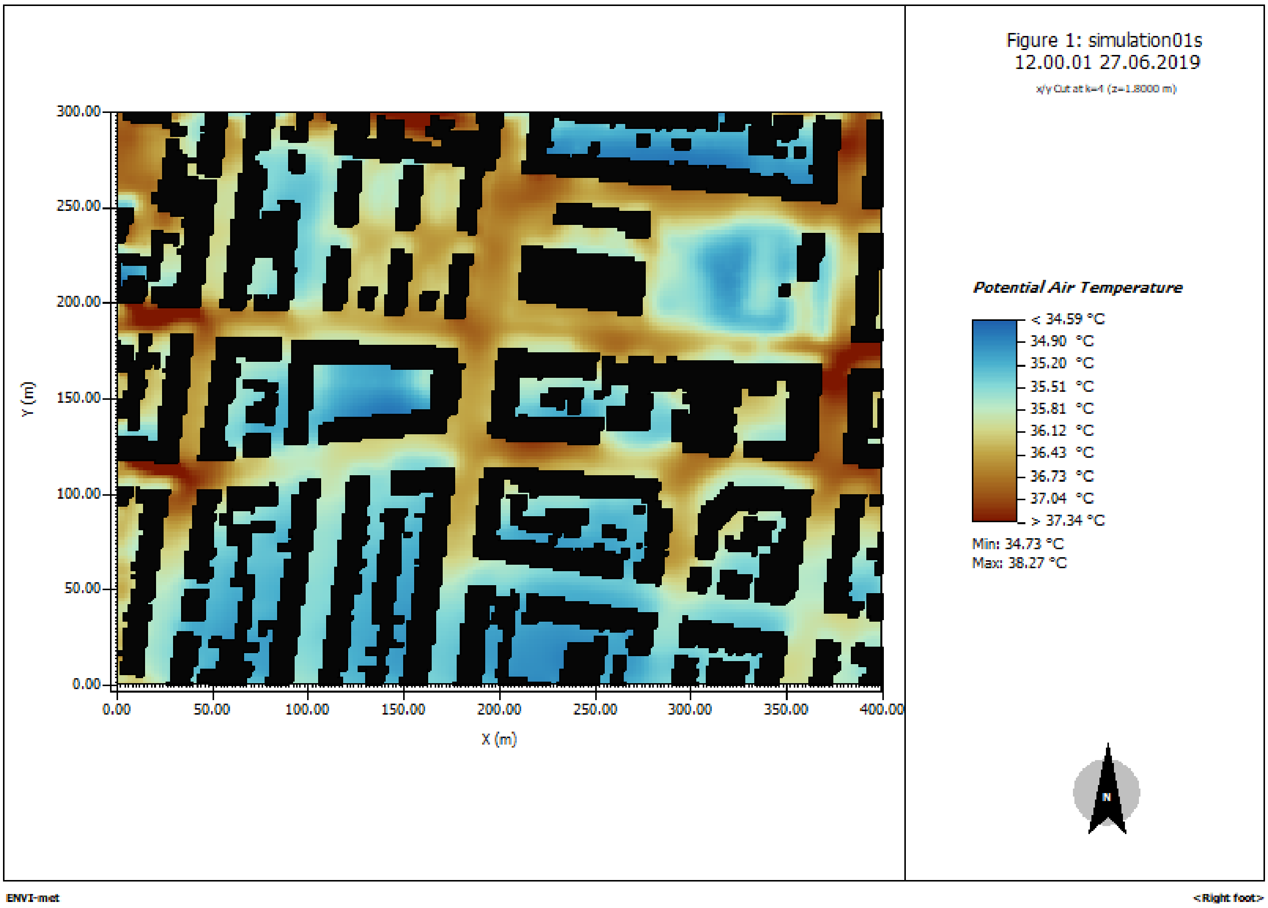


Figure 58. Potential air temperature, current state, 12:00

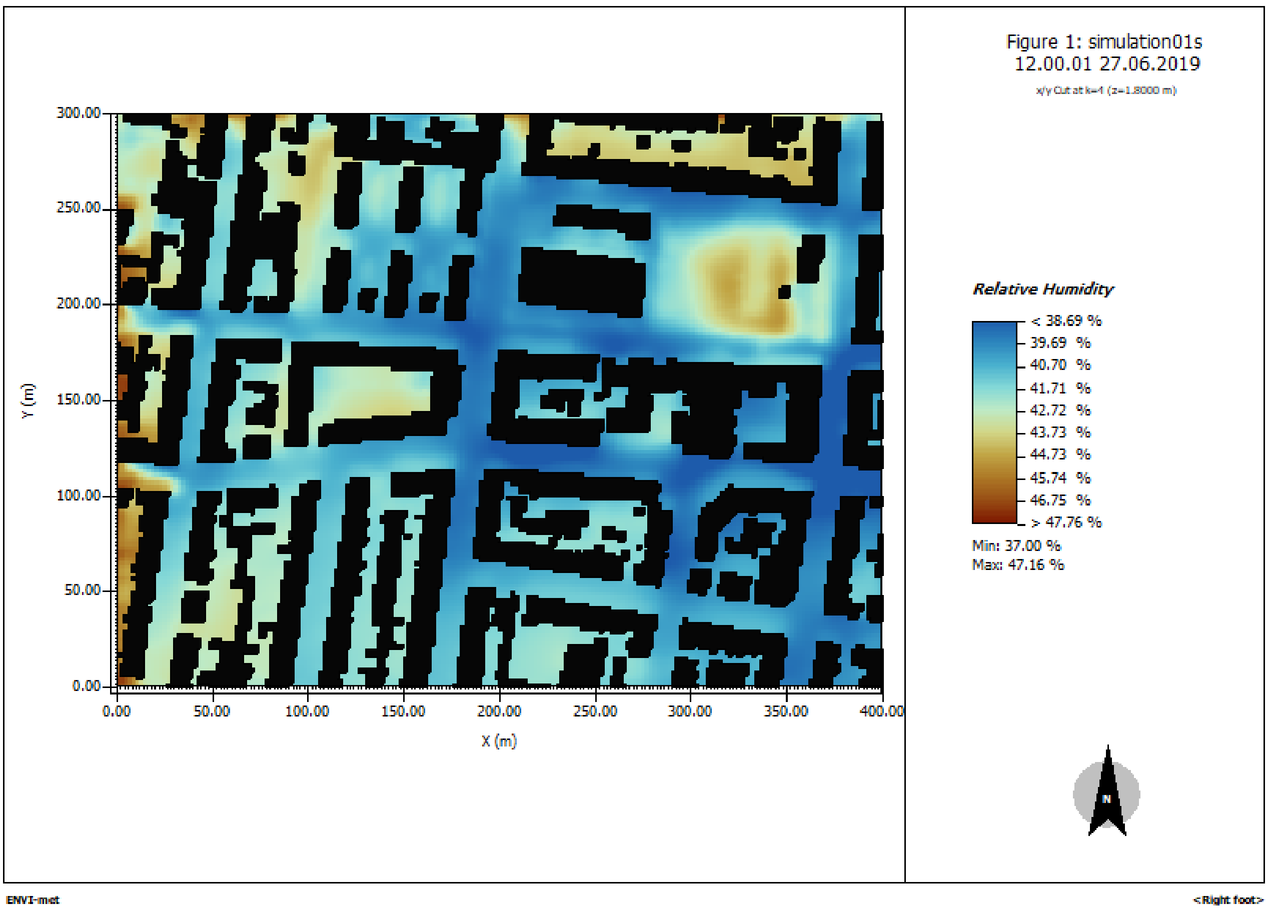


Figure 59. Relative humidity, current state, 12:00

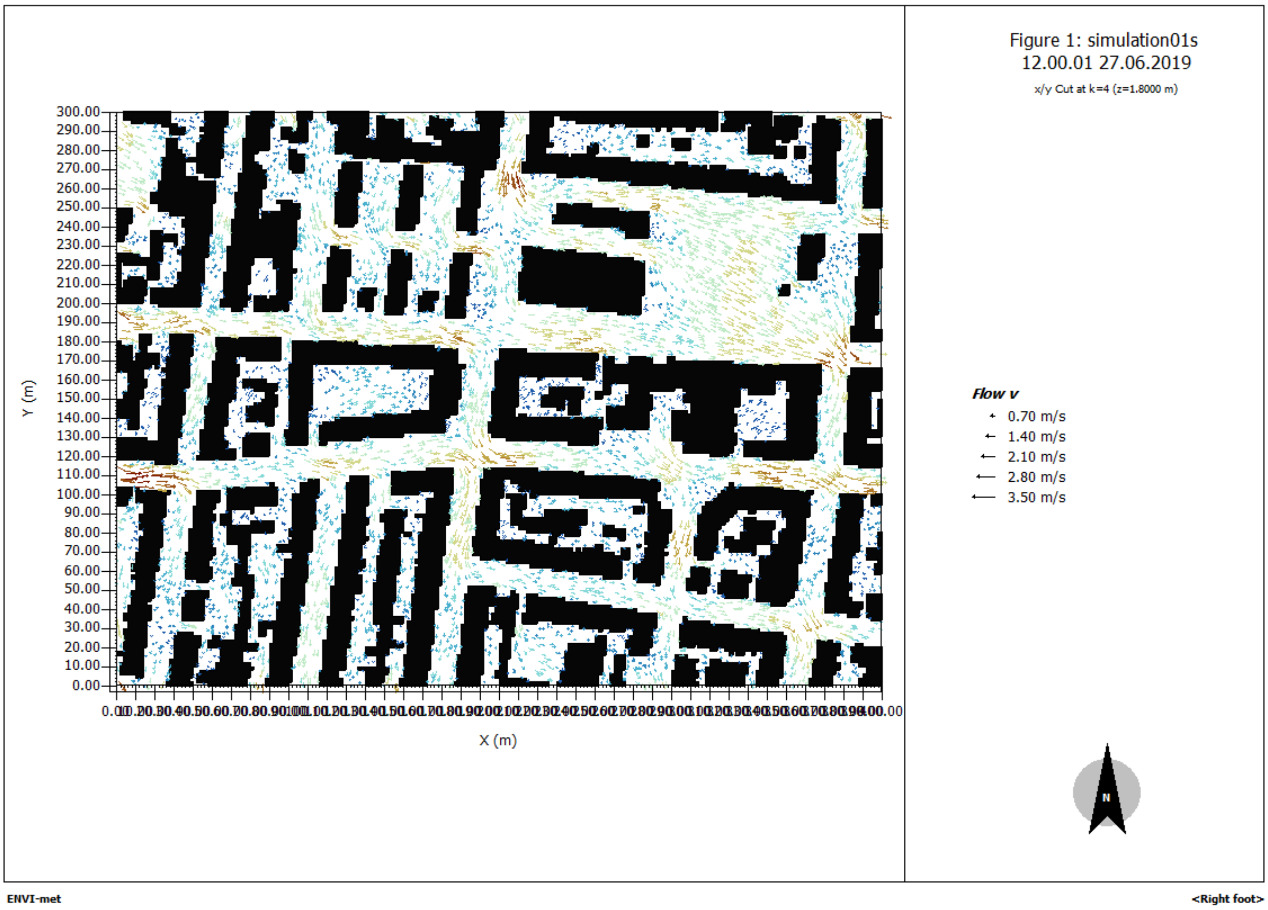


Figure 60. Wind speed and direction, current state, 12:00

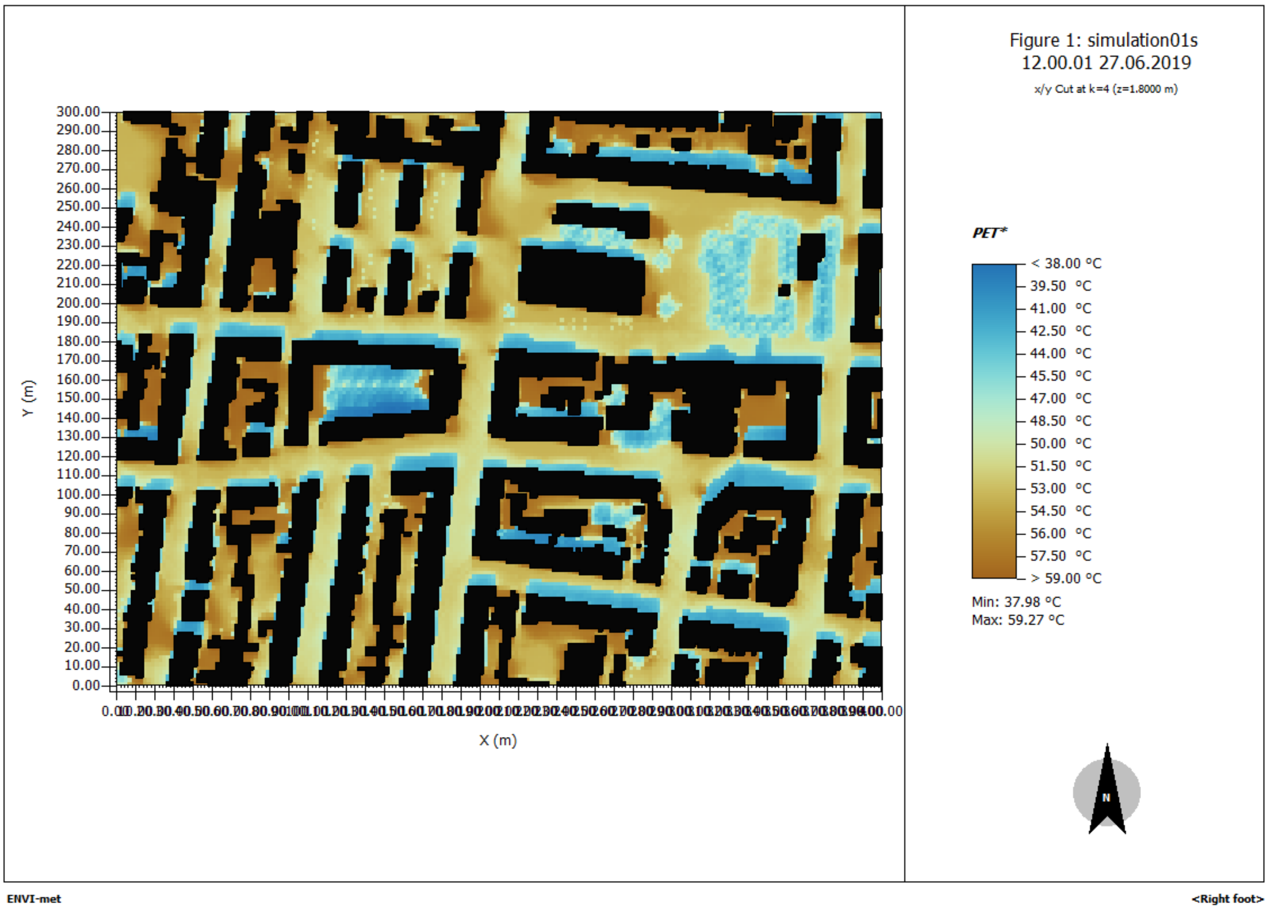


Figure 61. PET, current state, 12:00

15:00. The streets are almost completely radiated, with the shadows located on the western side of the north-south axes. The observations on reflected radiation are similar to the previous cases and related to the presence of radiation, the albedo and the presence of facades oriented towards the west. As in the previous cases, surface temperatures are strictly linked to the direct radiation, with values on the radiated portions of the asphalt streets ranging between 45° and 52°, with higher peaks, and values on the shaded portions of the asphalt streets between 35° and 42°. Surface temperatures in correspondence with trees are the lowest, with values between 24° and 35°. The potential air temperature along the two main axes ranges between 35° and 37°, with slightly lower values in correspondence with trees (around 35°). Direct radiation probably influences air temperature, since the values on the open spaces and on the east-west axes are higher compared to the internal spaces of the blocks and the north-south axes. As in the previous cases, relative humidity shows the opposite pattern of air temperature, with values up to 40% next to the trees, around 35% and 36% along via Carrera and via Asinari di Bernezzo, and slightly higher values inside the blocks or along the north-south axes (36%-37%). Wind speed and direction show the same distribution previously explained. Since the two streets are mostly radiated, the PET ranges between 48° and 53°, with peaks above 57° on a location in front of the church. Vegetation, due to its shading and evapotranspiration function, reduces the PET index to 38° to 43°, with lower values in the courtyard of the primary school (35° to 38°). Similar values are observed on the shaded portions of the asphalt streets. Concrete surfaces show high PET values (up to 57°).

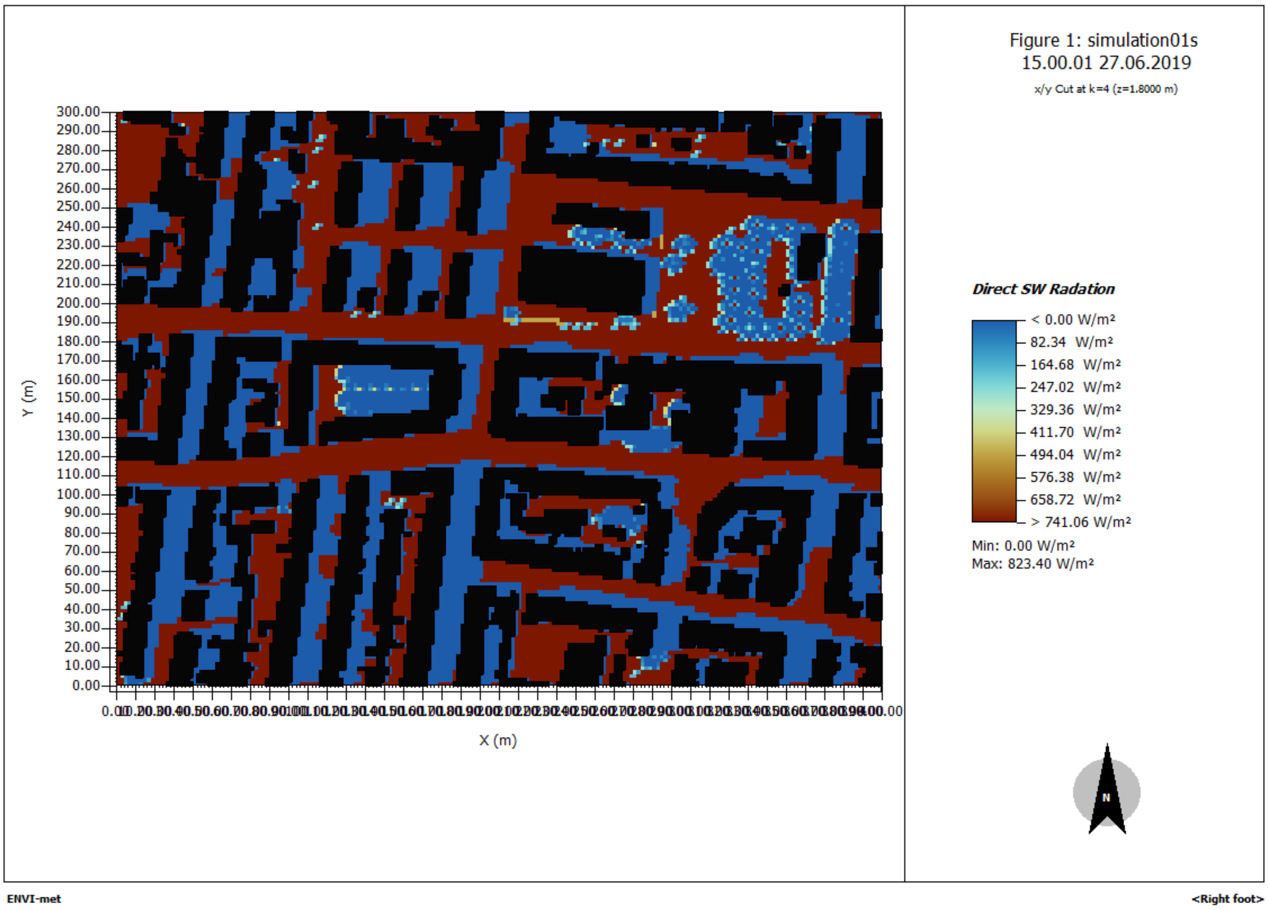


Figure 62. Direct radiation, current state, 15:00

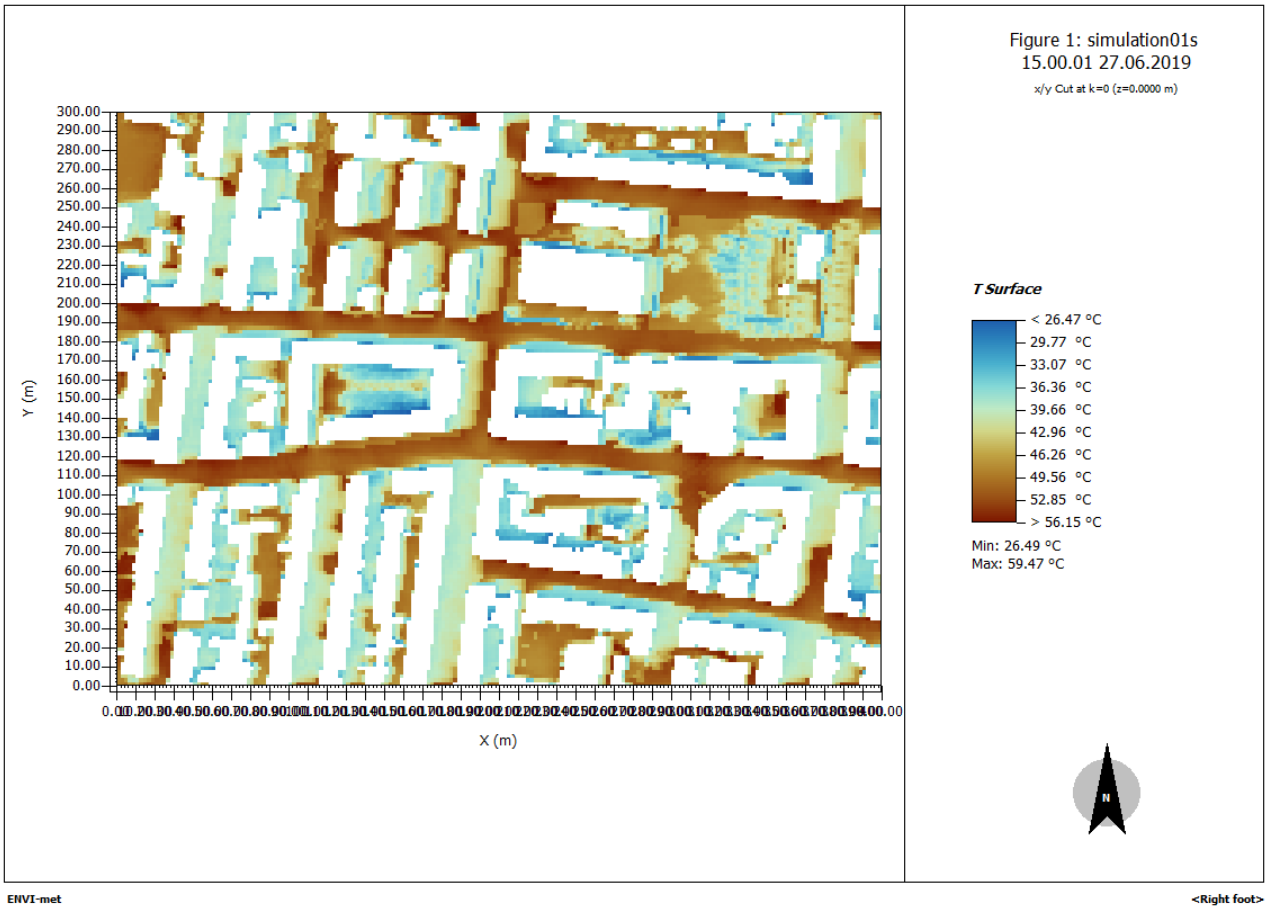


Figure 63. Surface temperature, current state, 15:00

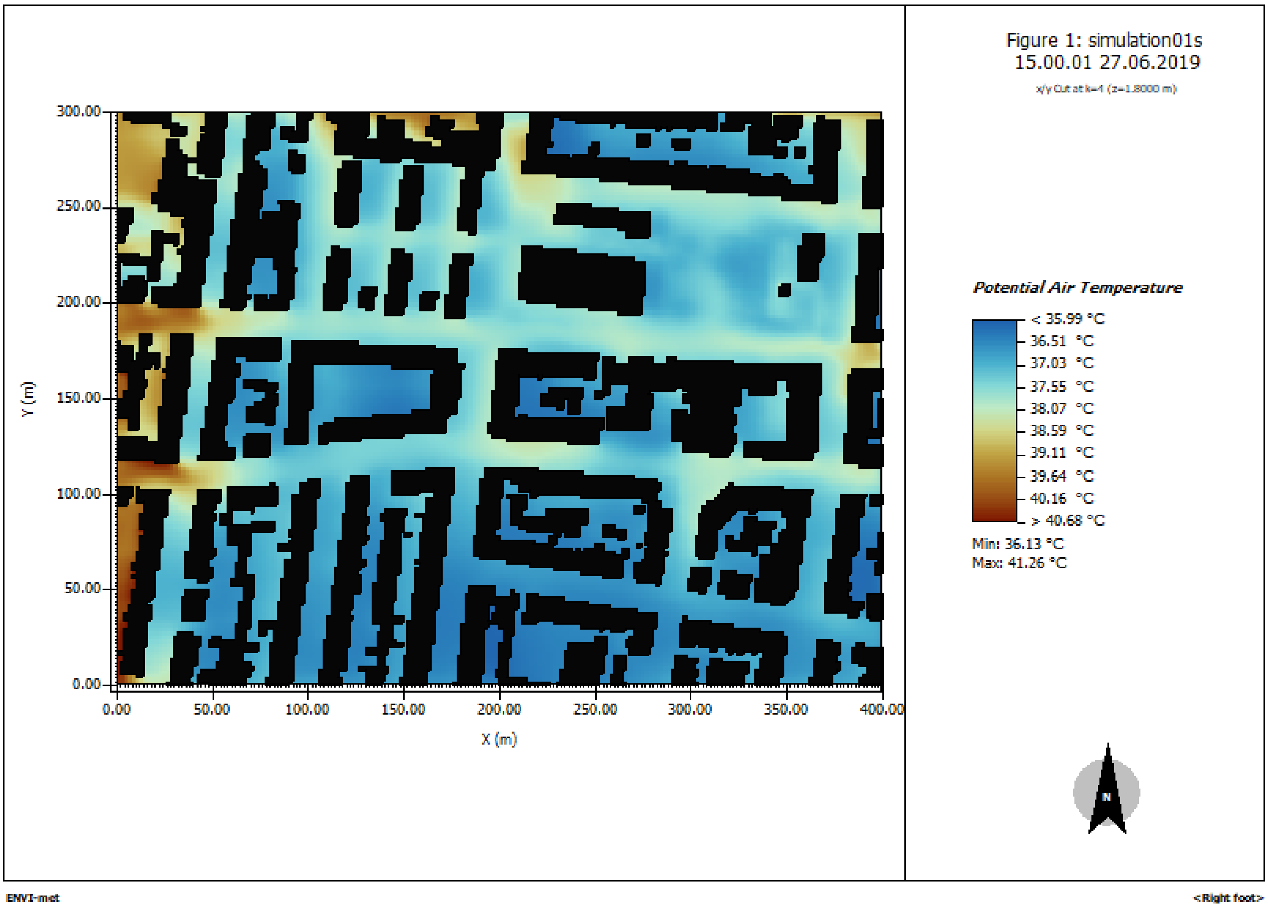


Figure 64. Potential air temperature, current state, 15:00

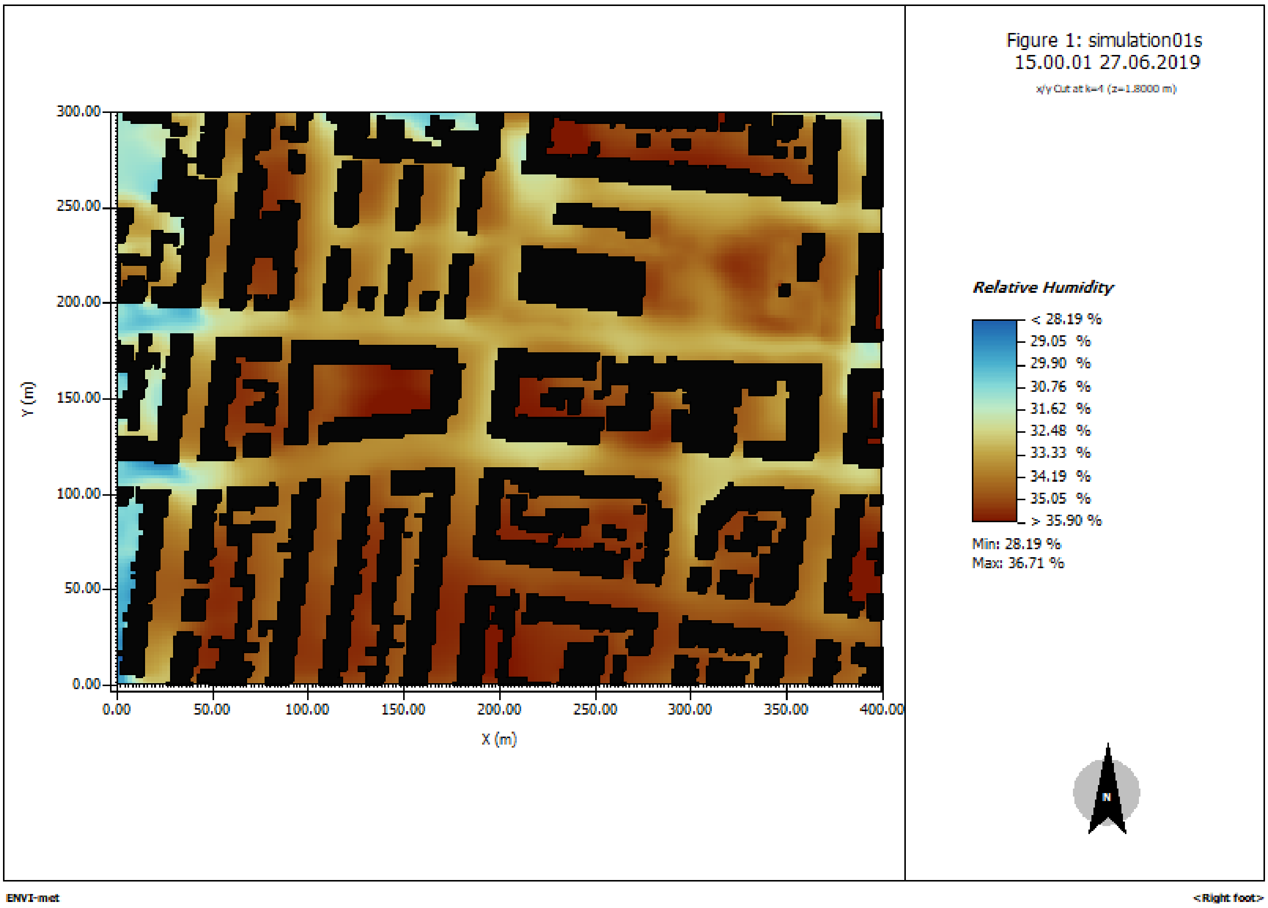


Figure 65. Relative humidity, current state, 15:00

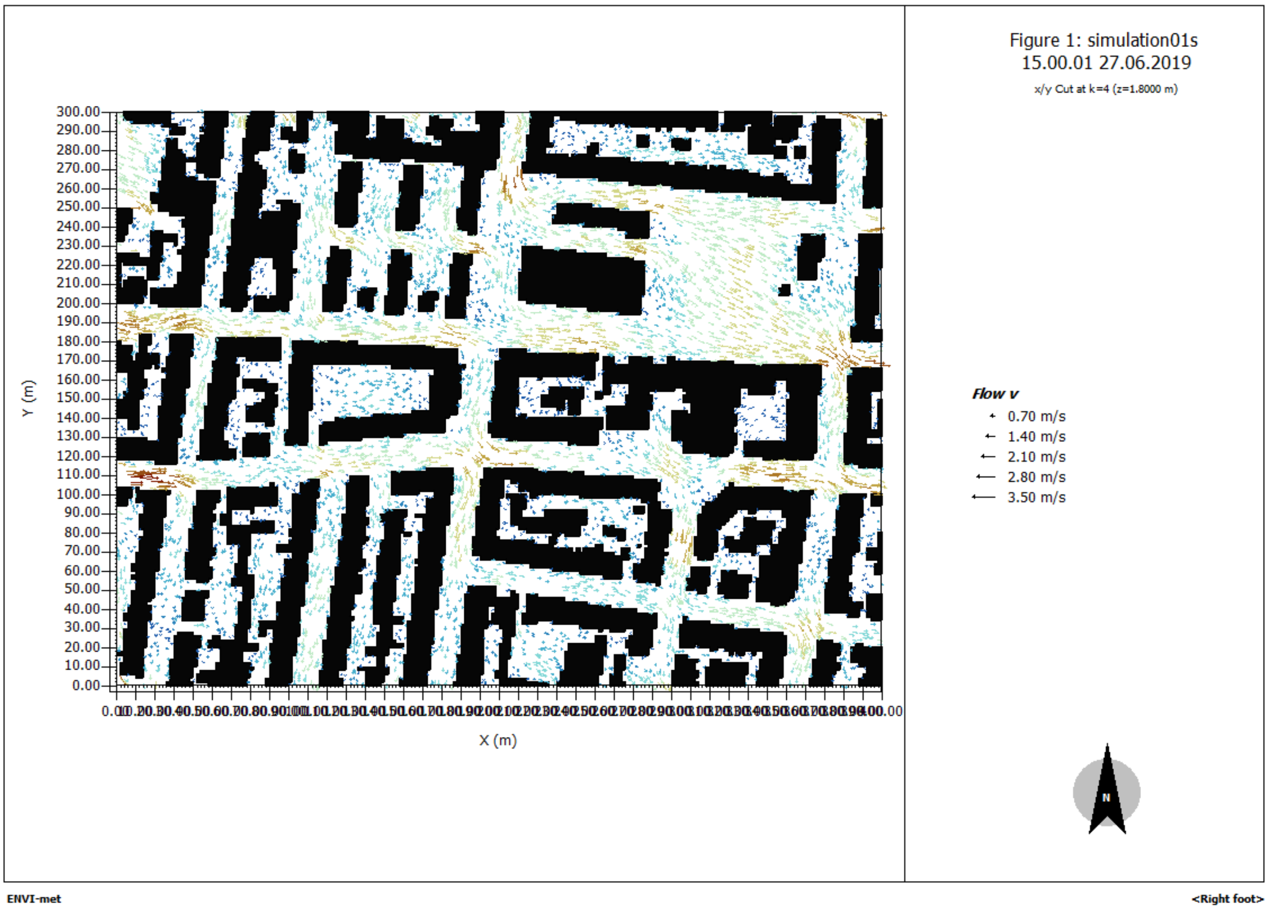


Figure 66. Wind speed and direction, current state, 15:00

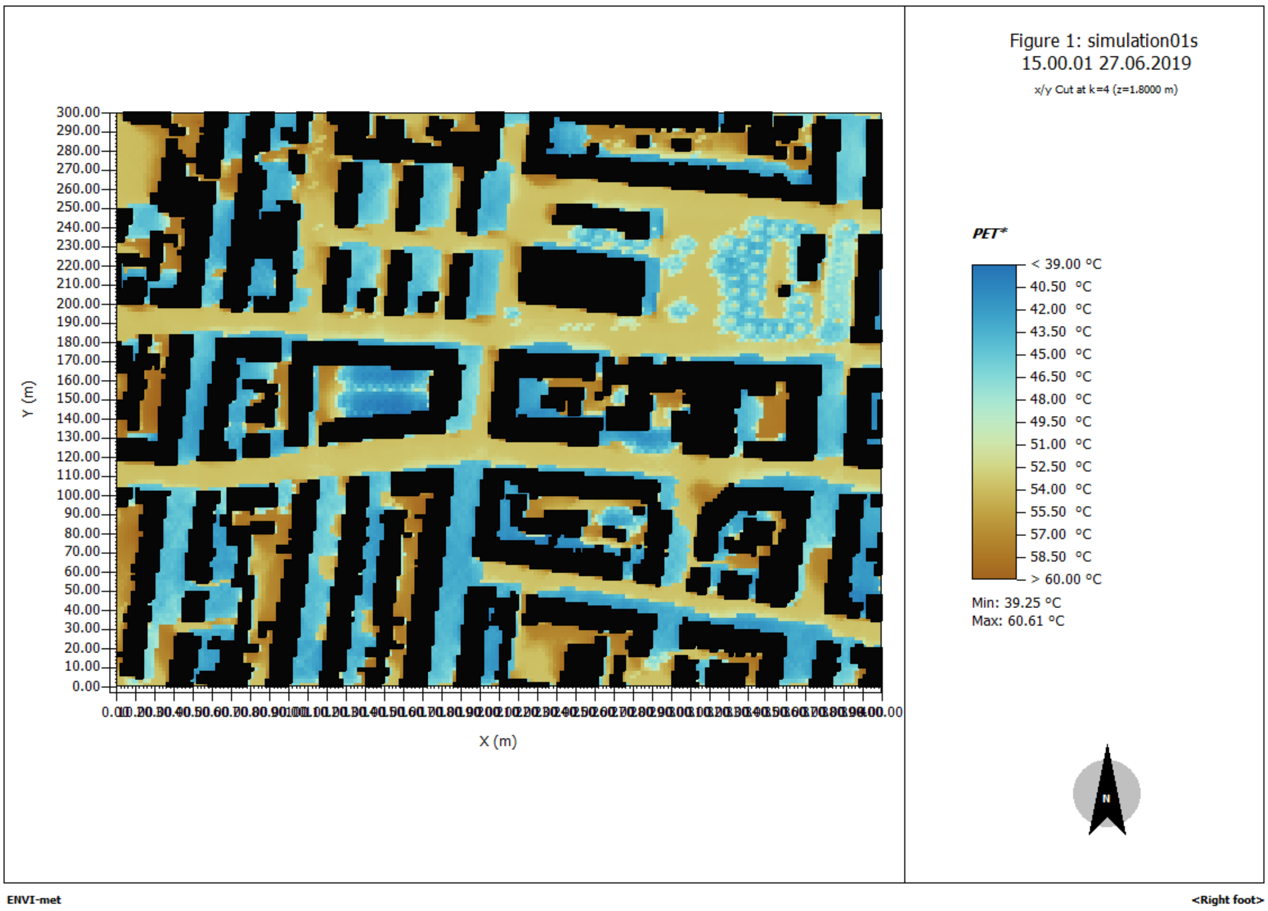


Figure 67. PET, current state, 15:00

18:00. The area almost completely lacks direct and reflected radiation, therefore, it can be hypothesised that the surface temperature is affected by the radiation of the previous hours. In general, the southern sides of via Carrera and via Asinari di Bernezzo show temperatures between 34° and 37°, while the northern sides show values between 37° and 39°. An area with temperatures between 39° and 41° is observed in front of the school Cavaglià on via Carrera. The areas close to the trees show values between 25° and 30°, with lower temperatures in the courtyard of the school "Duca d'Aosta". Potential air temperature shows a more homogenous distribution, with values between 34° and 34,5° on the south-eastern portion of the area, and between 34,5° and 35° on the north-western portion, regardless of the distinction between streets and courtyards, with the exception of the spaces with trees, with temperatures between 33° and 38°. Humidity shows the same pattern of air temperature, with values between 37% and 39%, with the trees rising the results up to 42%. The wind pattern is similar to the previous observations. The PET is slightly higher on the portions of the streets which are still radiated (41°), but, in general, it ranges between 36° and 41°. Lower PET is registered in the green area of via Carrera and in some of the internal courtyards of the closed blocks.

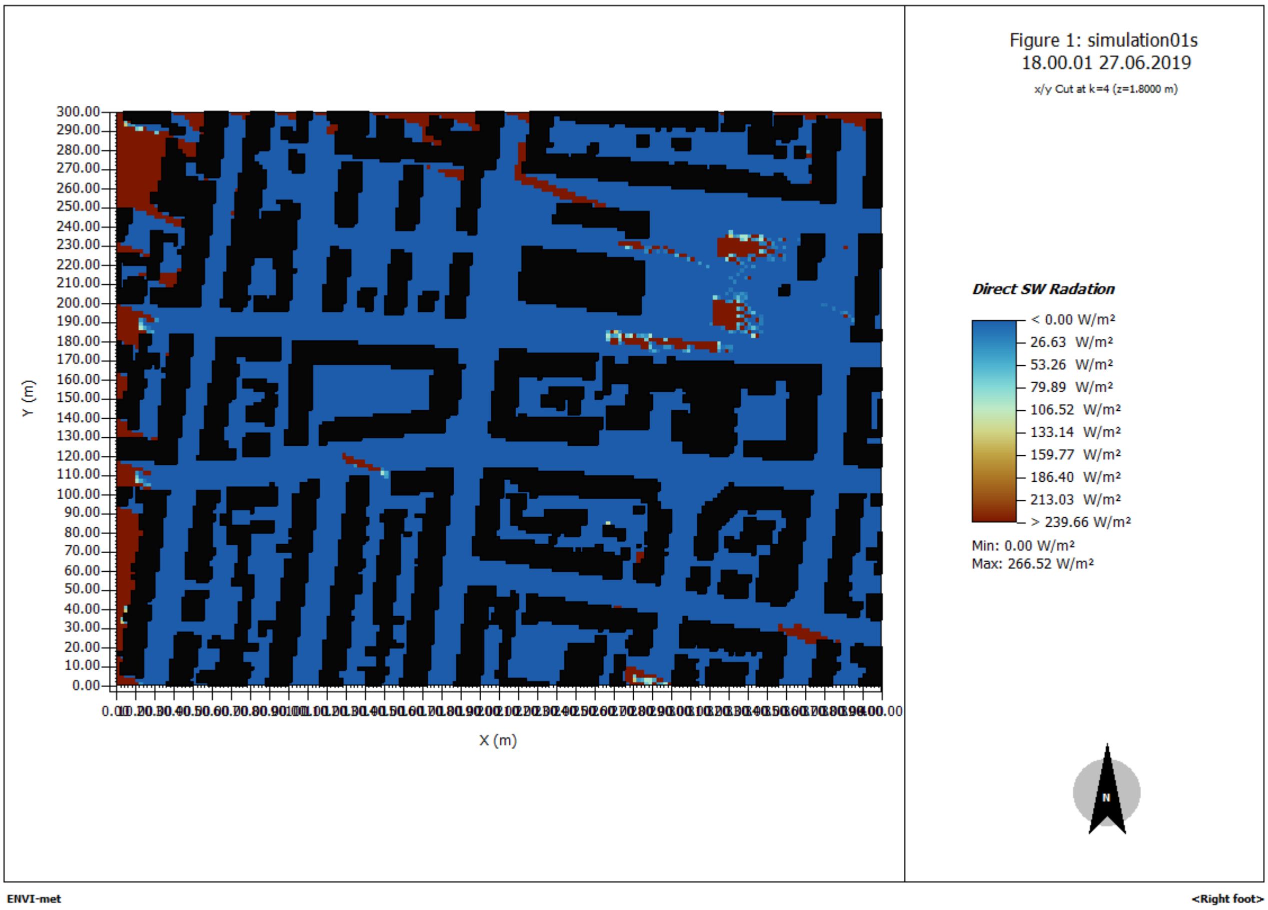


Figure 68. Direct radiation, current state, 18:00

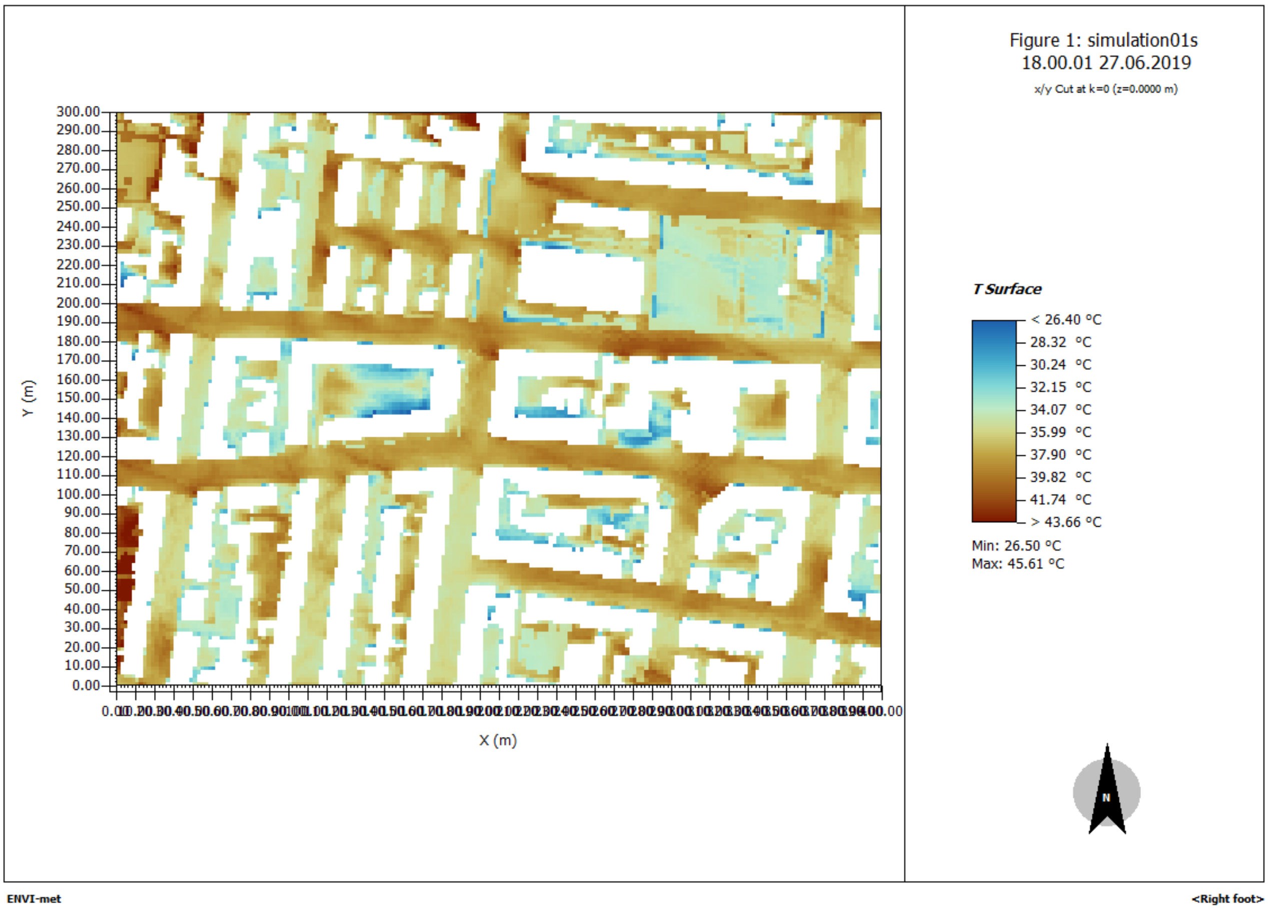


Figure 69. Surface temperature, current state, 18:00

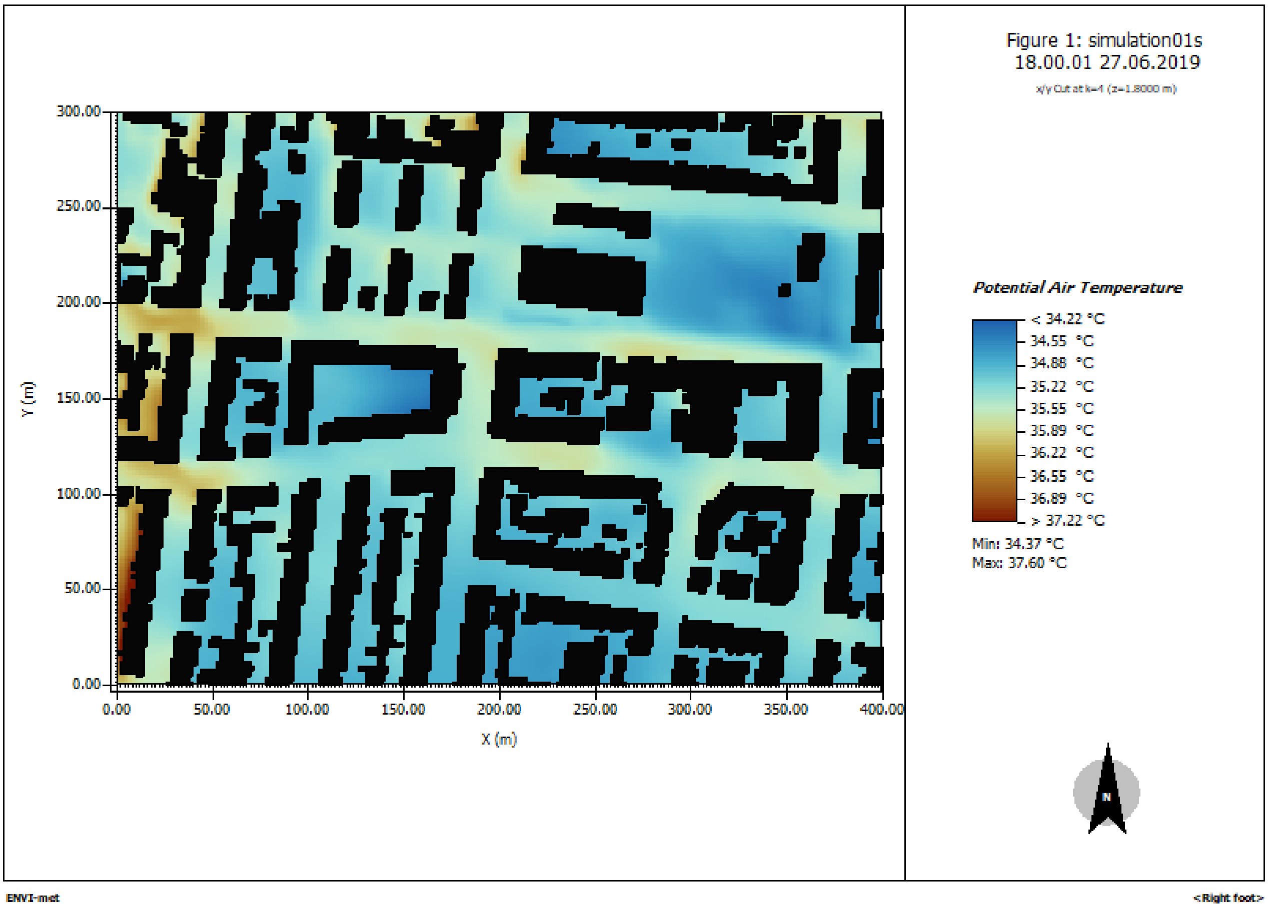


Figure 70. Potential air temperature, current state, 18:00

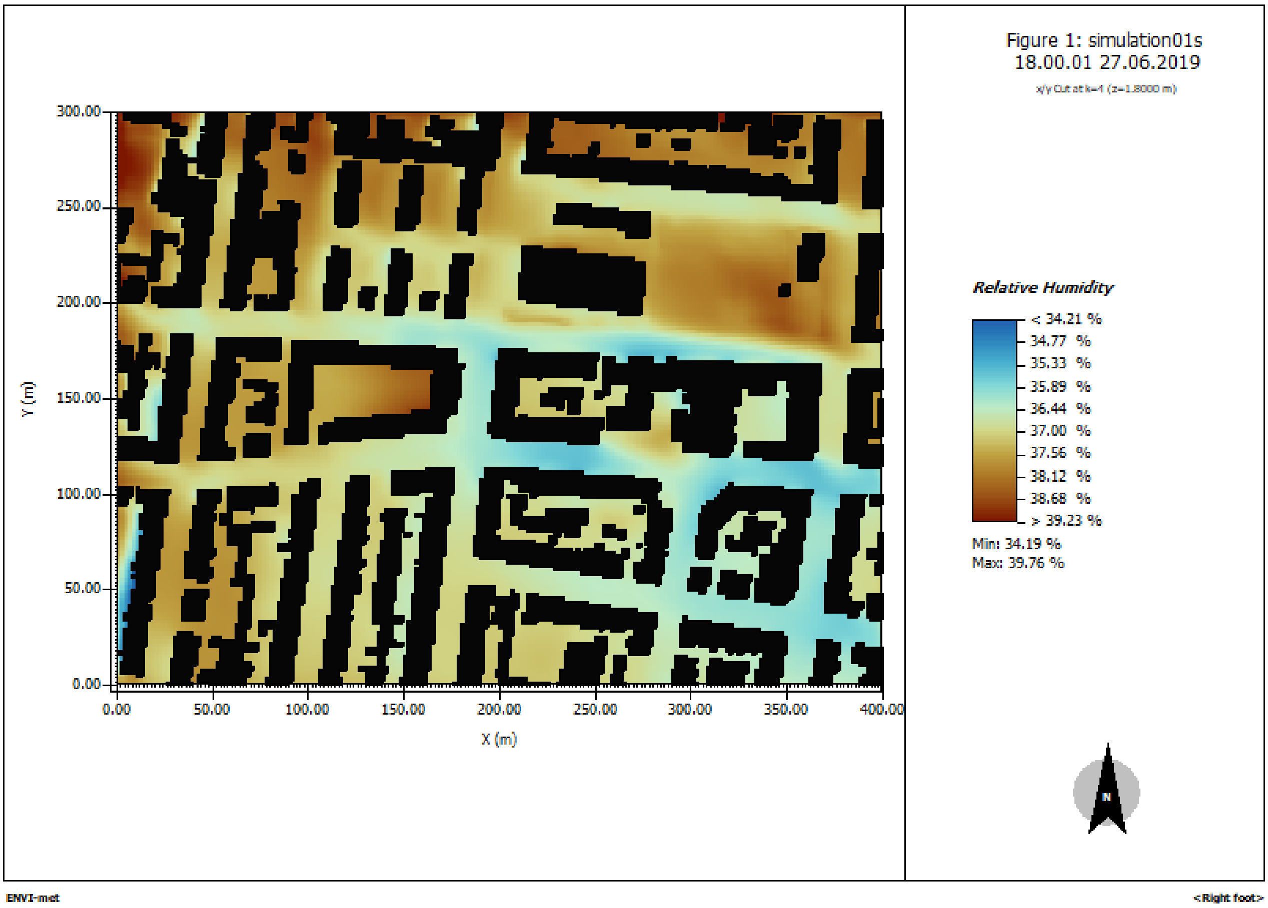


Figure 71. Relative humidity, current state, 18:00

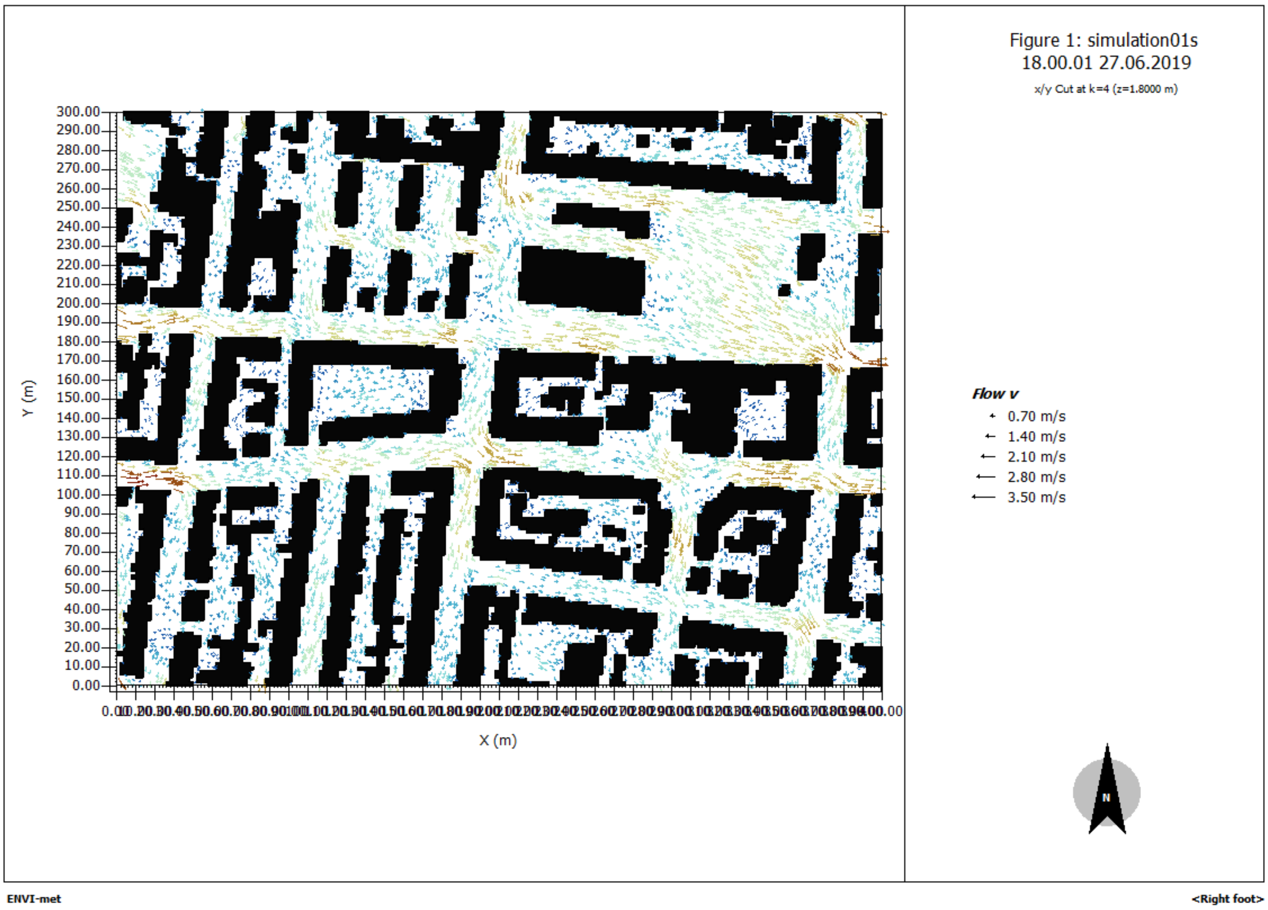


Figure 72. Wind speed and direction, current state, 18:00

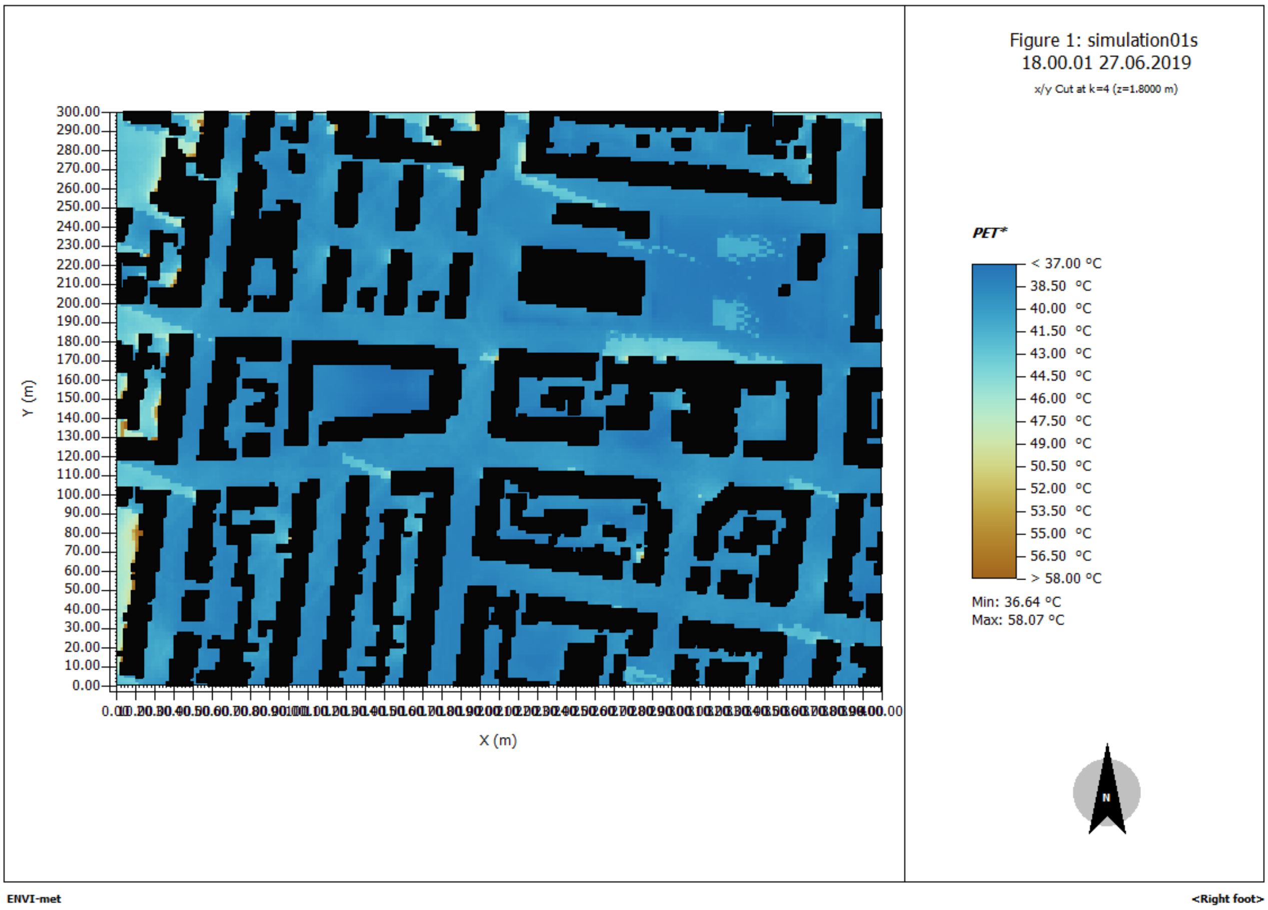


Figure 73. PET, current state, 18:00

5.2. Conclusions and key elements for the project

The analysis of the results of the simulation through the details of the different variables allows to draw conclusions of the current state of the area and its performance in terms of thermal comfort during a summer day, constituting a base for the designation of strategies allowing to improve its characteristics. The performance of the street changes according to the time, and it is most strictly related to the influence of direct solar radiation and shading. Between 07:00 and 08:00 sunlight completely covers the surfaces of the two streets, resulting in a first increase in the PET after the night. During the day, the temperatures gradually grow, but differences can be observed between the shaded side of the street and the one radiated by the sun, resulting in a better thermal condition mostly on the southern side, due to the impact of the buildings. Between 11:00 and 15:00 the highest PET values are recorded on the northern side of the streets, and on the wide open space corresponding to the intersection between via Asinari di Bernezzo and via Mogadiscio. At 15:00 the absence of shadow provoked by buildings constitutes an obstacle to thermal comfort. Between 16:00 and 17:00 the shadows are projected on the northern side of the streets. Starting from 18:00 the whole surface of the streets is shaded by the buildings. It was observed how the shadows projected by buildings allow to create better conditions for thermal comfort, but the importance of shadow provided by trees was verified. Despite the reduced surfaces on which it can be verified, it was observed that grass areas have a minor impact on the PET, even though the surface temperature appears to be lower compared to other materials. The comparison between surfaces with high and low albedo is difficult due to the different location, influenced by different conditions such as ventilation or shading.

Given the conclusions related to thermal comfort, some remarks can be evaluated regarding the needs for intervention on the public spaces along the two axes. These observations are referred exclusively to the aspect of thermal comfort, and they should therefore be adequately conjugated with the necessary transformations related to the requalification of public space, mobility issues, and the activities located along the streets. Considering the importance of shadow highlighted with the analysis, it can be noted that an increase in shading could be particularly beneficial during daytime. However, a possible intervention aiming at increasing shading would have to take into account the different needs related to specific times of the day. Shading elements would have to be placed with an orientation prevalently perpendicular to the axes, if the target time considered is morning hours (07:00-08:00) or afternoon (15:00-16:00), when the sun radiates parallelly to the axes. Between these two timeslots, and especially during the hottest hours of the day, a higher necessity is highlighted for the northern side of the streets, where the highest temperatures are recorded, even though the shading provided by buildings on the south is interrupted, especially on the western portion of via Asinari di Bernezzo. In this case, the prevalent orientation to be considered is the one parallel to the axis, in order to maximise shading on most of the sidewalks. A particular necessity was highlighted for the intersection between via Asinari di Bernezzo and via Mogadiscio, especially for the afternoon hours and on the eastern portion of the square. It was observed that the most effective elements providing shadows are surfaces named as «solid barriers» by Pejović (2022, p. 230), such as buildings. Given the impossibility to modify the built elements, alternative solutions could be selected. Vegetation resulted to be effective in increasing shading and improving thermal comfort, however, it must be noted that most important effects are registered where trees of large dimensions are located: given the absence of particularly wide spaces along the streets, an evaluation is necessary regarding the maximum size of the trees. The impact on the reduction of temperatures through materials with higher albedo or vegetated surfaces can be evaluated, even though, on the areas located in the study area, they were observed to have a higher importance for surface temperatures and on potential air temperature, but a minor impact on the PET. Moreover, even though wind values are not particularly high, it was observed how the two streets partially form canyons along which wind flows, constituting a potential positive element for thermal comfort: the transformations should take into account this element, by introducing solutions to increase shading, but without creating obstacles for the wind flow.

6. Project

6.1. Characteristics of the project

Starting from the proposals elaborated through sections in the context of the feasibility study previously mentioned, the present work provides an additional level of detail, adapted to the area of study, and it integrates measures aimed at improving thermal comfort. Based on the observations on the scenarios previously highlighted, a main scheme of design was selected, similar to the scenario 1. The selection of this scheme is justified, in the first place, by the choice of maintaining a separated bicycle infrastructure, instead of selecting shared schemes with vehicular traffic, due the presence of relevant volumes of traffic, considering also the presence of a public transport line, which could constitute an obstacle to a comfortable and safe use of the axis by cyclists. Moreover, a separated infrastructure is more suitable to an axis classified as neighbourhood street, as mentioned by Socco (2009): although, according to the SUMP (Città di Torino, 2010), only via Carrera is classified as such, the two streets have similar characteristics, and their role in the mobility system of the neighbourhood can be considered as equivalent. Furthermore, the choice of a shared infrastructure in this case would not be justified by a lack of available space, considering the section of the two axes, even though the allocation of a dedicated space to the new infrastructure would result in a redistribution of space, mostly detrimental to cars. The relevant presence of vehicular traffic along the streets can be related to their street category, since they have a key role for the displacements of the neighbourhood. It can be hypothesized, however, that the axes are used also for trips crossing the neighbourhood in order to reach destinations located outside of it, especially thanks to the direct connection between piazza Bernini and the access to Collegno. Given the role of the streets, an action of limitation of this component of traffic could be addressed by planning activities, in order to discourage through traffic and divert it to other axes. In this context, the decision of a shared solution could be evaluated where necessary, if accompanied by measures of traffic calming impacting vehicular traffic on the axes: this shows the importance of a multiscalar approach, as mentioned previously, highlighting how design measures on a single portion of a street is impacted by decisions made at a broader scale, such as the street hierarchy of the neighbourhood.

For this work, it was preferred to maintain the location of the bicycle path on the right side of the street, with the same direction of vehicular traffic. This decision is mostly intended to maintain a regular scheme, allowing cyclists to identify intuitively the location of the infrastructure, and avoiding unexpected conflicts with drivers, linked with the unusual location of cyclists on the carriageway: despite having advantages, as mentioned previously, the schemes locating the cycling path on the left side of the street are more complex and they can result in unusual interactions in case of turns. The scheme foreseeing cyclists to circulate in the opposite direction of vehicles on the bicycle path, and in the same direction sharing the space with vehicles, as mentioned, would allow increased possibilities for cyclists, since they could use two two-way axes, but it can be less intuitive, especially for cyclists not familiar with the area, and for drivers, who, while turning, would have to give priority to cyclists coming from the opposite direction.

As a general principle, the design aims at redistributing space between the users of the street, in order to allow the introduction of a separated cycling infrastructure as well as to provide adequate space for pedestrians. This is done by a reorganization of the space destined to cars: the lane is reduced to the minimum standards allowed by the regulations, freeing up space for other uses. Similarly, the intervention would result in a reduction of car parking stalls. Currently, parking is located on both sides of each of the two streets: given the limited available space, the introduction of the cycling path and green space inevitably results in a reduction of parking. The design proposal, however, foresees different scenarios, some of which aim at maintaining as much as possible car parking, in order to reduce the impact of the intervention on the number of stalls available, by adapting the dimensions of the other components. In any case, interventions for street safety, such as the ones improving visibility at intersections, have an impact on this component in every scenario.

On top of the overall redistribution of space along the axes, the design proposes specific interventions in correspondence with the elements of attraction identified previously, especially by extending the space available where relevant presence of pedestrians is expected at specific times. For example, increased pedestrian space is obtained in front of the post office of via Exilles, where large groups of people concentrate during mornings. An extension of pedestrian space is also located in proximity to the entrances of schools, with the aim of improving safety and providing a suitable space to be used especially during opening and closing times. Similarly, the church located on via Asinari di Bernezzo is used for religious celebrations, during which large presence of pedestrians is noted in front of the main entrance. The extension of the pedestrian space, in this context, is integrated in the redesign of the small square created by the intersection with via Mogadiscio, currently characterized by a large space destined for cars but not efficiently used. All scenarios aim at improving this condition, by increasing pedestrian space and by introducing vegetation, whose space is maximized, mostly due to the observation of a critical value of the PET on this site, highlighting the necessity for an intervention.

Along the whole axes, interventions of traffic calming are introduced by the proposal, varying according to the necessities linked with each scenario:

- The reduction of the lane for vehicles to minimum standards can be considered as a measure reducing speed, due to the lower available space, also linked with a visual perception for drivers
- The extension of sidewalks in correspondence with intersections. On top of reducing the distance that pedestrians have to walk on the carriageway, this allows improved visibility, by eliminating parked cars in proximity, constituting obstacles:

the Highway Code identifies a minimum distance of 5 metres from the closest side of the intersecting carriageway (art. 158 Codice della Strada – d.lgs. 30/04/1992 s.m.i.). The reduction of residual space of the vehicular lane, moreover, allows to induce drivers to reduce speed during the turns, by following an adequate curb radius defined by the sidewalk. Moreover, the extensions are used where possible in order to bring vehicles turning into intersecting streets to be located as close as possible to a perpendicular position to the crossing cycling path, increasing visibility in the manoeuvre in order to give priority to cyclists.

- Raised pedestrian crossings. The measure consists in the addition to the carriageway of ramps and of a platform at the same level of the sidewalks, in correspondence of pedestrian crossings. This produces a continuity in the spaces for pedestrians, as well as reducing the speed of drivers due to the difference in height produced by the ramps, on top of symbolically bringing motorized vehicles to a position of “guests” in a space primarily accommodating pedestrian needs (Socco, 2009). In this context, raised pedestrian crossings are located on the streets intersecting the two main axes, by contributing to the creation of an effect of “entrance” to the residential areas, by establishing a difference between the neighbourhood streets and the local streets intersecting them. Apart from the case of raised intersections, raised crossings are not located on via Asinari di Bernezzo and via Carrera, due to the presence of the bus line. Speed bumps and raised platforms constitute elements of discomfort for public transport: since this shares the same lane of private traffic, it is decided in most cases to avoid the use of these measures where the bus circulates

- Raised intersections. Similar to the previous measure, in this case the whole intersection is raised, and the effect is not limited to a single axis. Located in specific context, this tool allows to characterize furtherly the pedestrian character, by inducing drivers to adapt their behaviour. This measure is introduced by some scenarios at three intersections with specific characteristics: the intersections with via Capelli, characterized by the proximity with the schools Duca d’Aosta and Schweitzer, where increased attention to the objective of street safety is required, and the intersection with via Mogadiscio, with the objective of increasing the pedestrian character of the square, on top of increasing safety in the moments of high presence of pedestrians, for example when religious events take place. The scenarios introducing raised intersections take into account the necessary compromise between their benefits and the effect on public transport previously mentioned, considering that, especially on via Asinari di Bernezzo, the difference in height results to be frequent.

- Chicanes. Horizontal deflections to the carriageway are introduced by some scenarios along the two main axes. In general (Socco, 2009), chicanes are placed as speed-reducing measures, since drivers are forced to anticipate a modification of their trajectory, and due to the visual effect of closure they create along the axis. In the context of this work, horizontal deflections are introduced additionally in order to manage the extensions of sidewalks, for example in front of the church, or to allow an extension of the green strip, in order to guarantee plantings to be placed at a suitable distance from the buildings, according to the regulations. The dimensioning requirements linked with this last factor lead in some cases to a reduced deflection, with a negative impact on the effect on visual closure and speed reduction.

- Additional measures could be introduced in the design, although they were not represented, such as speed bumps. As previously mentioned, the placing of these elements has an impact on comfort for public transport users, limiting their placing on local streets. On the two main streets, the possibility of introducing cushions could be considered: their width limits the effect of speed reduction to cars, while vehicles whose distance between wheels is larger than the width of the cushion, such as buses or emergency vehicles, are not impacted by them. The use of these tools is not allowed by the Italian highway Code, however, their placing can be authorized in some cases as an exception to the law, and if their characteristics are described in the municipal regulations ("Regolamento viario"), on neighbourhood and local streets (Socco, 2009).

The dimensioning of the elements constituting the design results from technical regulations, as described as follows.

- In all cases, the width of the traffic lane for the area is maintained at 3.5 m, coherently with the minimum standard required by the New Highway Code for neighbourhood streets.

- The minimum width for a one-way separated cycling path, as reported by Socco (2009), is set by the ministerial decree 557/1999 to 1,5 m, with a possibility to exceptionally reduce it to 1 m for limited portions and with adequate signalling. In continuity with the proposal of the feasibility study for the axes, the width is extended to 1,8 m, in order to increase comfort for cyclists. However, due to the necessity to introduce an additional series of parking stalls, some scenarios foresee a width of 1,5 m or 1,7 m in some portions. Moreover, a separation from vehicular traffic is mandated by the same regulations, with a minimum width of 0,5 m. This element is maintained both if it serves the purpose to separate the cycling path from parking stalls or from the vehicular lane. According to the scenario, it can consist either in a green strip bordered by two stone curbs, or of a curb composed of impermeable material, such as stone, concrete or porhyrus.

- The minimum width of sidewalks is set by the New Highway Code at 1,5 m (Socco, 2009). In the area the existing sidewalks are relatively wide, ranging between 2,5 and 3,5 metres: the proposal, aiming at improving pedestrian spaces in terms of quantity and quality, maintains or extends the current extension where possible. However, due to the needs related to the simultaneous introduction of the cycling path and the green spaces with correct distance from the buildings, together with the maintenance of the vehicular lane and at least one strip of parking stalls, the width is in some cases reduced, by maintaining in all cases a minimum dimension of 2,5m.

- The ramps for the raised intersections and raised pedestrian crossings were designed with a slope of 10%, according to indications of Socco (2009), considering a height of the sidewalks of 10 cm. Pedestrian crossings are characterized by painted white strips, with dimensions of 2,5 m and 0,5 m, according to the Regulations of execution of the Highway Code (Regolamento di esecuzione del Codice della Strada, D.P.R., 16/12/1992 n° 495)

- The pedestrian ramps at crossings were designed according to the dimensioning of the guidelines of the City of Turin (Maggiulli et al., 2006), by adapting the measures according to the availability of space.

- As mentioned, the dimensioning of the chicanes derives not only from an objective of speed reduction, but also from the necessity of space required by the functions located along the street. As stated by Socco (2009), Italian norms do not regulate the design of these elements: it was therefore considered as a reference the case of the Swiss norms (Norma sulla segnaletica per il traffico lento, SN 640 829). Based on the dimensions and the typology of vehicles allowed, the two main streets correspond to the Swiss category of local streets, where chicanes are allowed. For the case considered, the construction used as a reference is the one with the ratio of 6/9 corresponding to the dimension of (Bv+Tv)/Lv, as shown in the scheme. In the case of the project, however, the width of the deflection Tv is 2 m instead of 2,5 m. This resulted in a modification of the construction in order to adapt it to the availability of space of the context, reducing the visual effect of closure, therefore possibly limiting its effectiveness.

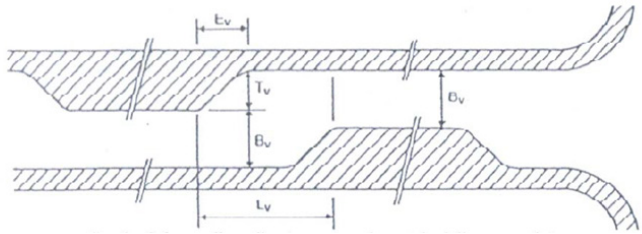


Figure 74. Chicane construction according to the Swiss norms (Norma sulla segnaletica per il traffico lento, SN 640 829)

- Particular attention was given to the curb radius used for the design of the sidewalks at the intersection. Stefanutti (2013) provides a historical overview of the Italian regulation in this context. For the purpose of this work, some of the regulations of the work are particularly relevant:

    1. The norms C.N.R. n. 90/83 “Norme sulle caratteristiche geometriche e di traffico delle intersezioni stradali urbane”, with a specific deatail on urban intersections, introducing the construction of the “tricentric curve” which will be exposed subsequently;

2. The norms C.N.R. n. 150/1992 “Norme sull’arredo funzionale delle strade urbane”, providing details about the design of specific elements of the street, such as road markings or driveways;

3. A study, named “Studio a studio a carattere prenormativo - Rapporto di sintesi – Norme sulle caratteristiche funzionali e geometriche delle intersezioni stradali”, conducted in 2001 by the Universities of Rome and Trieste with the objective of providing the premises for an updating the existing norms;

4. The norm resulting from the study, D.M. 19/04/2006, characterized by a lower level of details regarding the criteria for design, leaving higher discretionary power to the designers.

The norms 90/83 regulate multiple typologies of intersection. Among the typologies prescribed by the article 3 of the Highway Code, the intersections in the area are at-grade, meaning that the traffic flows using the intersection are not separated, and linear, not characterized by roundabouts. For this category of intersection, the norms identify the possibility of creating specialized lanes, for the accumulation (“corsie di accumulo”) and for the entrance (“corsie di immissione”), providing a specific space destined to vehicles using the intersection to turn. Based on the presence of these elements, the norms provide the details necessary for the dimensioning of the components of the intersection. In order to define the internal margin of the carriageway for the right turns, corresponding to the connection between the main street and the secondary one, the norm introduces the tool of the “tricentric curve”, defined in the paragraph 5.3. Given the characteristics of the fabric characterizing the area of study, it is impossible to define sufficient space in order to introduce specialized lanes. In the paragraph 5.6, moreover, the norms state that for the intersections which are not provided with specialized lanes, specific space should however be destined to the intersections, by verifying the turning path layouts of the vehicles circulating on the streets, using the tricentric curve in order to define the margins of the carriageway, similarly to the prescritptions regarding the intersections of paragraph 5.3. The norms mention the possibility of exceptions, for which a single radius can be used, corresponding to 8 metres in presence of cars or 12 in presence of other types of vehicles. However, the conditions for this approach are not specified by the norms. The tricentric curve consists in the juxtaposition of three arcs of a circle, deriving from three different radiuses, using the following parameters:

- Angles:
  - $\alpha 1 + \alpha 2 + \alpha 3 = \delta$ (with δ being the angle between the two margins)
  - $\alpha 1 = \alpha 3$
  - $\alpha 2 = 5{,}5\ \alpha 1$
- Radiuses:
  - R1: R2: R3 = 2,5 : 1 : 5,5

The value of R2 defines the different values of the construction, and it varies according to the angle of intersection between the two axes and the street categories. The norms synthesise the values of R2 in a table. Based on these values, the construction of the curve can be done according to the following scheme.

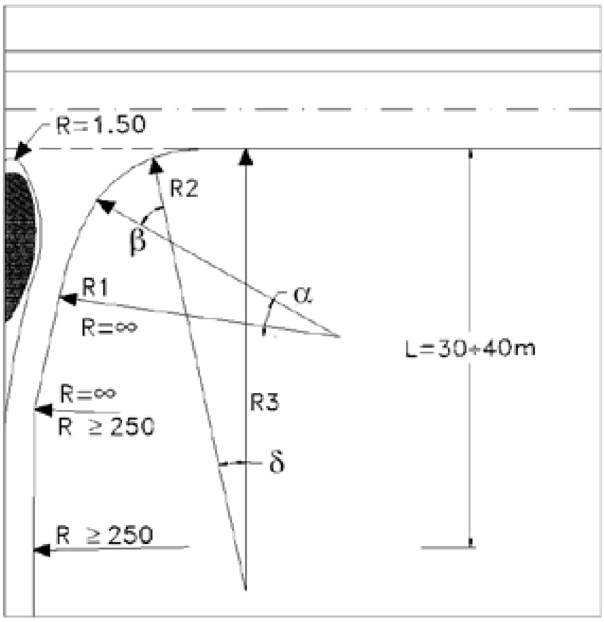


Figure 75. Tricentric curve construction (Stefanutti, 2013)

While the study of 2001 uses the same criteria, the resulting norm of 2006, as mentioned, does not provide detailed instructions regarding the geometric dimensioning.

In addition to the criteria for the minimum radiuses for the right turns stated by the norms, Canale (2009) highlights the necessity to consider the turning path of the vehicles using the intersection, so that sufficient space is available for the maneuvers of larger vehicles. The turning path can be traced using additional values, complementary to the ones of the tricentric curve. These values are provided by Canale (2011), together with detailed values of R2, according to a wider range of angles of intersection between the two axes. The values used for the tracing of the tricentric curve, as well as the turning path, depend on the category of the streets intersecting. In the work of Canale (2011), in the section regarding measures for traffic calming, it is mentioned that lower radiuses can be considered in order to reduce vehicular speed, however, no specifications are detailed.

With the objective of complying to the regulations in force, and especially to consider the possibility for emergency vehicles to access the streets located in the area, the method initially chosen for the tracing of the intersections in the area followed the criteria of the tricentric curve proposed by the CNR, integrated with a verification of the turning paths according to the values of Canale (2011). However, it was verified that the application of the values corresponding to the intersection between streets belonging to the categories E and F, resulted in paths which are excessively wide for the context, reducing the space for pedestrians, showing an impossibility of application of the construction in the context, due to the high values of R2. Therefore, a different method was applied, based on the functional evaluation of the accessibility to vehicles rather than on the application of the norms by the CNR. The priority in the design of the intersections was given to the accessibility of emergency vehicles. It must be noted that it was not possible to verify such condition for all vehicles, such as firetrucks of large dimensions, which might need the application of specific criteria. However, the Highway Code states that for streets belonging to the category F, the largest vehicles admitted are trucks (autocarri). The intersections were therefore designed by verifying the access of these vehicles. This was done through the design of curbs with a single radius of curvature, ranging from 6 m to 8 m, and by providing sufficient space in the intersection to the turning paths of a truck. The tracing of the turning paths was obtained through the comparison with a project published by the municipality of La Loggia, Turin (Comune di La Loggia, 2021), by overlapping the turning path to each intersection.

In order to improve thermal comfort, three main measures are proposed as an integration to the design of the street: shading using newly-planted trees, permeable surfaces covered by grass, high albedo materials for pedestrian contexts. As highlighted by the literature, and as confirmed by the results of the simulation of the current state, the main effect in improving thermal comfort is provided by shading. The main objective, therefore, is the maximisation of shading on pedestrian areas, and in particular to both sidewalks, in order to allow comfortable pedestrian itineraries on the axes, with adapted conditions to the warmest periods of the year, contributing to the attractiveness of public spaces in the areas. As previously described, given the prevalent east-west orientation of via Carrera and via Asinari, it is relevant to consider the shading effect of the buildings: during the warmest hours of the day, the sidewalks located on the southern sides of the streets benefit from it, although it is affected by the discontinuities at the intersections. During the hours before the sunset, the effect is gradually shifted to the northern side. With the goal of maximizing the effect of shading when the PET is the highest, therefore during the central hours of the day, it was decided to concentrate the effect of planting on the northern side of the streets: the project foresees therefore the creation of a tree line on both axes, located next to the sidewalk, in order to maximise the effect on pedestrians. A particular arrangement is proposed for the square at the intersection between via Asinari di Bernezzo and via Mogadiscio, where additional space is available: the northern side privileges the pedestrian use linked with the church, with a prevalence of paved materials, although shaded by trees placed in continuity with via Asinari di Bernezzo, while the southern side is prevalently covered by grass, with additional trees increasing shadowing, especially due to the critical PET value observed. The dimensions of the trees are mostly linked with the availability of space and the requirements in terms of distance stated by the municipal regulations. Literature highlighted how trees should not constitute obstacles to wind flow, since this would have a counterproductive effect on comfort: on the two streets wind flows from west to east along the canyon formed by buildings, it can be hypothesized that the alignment of planting to this direction is does not negatively affect wind, as a planting perpendicular to the street would do.

As a guideline for the dimensioning for the placing of trees, the main tool considered was the municipal regulation on public and private greenery of the City of Turin (Regolamento del Verde pubblico e privato della Città di Torino), integrated with additional recommendations and the comparison with existing cases and projects in the city. The main distinction operated by the regulation is based on the dimensions of the species. Trees are therefore divided into three categories (art. 28):

- First category: higher than 16 m
- Second category: 10-16 m
- Third category: lower than 10m

Due to the dimensioning requirements which will be illustrated, the proposal foresees the introduction of plants belonging to the second and third categories. The application of some of the dimensioning norms contained in the regulation follows the division in categories. For the purpose of this work, the criteria contained in the article 29 are fundamental for the dimensioning of the area destined to the planting. For each tree, a permeable area should be provided, with dimensions depending on the category, namely 6 sqm for the second category, and 3 sqm for the third category. This element is reflected in the design where the tree planting is located in alternance with car parking stalls. In order to maximise the availability of car parking without affecting the space for trees, two typologies of green areas are introduced, depending on the category of tree foreseen. The key factor influencing the choice of the tree category is the distance from buildings, regulated by the article 61. While the minimum distance of the trunk from the sidewalk is of 1 m in all cases, the distance from the buildings is of 6 m for trees belonging to the second category, and 4 m for trees belonging to the third one. This element is fundamental since it largely influences the design: the necessity to guarantee the sufficient distance led to the insertion of a green strip on the northern side in some cases, reducing the available space on the remaining portion of the street. Since the norm refers specifically to a distance from buildings rather than from the boundaries of the property, in the cases where the building is located backward from the boundary, such as the school "Duca d'Aosta", the distance is calculated from the walls of the building, reducing the need for additional space on the street. Furthermore, indications regarding the distances from the intersections are reported by ministerial regulations (Circolare n. 8321, 11-8-1966, Ministero dei lavori pubblici). Regarding the distance between the trees, the regulation does not provide specific indications. It must be noted that this element largely depends on the selected species, however, the reference used was a manual for greenery of the city of Turin (Bovo et al., 1997), specifying a minimum distance of 7-10 metres for trees lower than 15 metres. This distance was considered in all cases, even though further detailed observations should be made in the context of a more specific project regarding vegetation.

As mentioned, two typologies of trees were selected, based on the availability of space. Although more detailed studies should be conducted in order to select the appropriate species for the context, some examples can be selected. In all cases, the trees should be deciduous, in order to maximise the shading effect during summer, and to allow light to reach the buildings during winter. As stated by the municipal regulations, the species should not belong to the "black list" of invasive species provided by the Region. (Regione Piemonte, n.d.). Examples of trees belonging to the second category can be selected in the context of the area of study: according to the GIS database of vegetal species of the municipality of Turin, the species Acer Campestre is located in the planting along via Valgioie, located to the south of the selected area. It can be noted that, despite the height of the trees, the distances between the trees and between the trees and the buildings are lower than the ones indicated previously, probably linked with different regulations than the ones currently in force. According to the tool attached to the "Prontuario del Verde" produced for the city of Vicenza (Vicenza Forum Center, 2023), the two species Celtis Australis and Celtis Occidentalis, belonging to the second category, are adapted to period of drought and to air pollution, in Turin these species are present especially on larger boulevards, such as corso Svizzera, corso Vinzaglio, corso San Martino. Regarding the trees belonging to the third category, recent interventions in the city, such as the redesign of corso Umbria, introduced the species of Pyrus Calleryana, particularly adapted to the context of climate change (Città di Torino, 2023). Alternatively, the species Carpinus Betulus is also used for tree-lined streets, and it is adapted to long warm summers (Terzuolo et al., 2004), the species Ostrya Carpinifolia was used for example for the plantings along corso Verona in Turin.

As a second measure, literature showed that green areas contribute to the reduction of temperature, thanks to evapotranspiration processes, although the effects resulted to be limited in the simulations performed on the area. The design introduces green areas where sufficient space is available: it is preferred, where possible, to use green strips as the areas where plantings are located, however, in some cases, trees are alternated with parking stalls, due to the limitedness of the street section. Green strips are also introduced in the cases where the traffic lane is reduced, the residual space cannot be reused for car parking, due to insufficient width, and an extension of the sidewalk would be superfluous. Additional green spaces are some of the strips having the function of separating the cycling path from vehicular traffic or parking, however, due to their reduced dimensions, their presence could not be integrated in the model for the simulation. For the purposes of the simulation, the same typology of grass was used as the one considered in the first phase.

Finally, the choice of materials was important as a tool to improve thermal comfort in the area. It should be noted that the design proposed mostly aims at proposing a distribution of space on the street, while an increased level of detail could be addressed by a proposal focusing on the design of public spaces: in this context, the choice of materials is referred to the main organization of space, while increased detail could be studied for specific portions of the site, such as the square in front of the church "Divina Provvidenza". As a general principle, asphalt is maintained for the portions of the carriageway used for vehicular circulation. This corresponds to the material with albedo 0,15 used for the first simulation. It could be hypothesized to consider different materials, however, this surface was chosen considering other interventions in the city of Turin as examples. The theoretical framework showed how the conclusions of the literature are conflicting about the materials used for pedestrian areas, since high albedo materials, while reducing surface temperature, might be detrimental due to the reflection of light, which impacts the comfort of users. It was decided, therefore, to use a material with an albedo of 0,3, according to the recommendations contained in Dessì et al. (2017). In the software, the material "Granit pavement – single stones" was used, with an albedo of 0,35. In order to provide coherence with other recent interventions in the city, the colour of the bicycle path was maintained as red: the material was associated with "Asphalt road with red coating" in the software, with an albedo of 0,4. As stated in Socco (2009), raised intersections should be provided specific colour or material, in order to emphasise their specific character. Despite the need for continuity with pedestrian areas, however, these spaces are treated differently in terms of materials, since the flow of vehicles can affect their integrity (Socco, 2009): it was therefore preferred to use coloured asphalt, selecting the same material of the bicycle path, due to similar albedo to the characteristics listed by Dessì et al. (2017). As it will be highlighted by the sections attached to the project, additional materials could be considered in more detailed focuses, such as the use of porphyry strip serving as a visual and tactile separation between the sidewalk and the cycling path. The reduced dimensions of these elements, however, cannot be distinguished in the modeling with the software, due to the size of the grids. Finally, it was hypothesized to use permeable materials for parking stalls, constituted by concrete strips alternated with empty portions with terrain treated in order to allow the growth of grass (Dessì et al., 2017). This configuration has an albedo of 0,2 – 0,3.

6.2. Project scenarios

Based on the general criteria illustrated, the project is articulated in different scenarios: with a common general organization of the design, the scenarios differ in relation to the different degrees of priority attributed to the functions of the street. As mentioned previously, decisions on the allocation of space are the result of a compromise between the different needs related to the uses of the street. Considering the presence of some invariable elements in the dimensioning, such as the vehicular lane, the sidewalks and the cycling path, the surface related to the other components can be distributed differently according to the priority. In particular, the introduction of tree plantings is considered in all cases, however, the decision on the placing of trees belonging to the first or second category influences the design, due to the different distances which should be respected.

The scenarios are named after the elements characterising them. The first element of distinction allows to divide them into two main groups:

- G. Priority is given to the maximization of green spaces and size of the trees, by taking space mostly by reducing parking stalls
- P. Despite the introduction of green areas and measures for thermal comfort, as well as the bicycle path, an attempt is made in order to maintain a maximum number of parking stalls, given the high demand of the area, by reducing the size of other spaces on the street

A second level of distinction is referred to the differences in height of the different components of the street:

- H. The bicycle path is raised at the same height of the sidewalks, assumed at 10 cm
- L. The bicycle path is at the same height of the vehicular lane, separated by a curb
- R. The traffic calming measure of the raised intersection is introduced, the bicycle path is at the same level of the sidewalks
- S. The whole surface of the street is raised, including the vehicular lane

Moreover, some of the scenarios are characterized by further distinctive elements:

- T. Horizontal deflections are introduced to the vehicular lane, in order to guarantee the distance necessary to place trees belonging to the second category

This classification results in different scenarios:

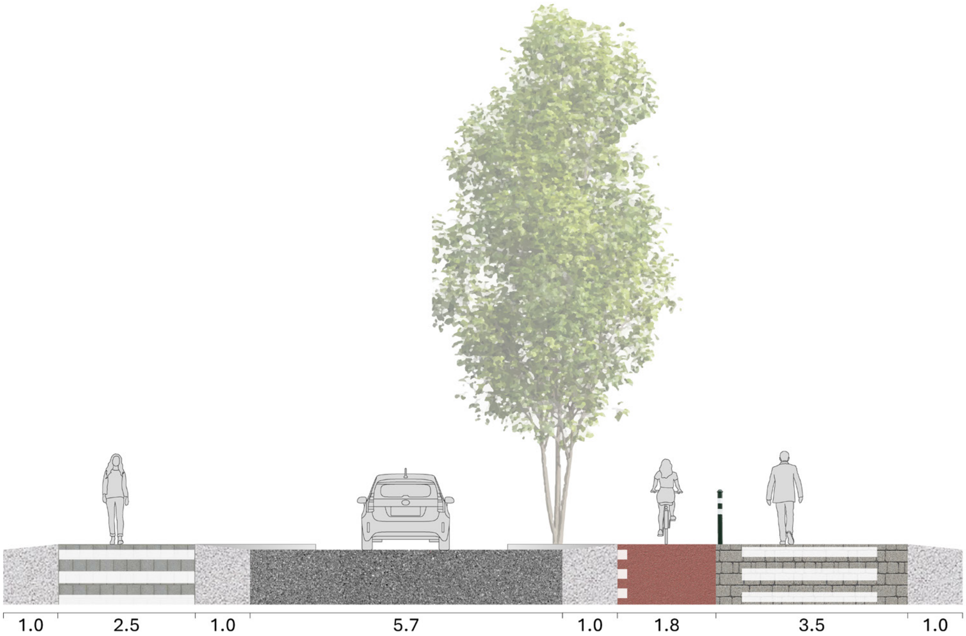
- GH
- GR
- GS
- GLT
- GRLT
- GST
- PH
- PR
- PS

Scenario GH. The scenario introduces the bicycle path contiguously to the sidewalks, on the right side of the street, as explained previously. The bicycle path is located at the same level of the sidewalks, therefore, the raised crossing on the intersecting streets includes both the pedestrian and the cycling crossings. Along via Carrera, the introduction of the bicycle path requires additional space, imposing the removal of the parking stalls located on the southern side of the street. On the northern side, the stalls are alternated with the space destined to tree plantations. The parking stalls are separated from the bicycle path by a green strip with a width of 0,5 m. Alternatively, in order to improve accessibility between the stalls and the sidewalk, portions of this surface could be paved. Extensions of the sidewalks are located at the intersection with via Capelli, in correspondence with the school "Duca d'Aosta", and in front of the access to the kindergarten "Cavaglià", requiring the introduction of a chicane, in order to shift the vehicular lane, located contiguously to the southern sidewalk, as well as to reduce the speed. On via Asinari di Bernezzo, the linear scheme of the scenario locates the trees, alternated with parking stalls, directly next to the northern sidewalk. On the southern side, next to the bicycle path, residual space is obtained from the reduction of the vehicular lane. While on the section between via Capelli and via Baveno the width of this space is 2,5 metres, allowing the introduction of parking stalls and of the element of separation from the bicycle path, on the remaining portions the width is limited, and it is therefore used for a green space, with the possibility of introducing trees of small dimensions. Since the trees are located without additional space in proximity to the northern sidewalk, the distance from the buildings is limited: apart from the portion in front of the elementary school, which is located backward from the street, the design allows the introduction of trees belonging to the third category. The extension of the sidewalk in front of the church requires the creation of a chicane, also serving as a tool for traffic calming. Due to the necessity of reserving 1 m for the introduction of the ramps of the raised pedestrian crossings, the width is maintained for the curb of separation between the vehicular lane and the bicycle path. The scheme of the western portion of the street is proposed to the east of via Salbertand, by imposing a horizontal deflection of the trajectory of vehicles on the intersection. On both streets, since the bicycle path is at the same height of the sidewalks, the bus stops are directly accessible from the sidewalks. Similarly to other scenarios, the sidewalks of via Capelli in front of the school "Duca d'Aosta" are extended, in order to provide additional comfort during the times of opening and closing, and trees were introduced.


Scenario GH
1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
BUS
4
8
9
m 5 10

Section 1



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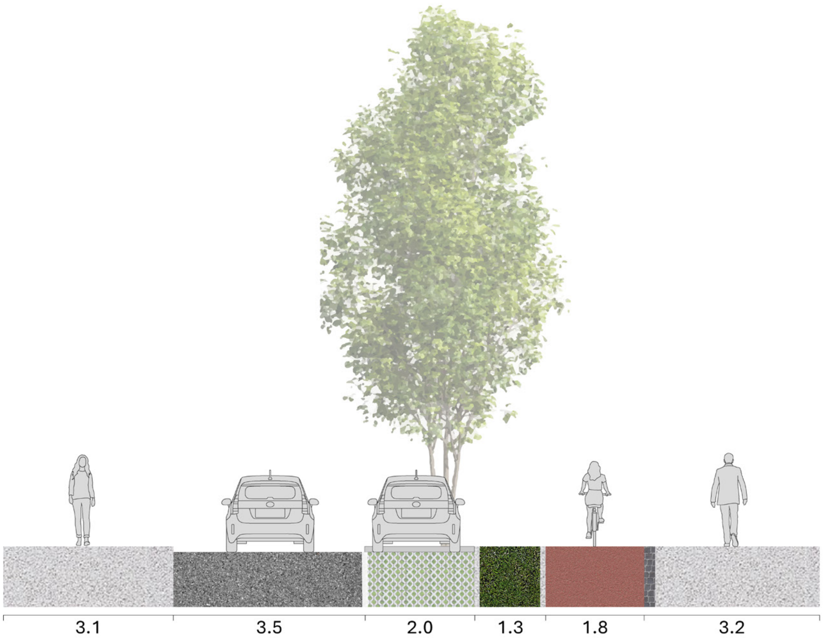

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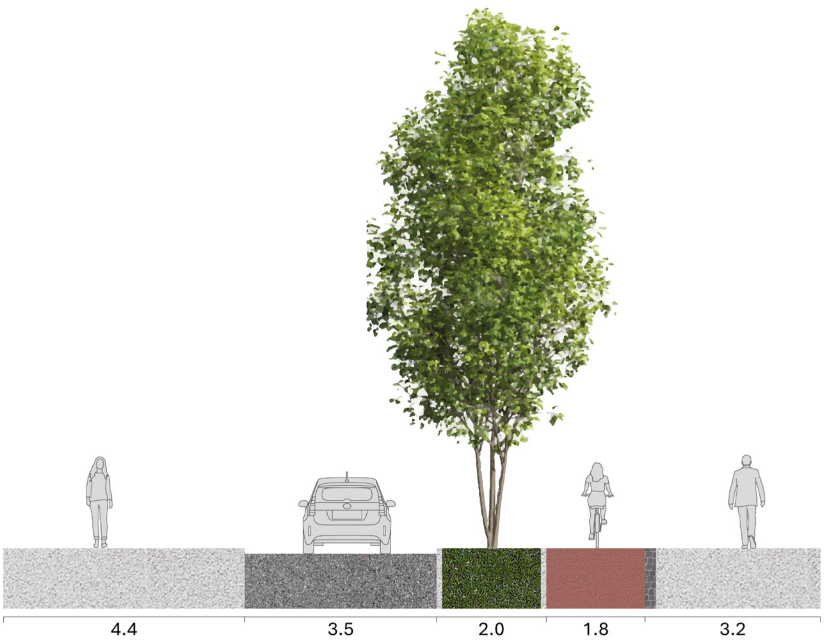

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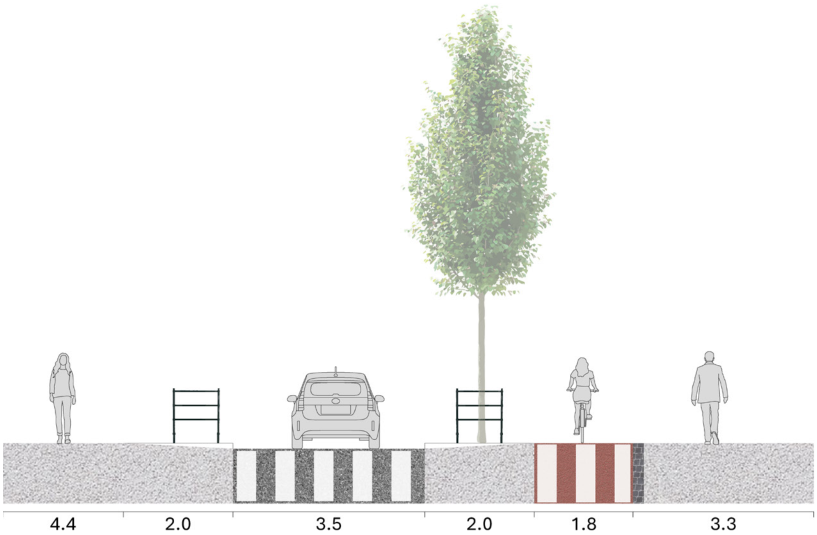

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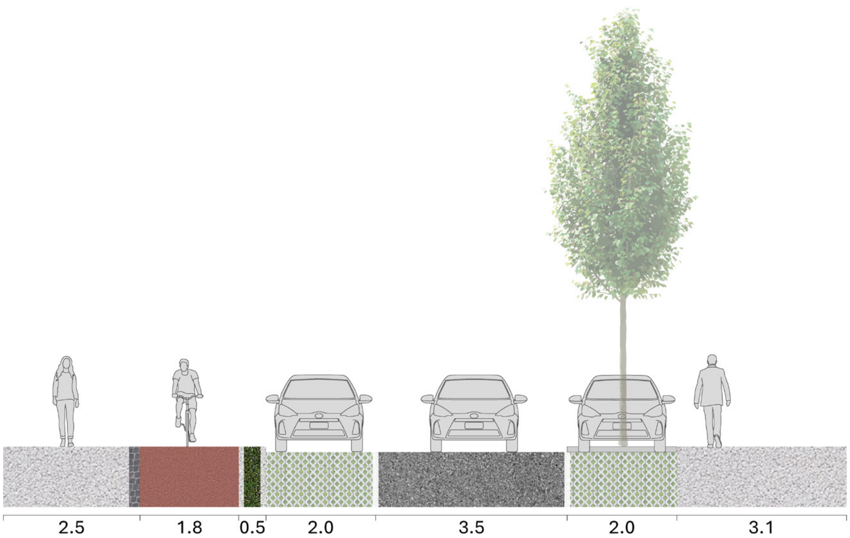

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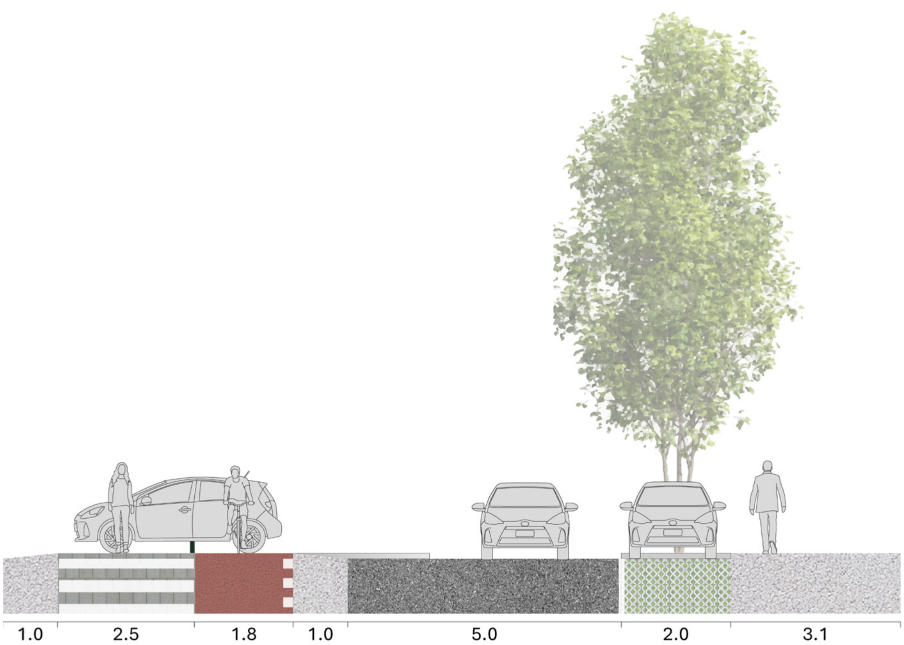

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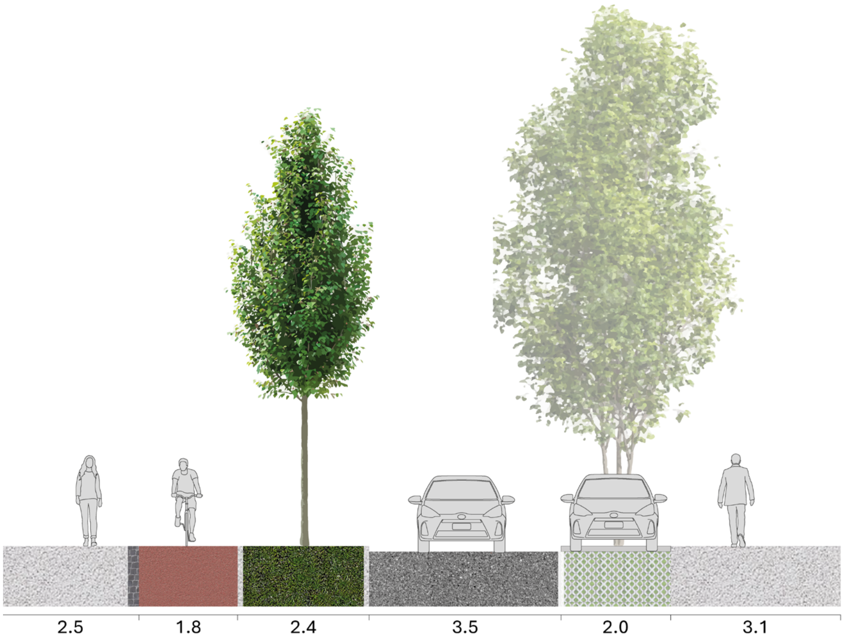

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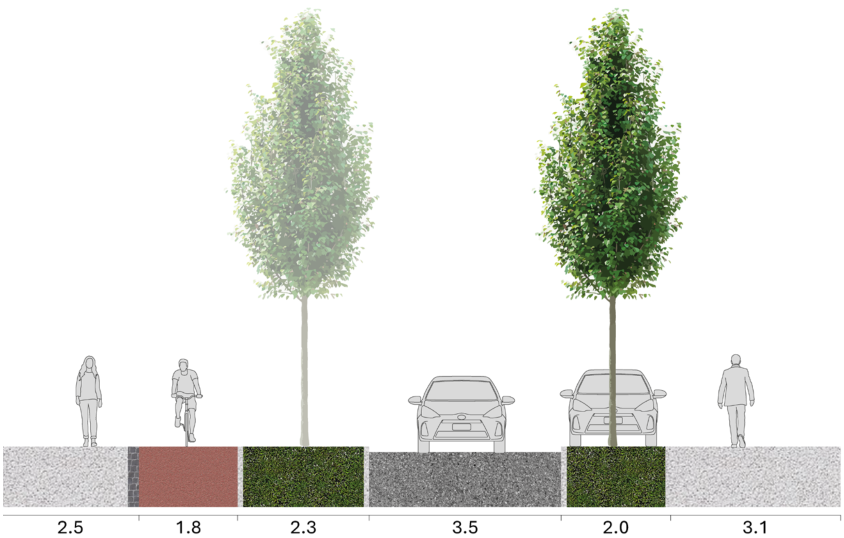

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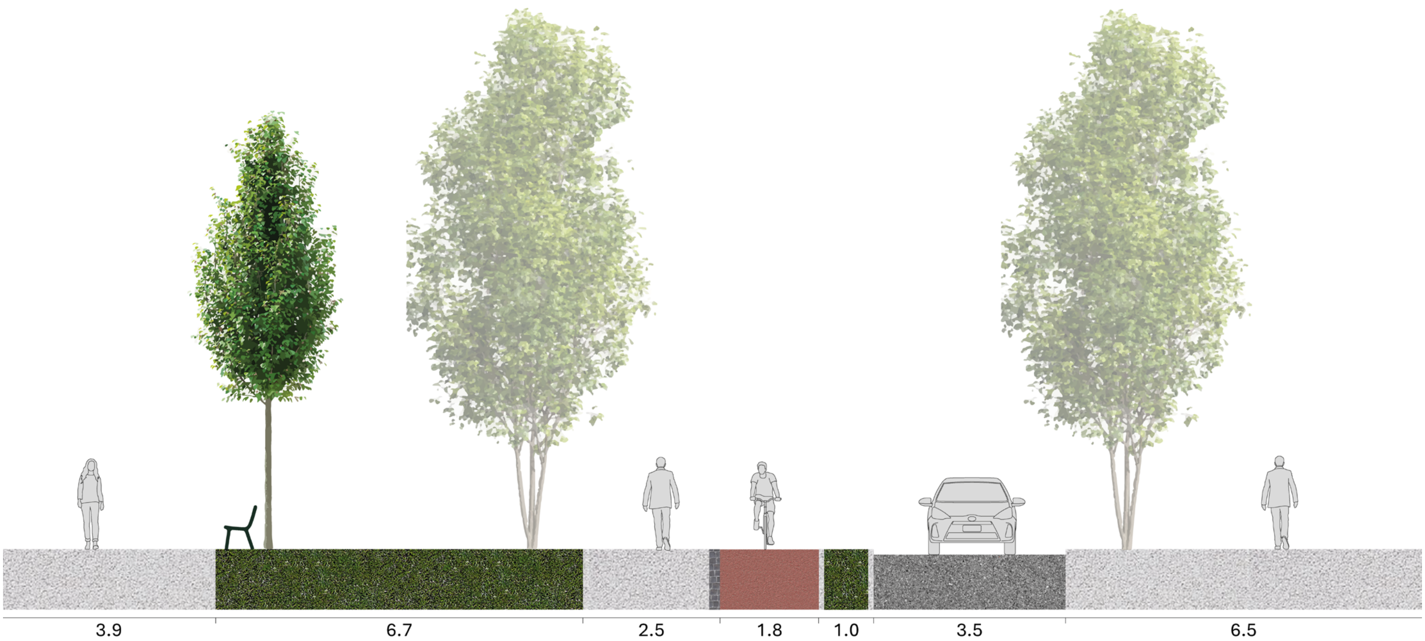
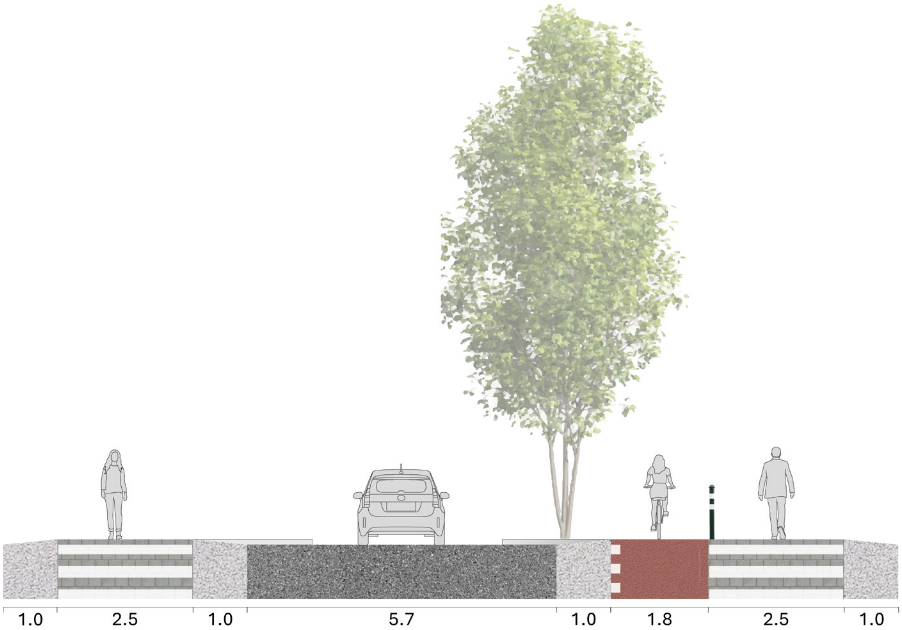


Scenario GR. The scenario differs from the previous one because of the introduction of the raised intersections. In correspondence with the elementary school and with the church, therefore, the vehicular lane is at the same level as the sidewalks and the bicycle path, meaning that it should be separated with vertical elements, such as bollards. An effect of continuity is provided to the square at the intersection with via Mogadiscio. A criticism on this scenario is related with the proximity of the two traffic calming measures of the chicane and the raised intersection, located at a limited distance from each other. This critical element is solved through a different configuration of space by other scenarios, however, in this case, the coexistence of the two elements is necessary to maintain at the same time the extension of the sidewalk in front of the church and the principle of the raised vehicular space.


Scenario GR
1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub

N
BUS
4
8
9
m 5 10

Section 1



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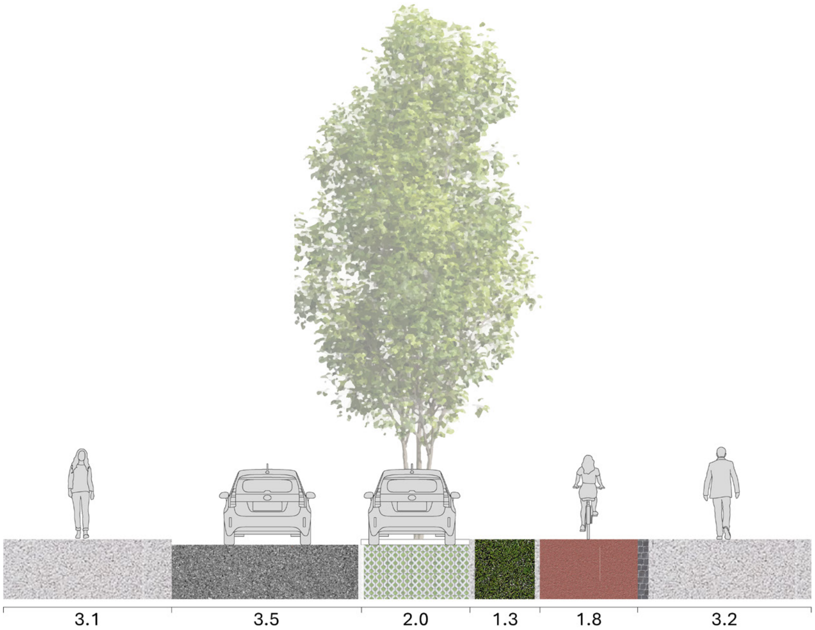

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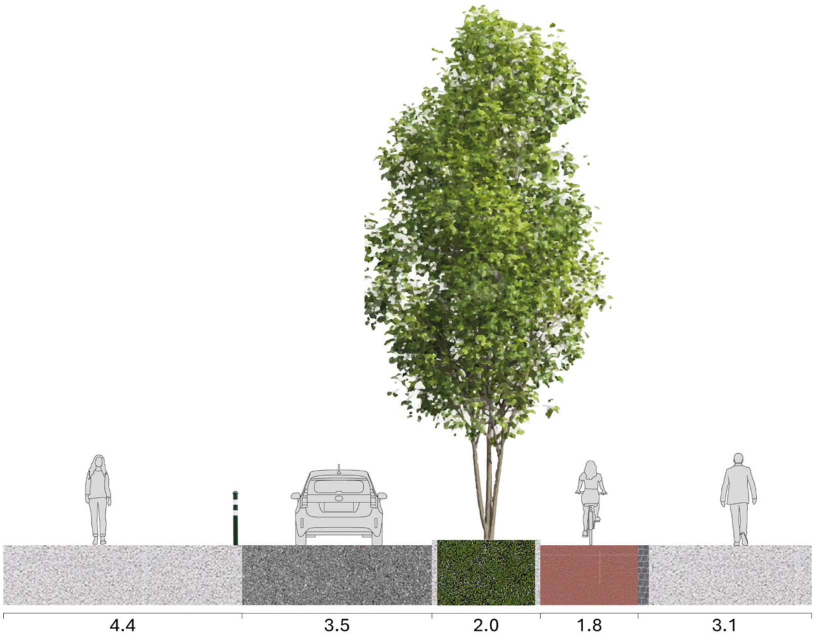

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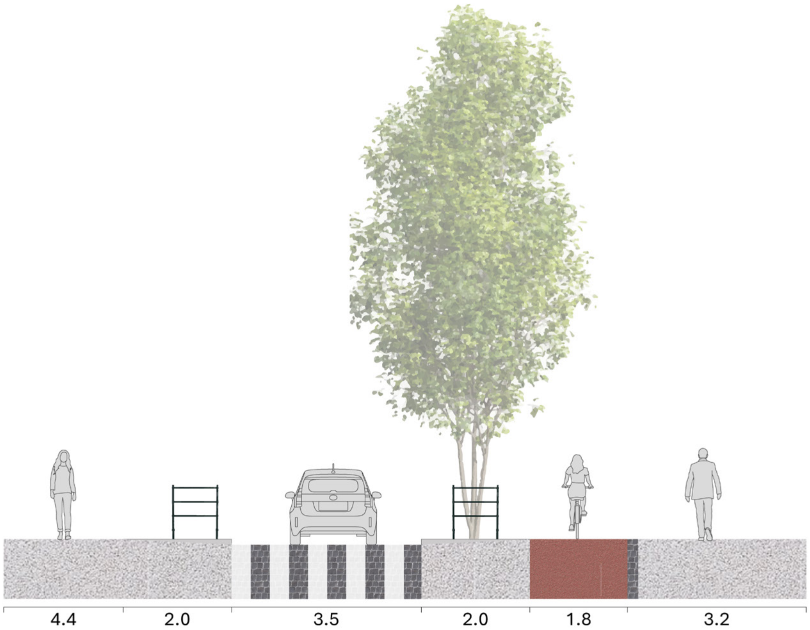

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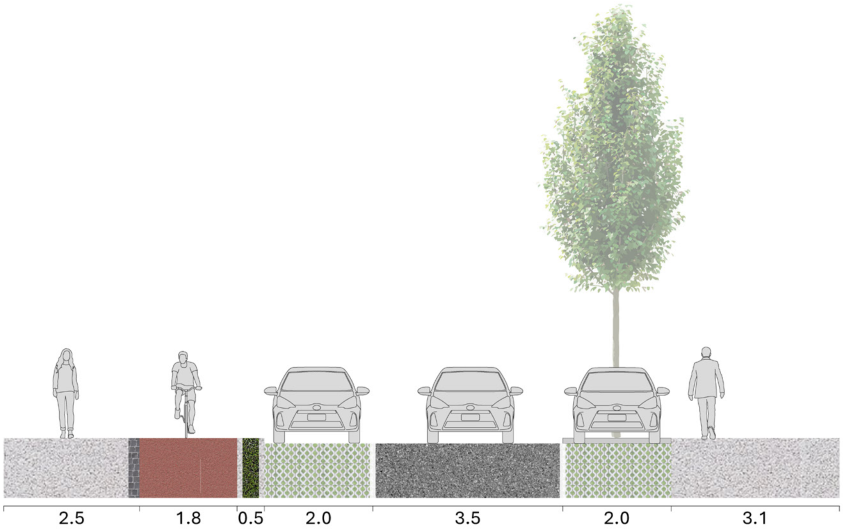

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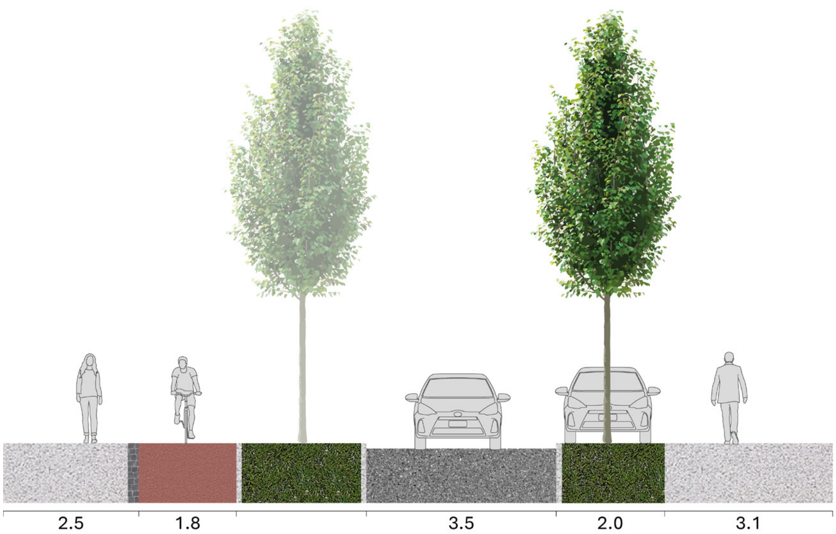
Section 7

Section 8



Section 9

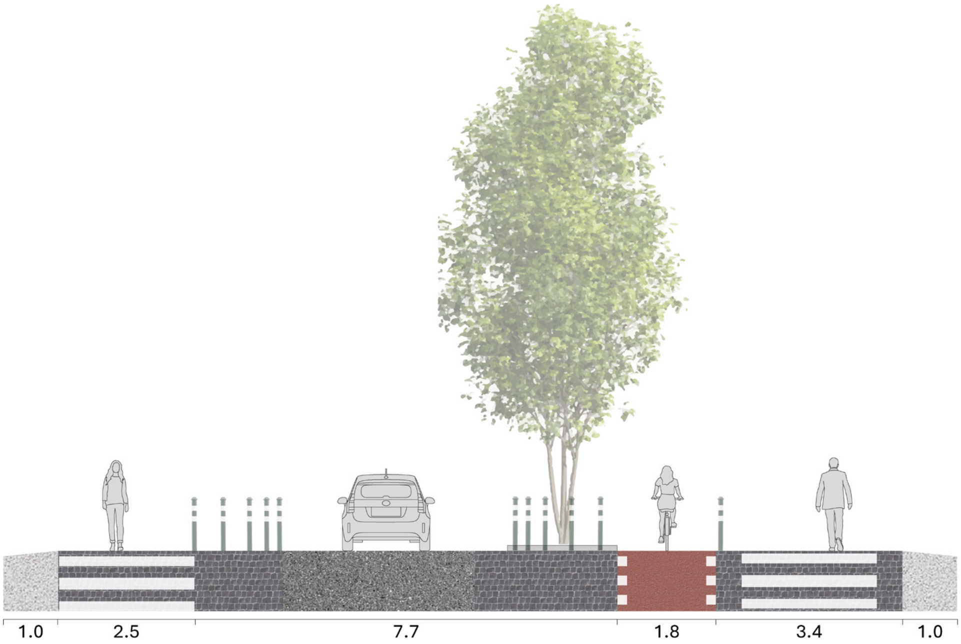
Scenario GS. The scenario is characterized by a continuous surface, where the vehicular lane is at the same level of the sidewalk and bicycle path. This could increase the pedestrian character of the street, although a separation would still be in place, but an effect on traffic calming could result from the visual effect related to the limited demarcation of the spaces destined to vehicles and pedestrians. This requires elements of separation along the whole length of the street, such as bollards. The absence of differences in height along the vehicular lane allows comfort to public transport users, but it limits the capacity of the design to reduce speeds. The green spaces located in proximity to the vehicular lane are furtherly raised, in order to avoid their occupation by vehicles. Moreover, public transport stops are raised, in order to guarantee accessibility to the buses, requiring the use of ramps to reach the level of the sidewalks. In this scenario, the chicanes constitute elements of traffic calming, and the redundance with the raised intersection in front of the church is avoided.

Scenario GS


1
2
3
5
6
7
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
4
8
9
m 5 10

Section 1



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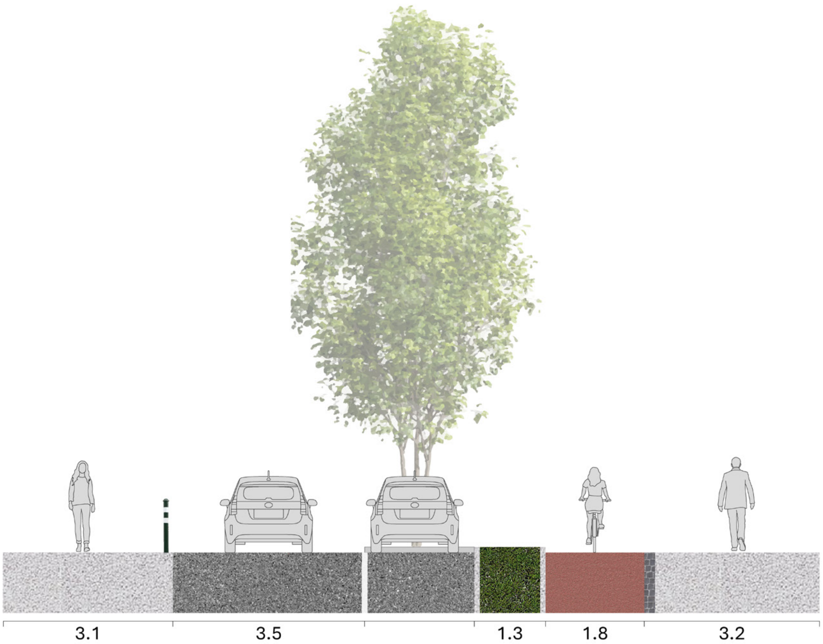

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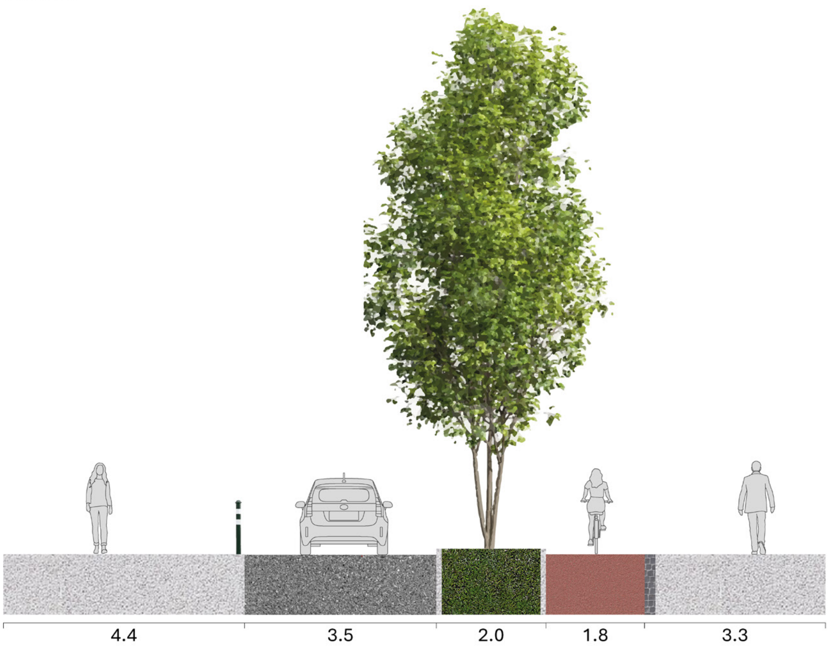

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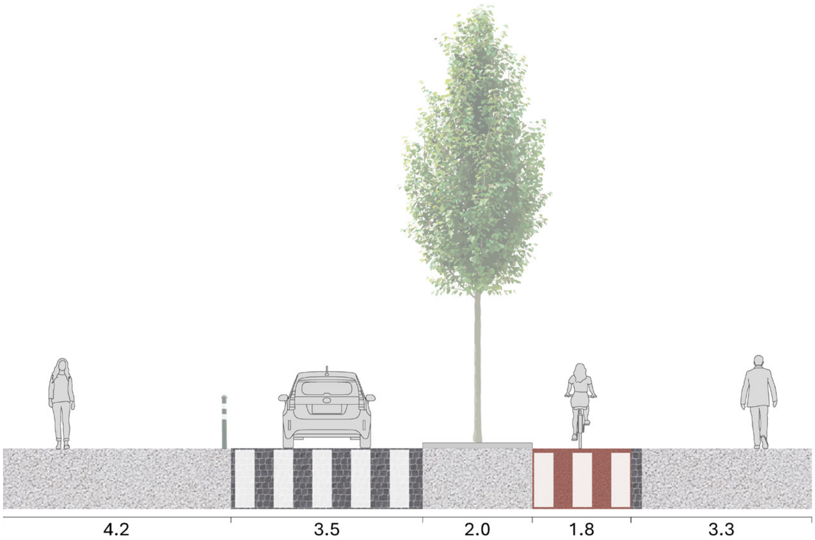

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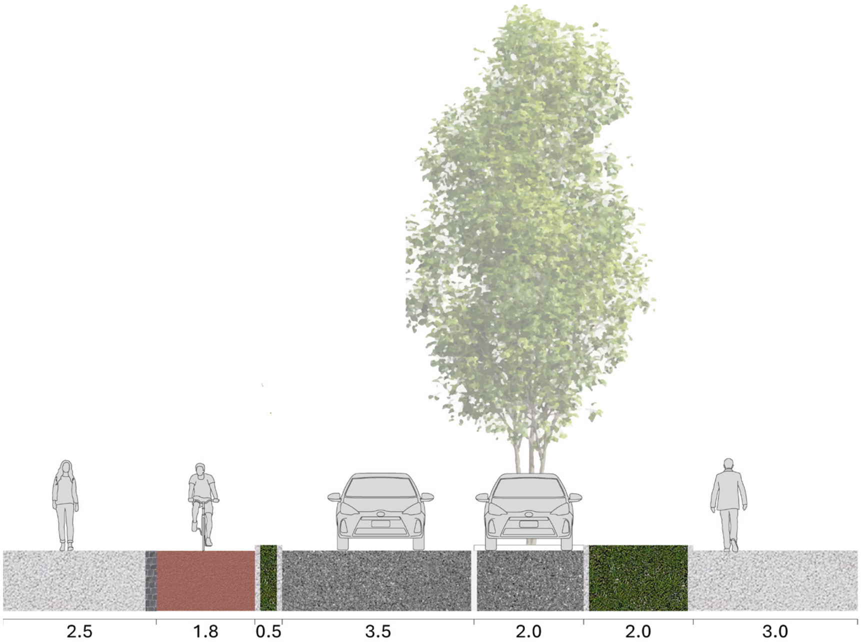

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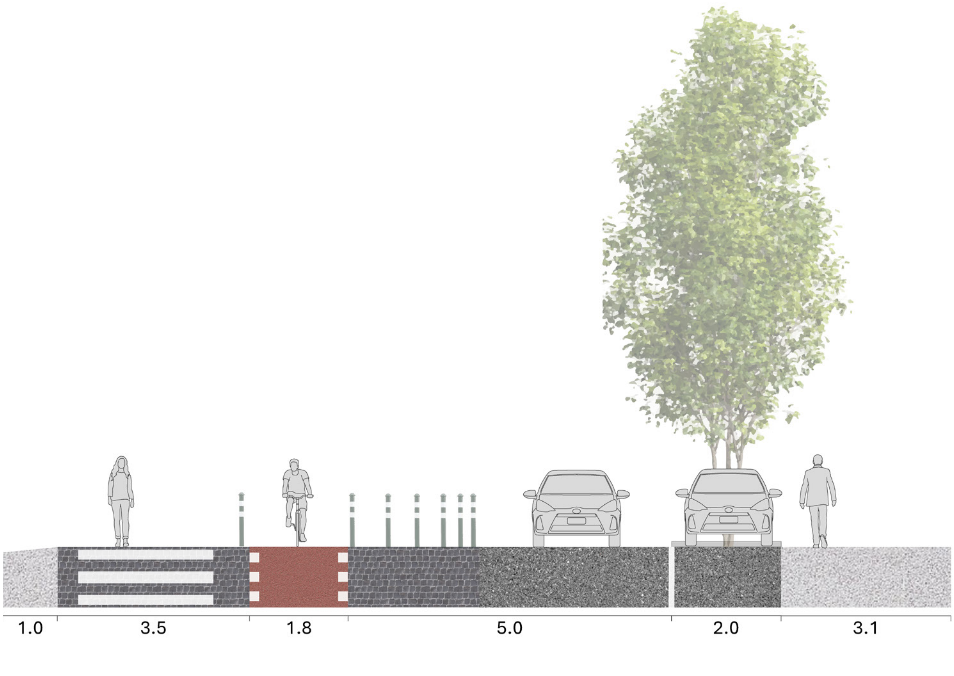

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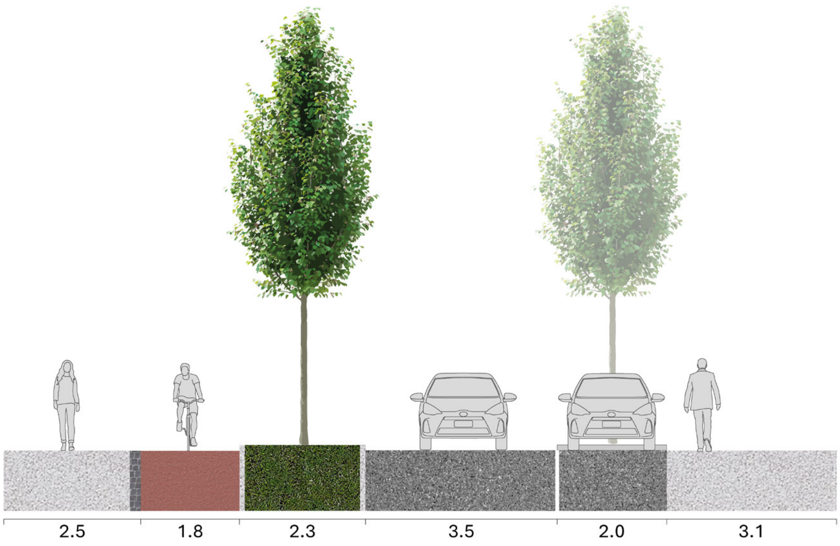
Section 8



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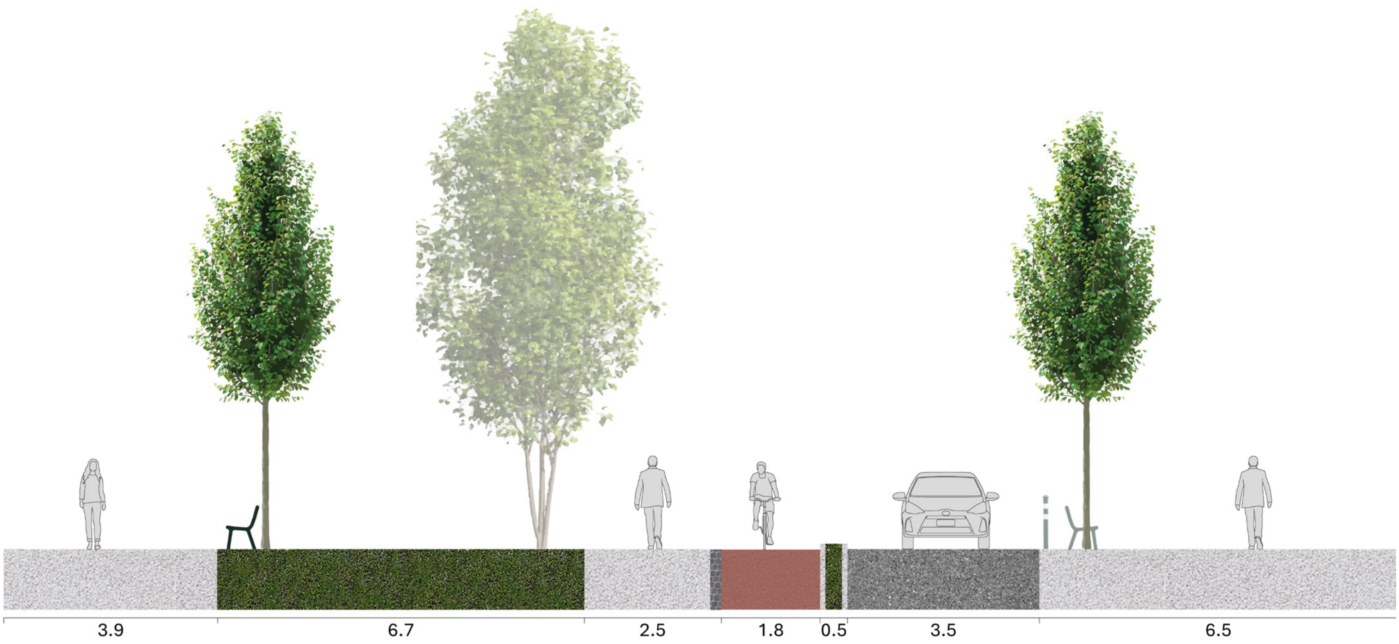

Scenario GLT. In this scenario the bicycle path is at the level of the vehicular lane. At the raised crossings therefore, the ramp is located between the bicycle path and the sidewalk. Moreover, a separation is required from the vehicular lane: along via Carrera, the separation from the parking stalls is provided by the green strip, along via Asinari di Bernezzo, the green strip separates the bicycle path from the vehicular lane. The configuration of the street design for this scenario aims at allowing trees belonging to the second category to be placed along via Asinari di Bernezzo, differently than in the one of the previous scenarios. This is possible through the elimination of parking stalls along via Asinari di Bernezzo between via Exilles and via Baveno, due to the necessity to increase the distance between the trees and the buildings on the northern side. This distance is maintained also between via Capelli and via Salbertand. Due to the backwards location of the building of the elementary school, the trees can be placed at a smaller distance from the sidewalk. At the intersection with via Salbertand, a chicane is introduced in order to increase visibility for right-turning vehicles towards the cycling path. Although the cycling path is located at the same level of the vehicular lane, some exceptions are made, in correspondence of bus stops, in order to allow direct accessibility for pedestrians reaching the stop. In these cases, ramps are foreseen, with reduced slopes in order to improve comfort for cyclists. At pedestrian crossings intersecting the bicycle path, a ramp for pedestrians is located on the sidewalk.


Scenario GLT
1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
BUS
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8
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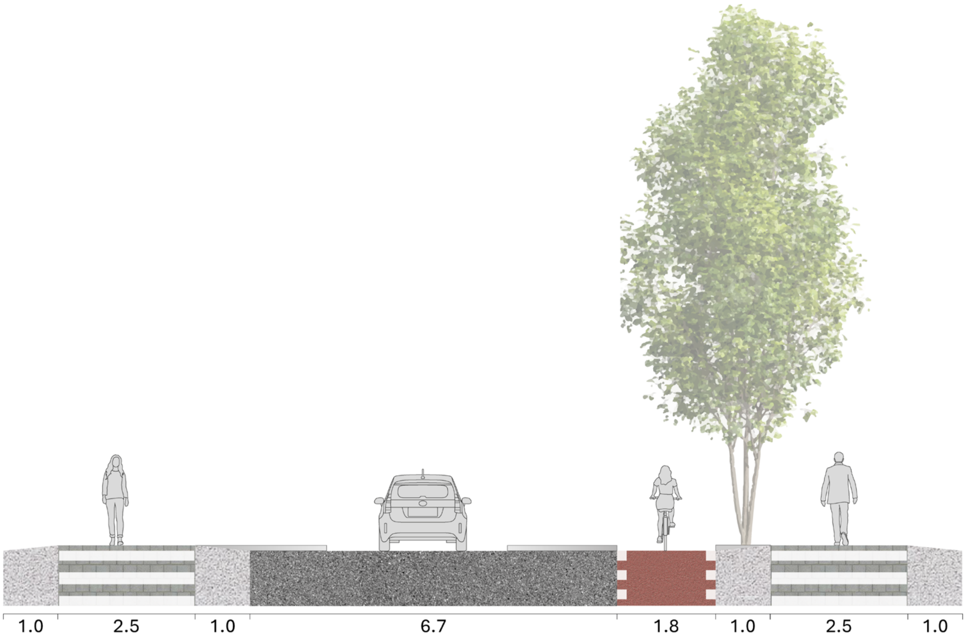
m 5 10

Section 1



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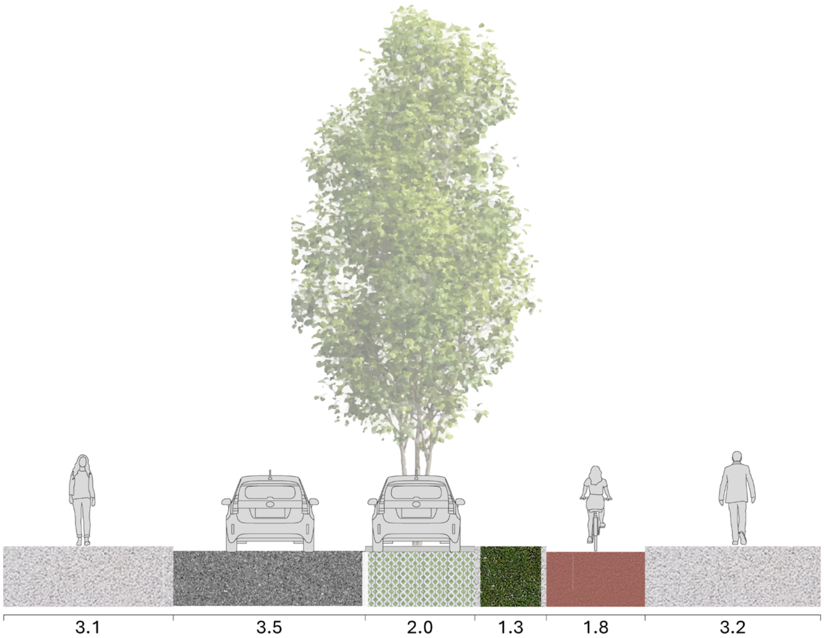

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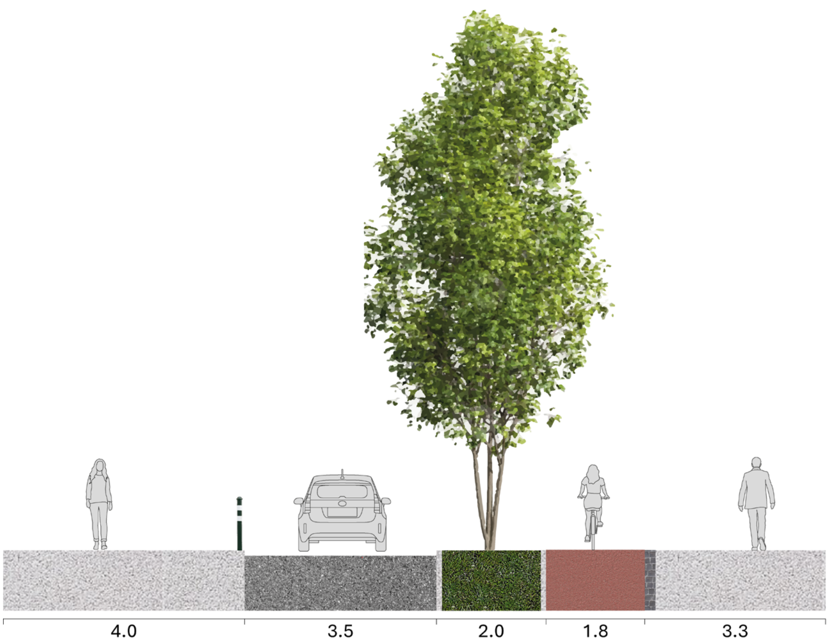

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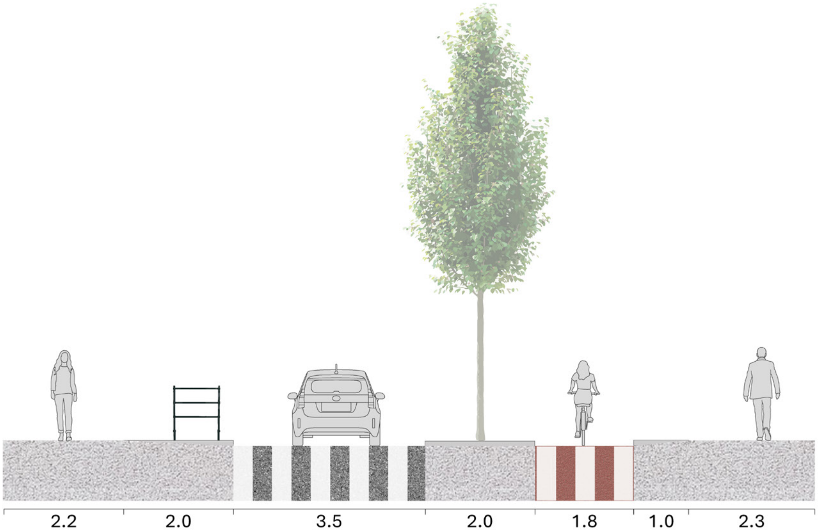

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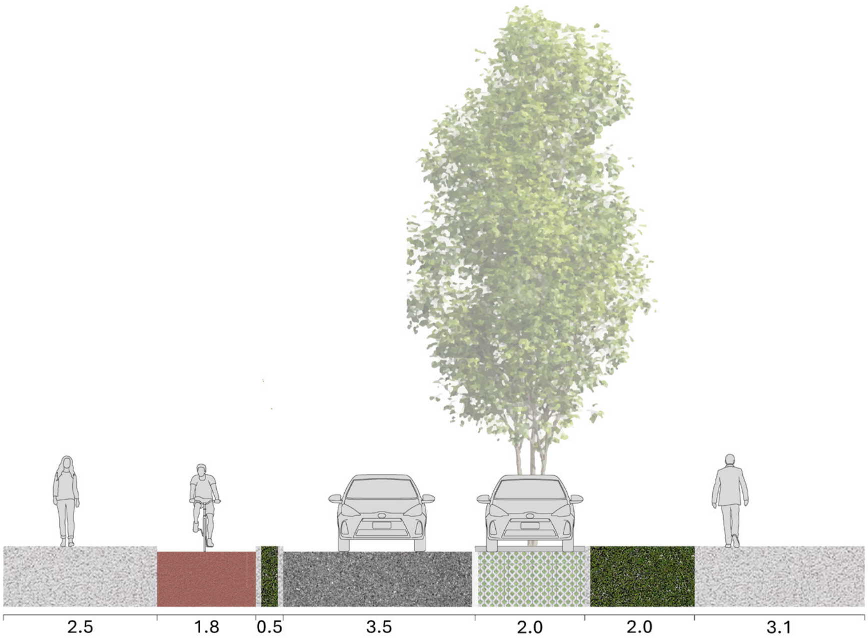
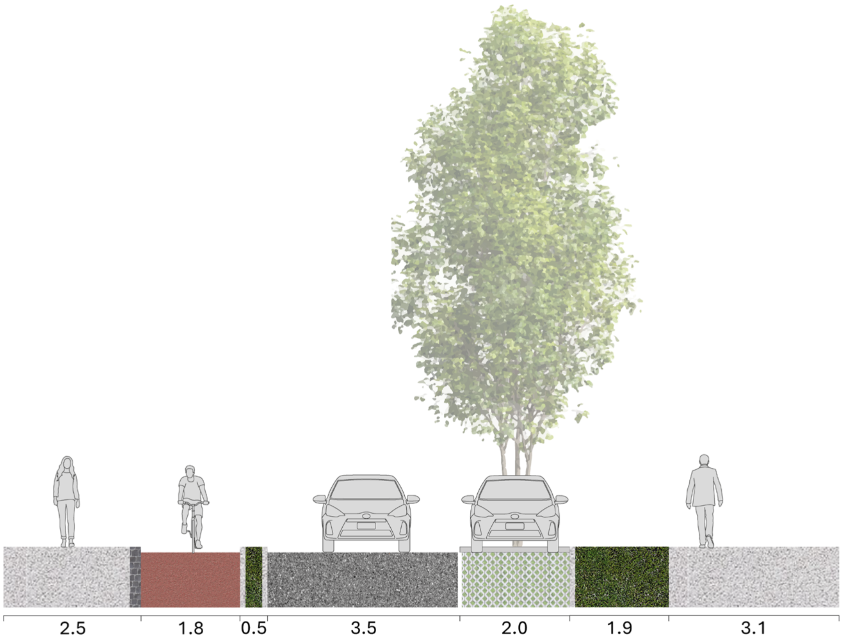


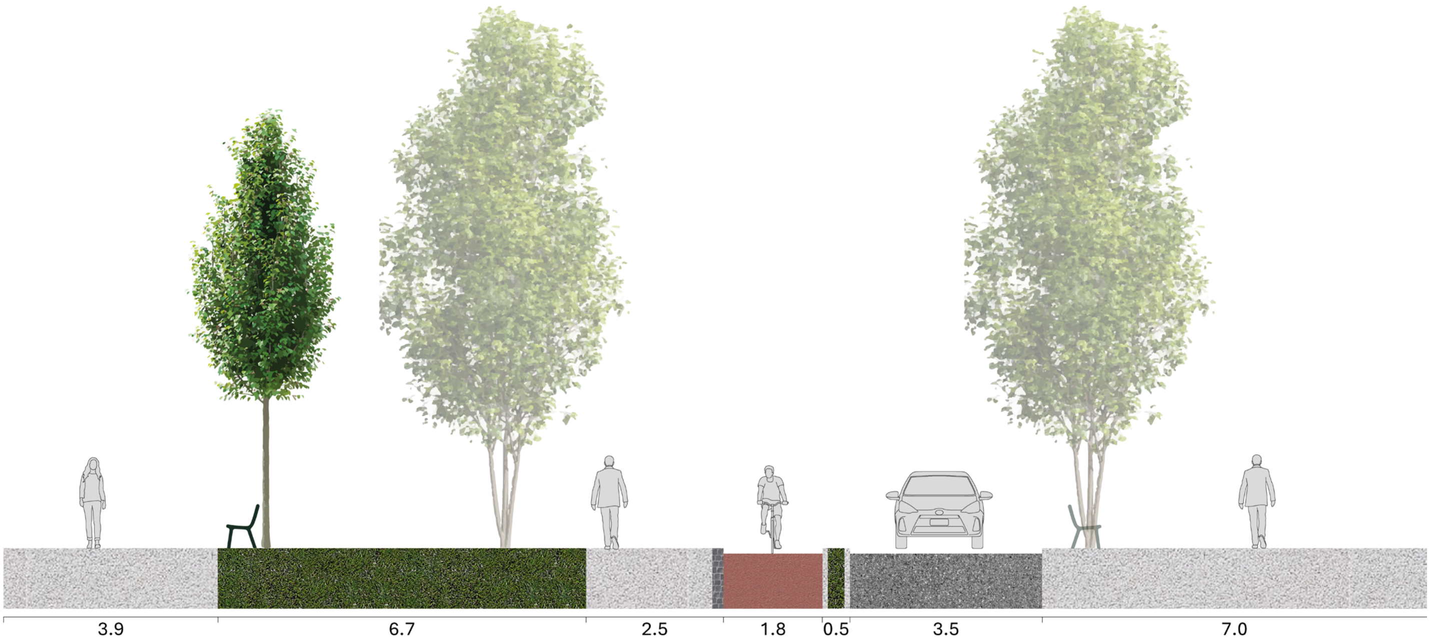
Section 6

Section 7

Section 8



Section 9

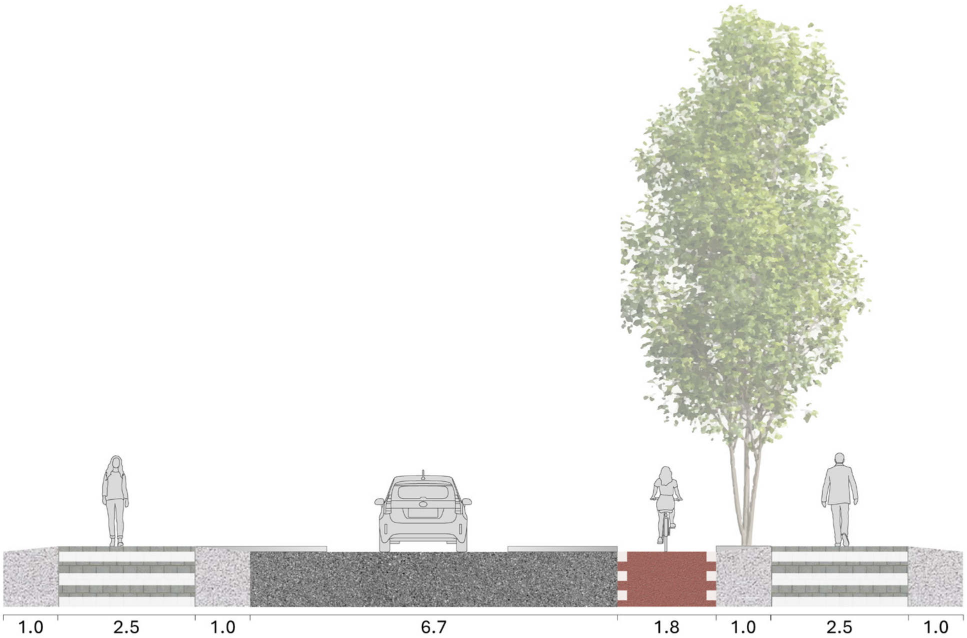


Scenario GRLT. This case consists of a combination of the scenario GLT with the raised intersections. The main reason for this is related to the necessity for a speed reduction measure in correspondence with the intersection with via Mogadiscio, given the linear path of the vehicular lane. Due to the priority given to the placement of higher trees, the distances do not allow the placing of ramps for raised crossings between the bicycle path and the vehicular lane: it is therefore necessary to maintain the bicycle path at the lower height. However, due to the presence of raised intersections and bus stops, the level of the bicycle path varies: on via Carrera, ramps are located before and after the bus stops after via Salbertrand, and before and after the intersection with via Capelli, in order to include both the section with the raised intersection and the bus stop. Along via Asinari di Bernezzo, in order to avoid multiple changes in height, and due to the absence of constraints, the portion of the bicycle path between the bus stop of via Capelli and the intersection with via Salbertrand is at the level of the sidewalk.


Scenario GLRT
1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub

N
BUS
4
8
9
m 5 10

Section 1



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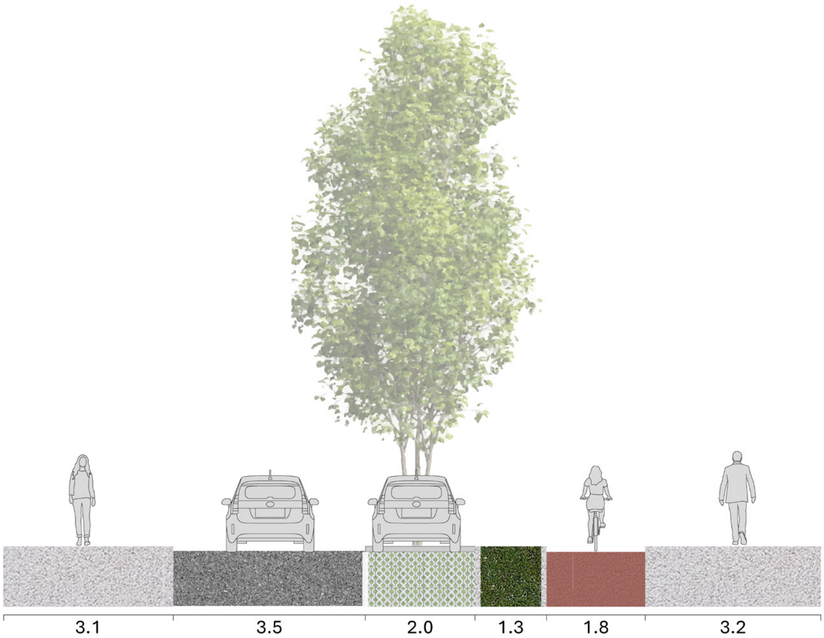

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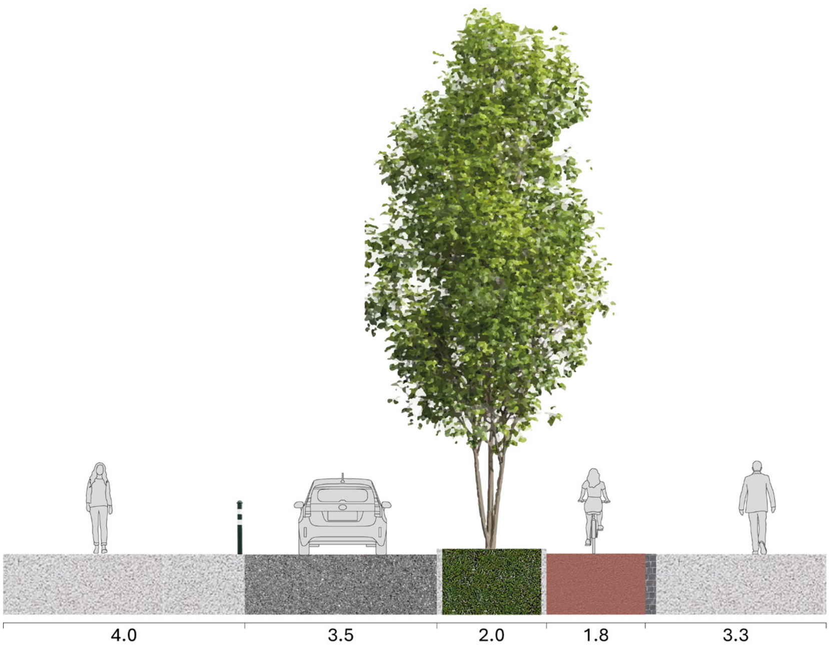

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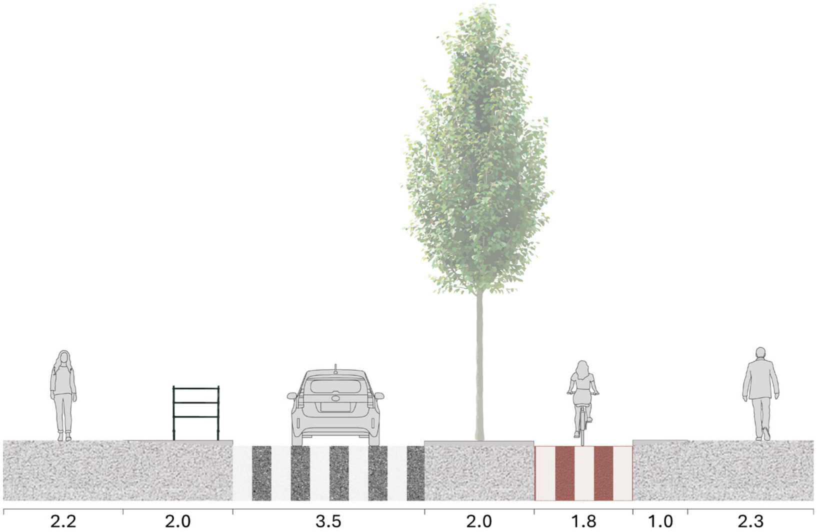

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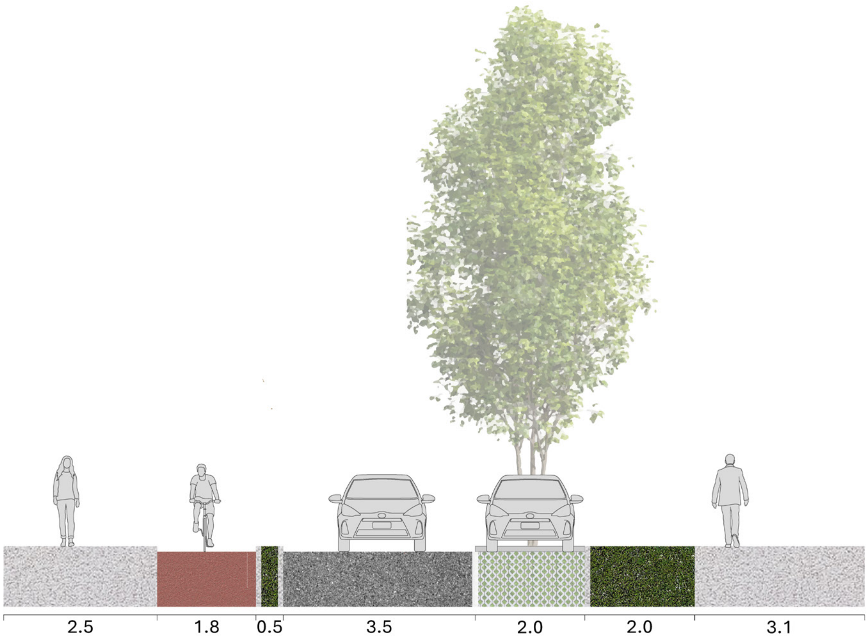
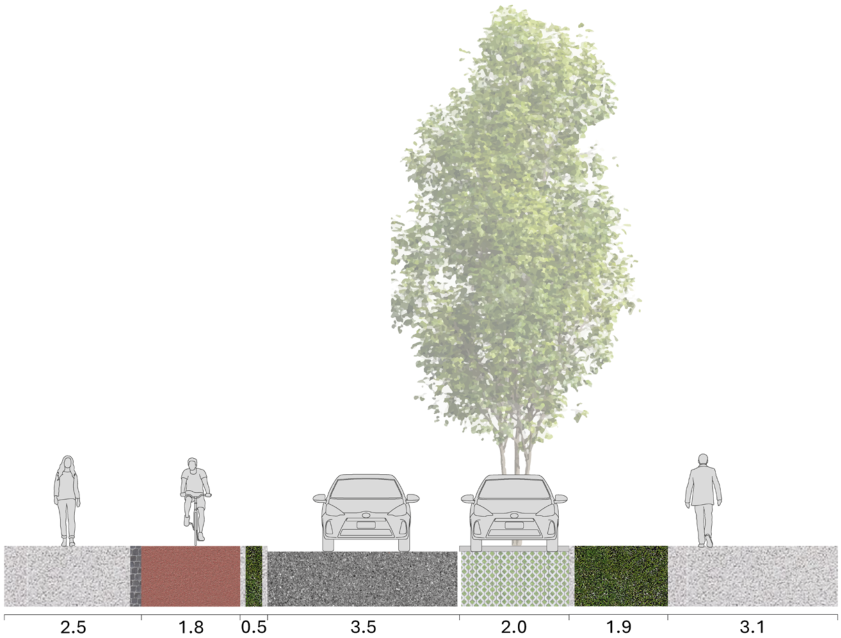


Section 6

Section 7

Section 8



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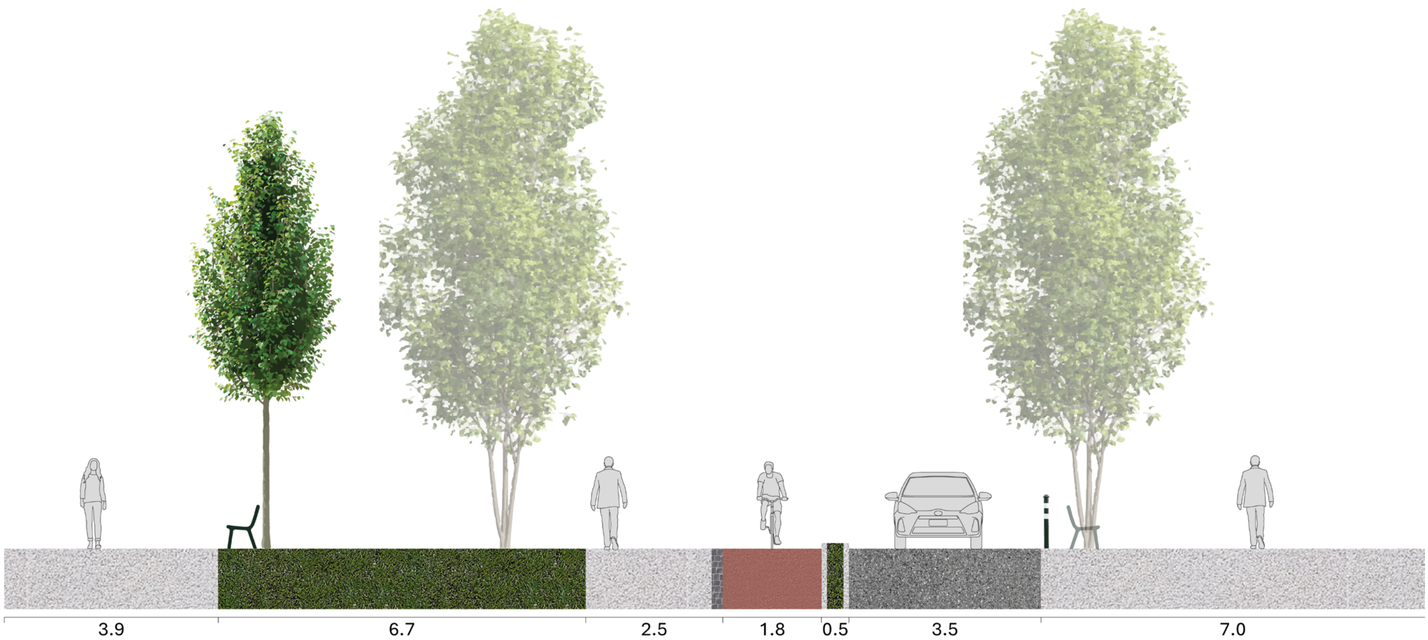
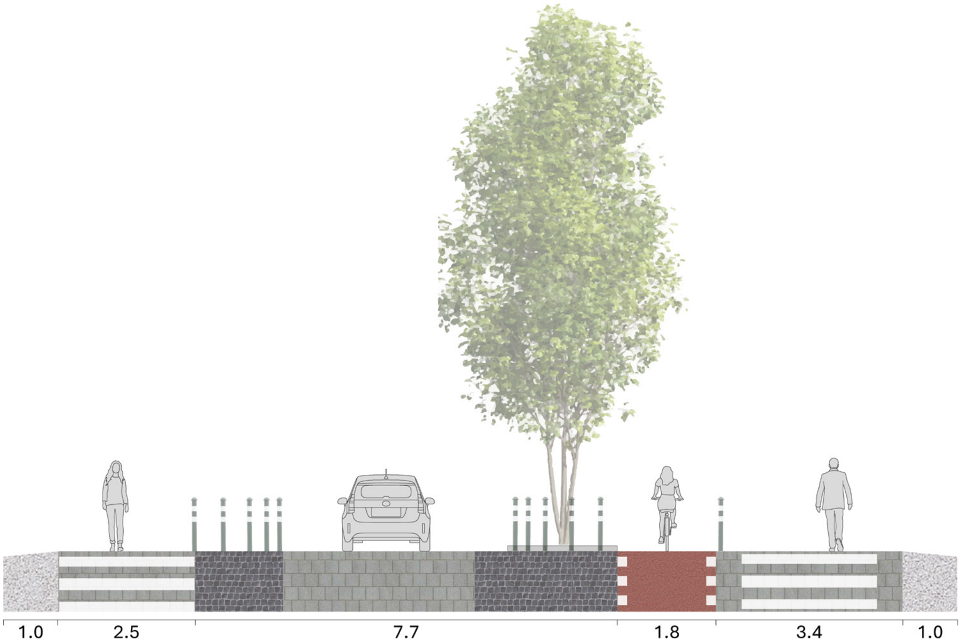


Scenario GST. The scheme is derived from the scenario GLT, by raising the whole surface at the same level. The purposes of this measure are the same illustrated previously. The chicanes on via Asinari di Bernezzo allow the placement of higher trees on all portions of the street.

Scenario GST


N
4
8
9
m 5 10

Section 1



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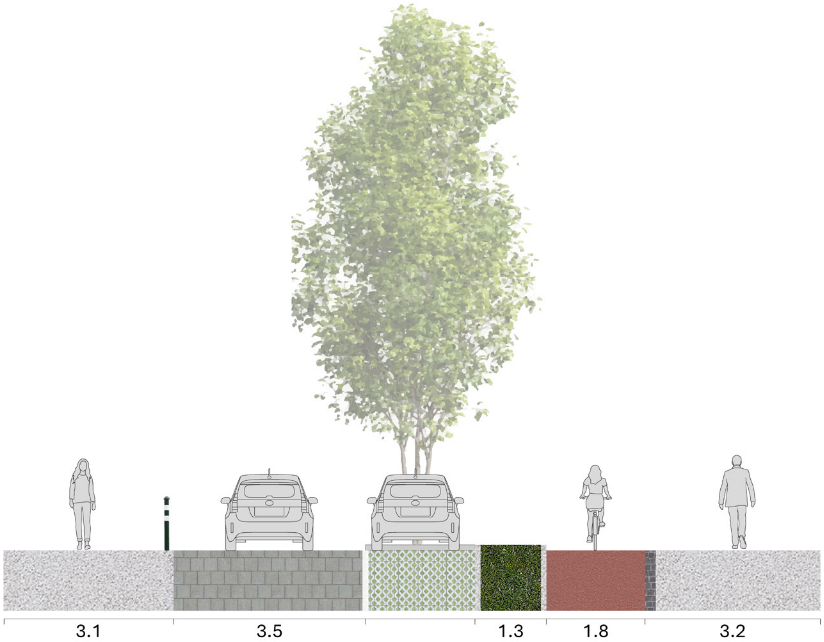

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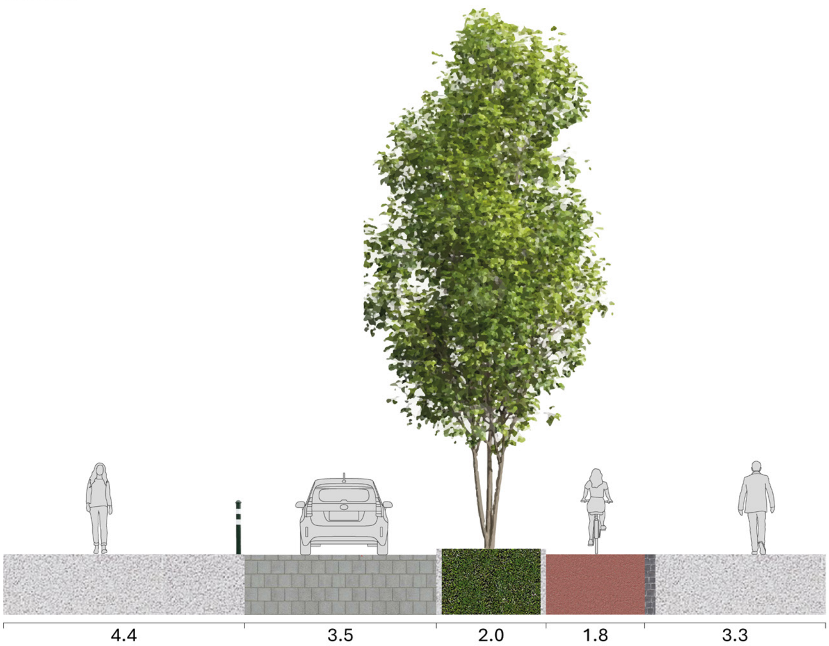

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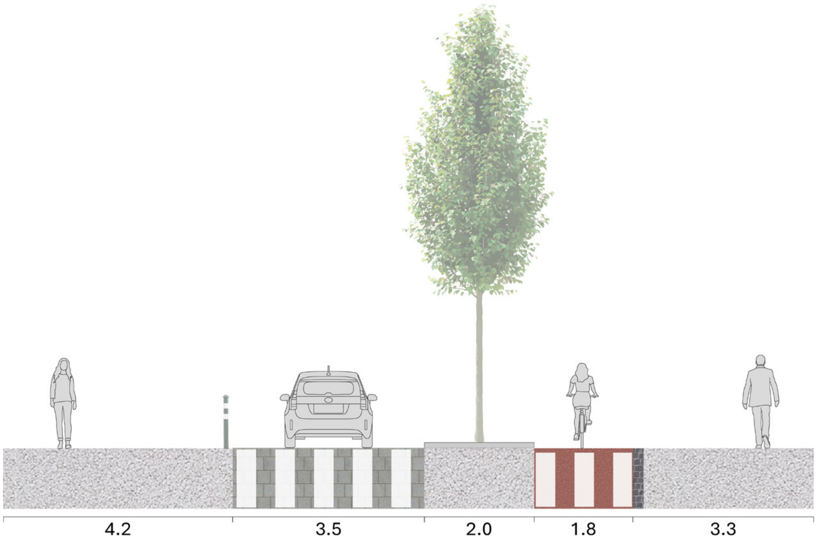

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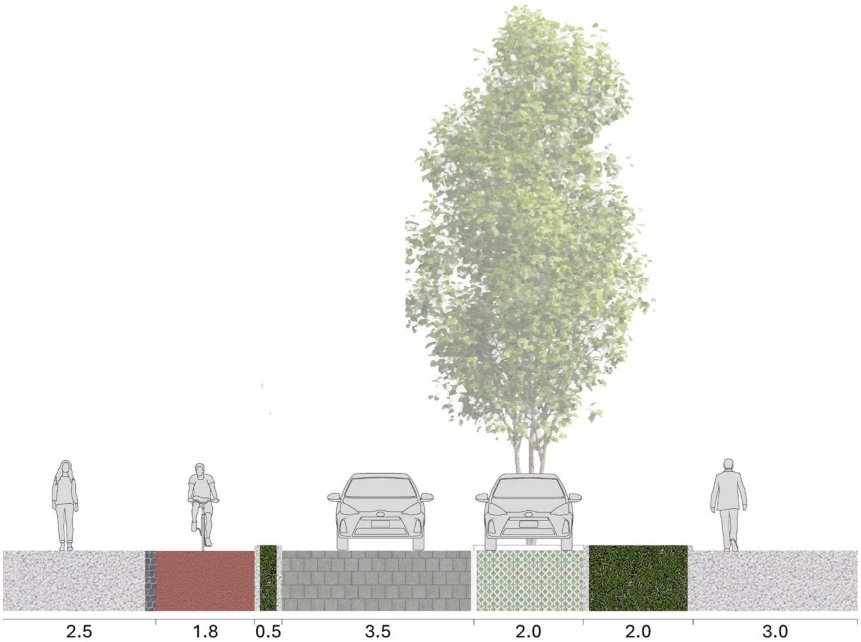
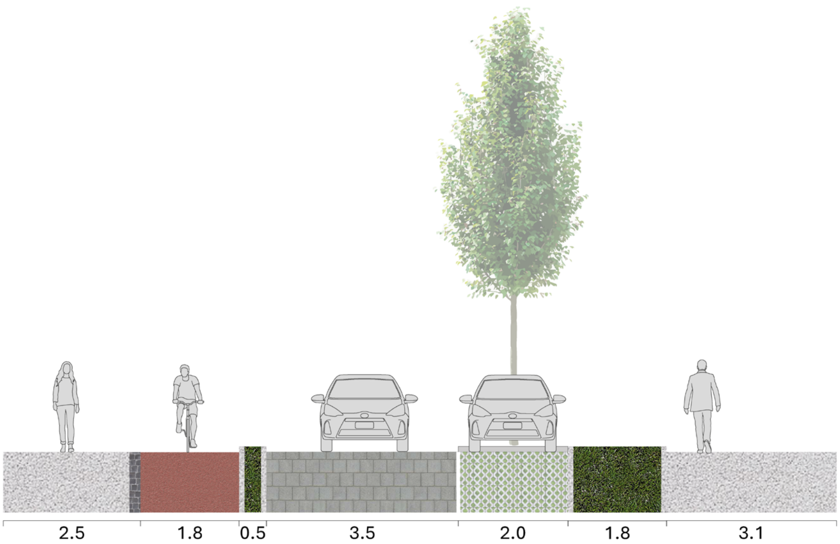


Section 6

Section 7

Section 8



Section 9

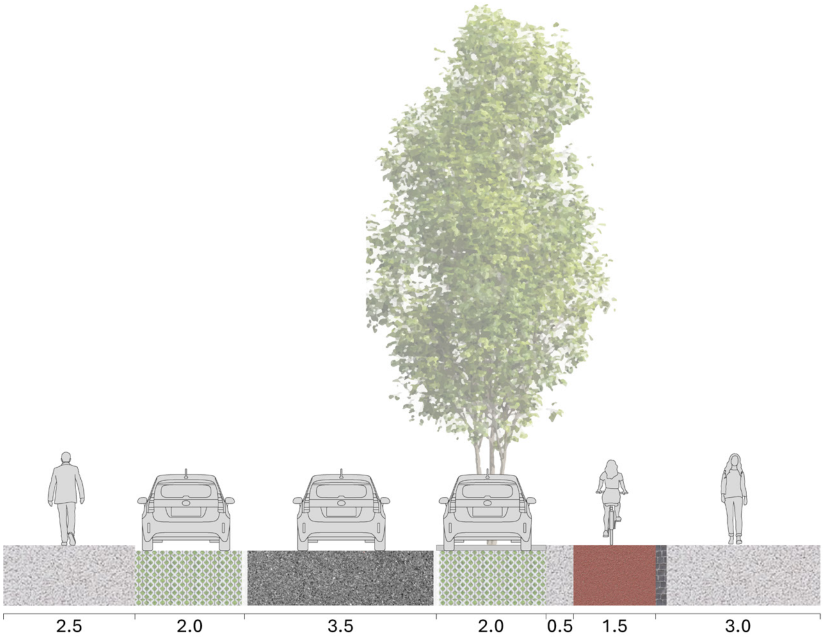
Scenario PH. As mentioned, the scenarios belonging to this group have as a common priority the maintenance of a larger number of parking stalls, where possible. The additional space required for this purpose, due to the impossibility to reduce the vehicular lane and the distances for trees, is obtained through a narrowing of the bicycle path, brought to minimum standards of 1,5 metres on via Carrera and to 1,7 metres on via Asinari di Bernezzo, and to a narrowing of sidewalks, by maintaining in all cases a minimum distance of 2,5 metres. A redesign solution detrimental to bicycle and pedestrian space in favour of car parking stalls does not appear to be coherent with the objectives of modal shift, however, this can be a compromise between multiple needs, by maintaining adequate standards for the different functions, while proposing a less impacting solution on the parking offer. Along via Carrera, the southern sidewalk was narrowed, since on the northern sidewalk it was necessary to maintain the sufficient distance for the trees. In comparison with the other scenarios, the scheme allows to have an additional line of parking stalls on the southern side. Similarly, parking stalls are installed on the southern side of via Asinari di Bernezzo, separated by a 0,5 m strip from the bicycle path, located at the height of the sidewalks. The strip can be constituted by stones or by a green space between two curbs. On via Asinari di Bernezzo, the intention to locate the series of parking stalls on the southern side impacts the distances required for the trees, allowing higher trees to be placed only in correspondence with the elementary school. An extension of the sidewalk in front of the church is maintained, by modifying the layout of the street, which requires the elimination of parking stalls.


Scenario PH
1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
BUS
4
8
9
m 5 10

Section 1

Section 2



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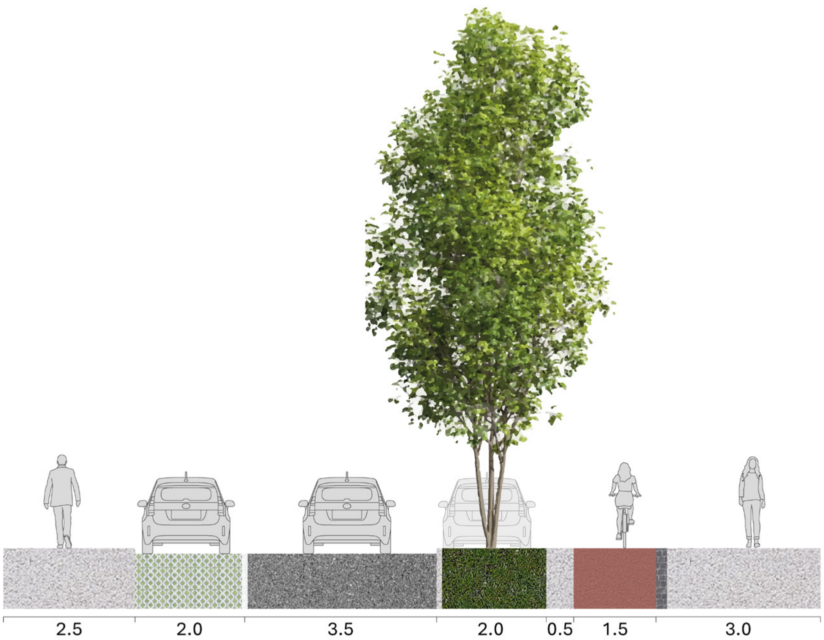

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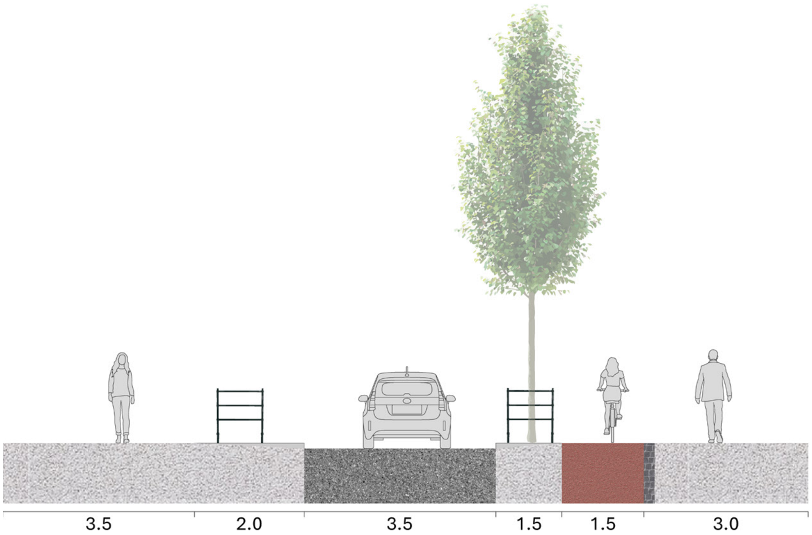

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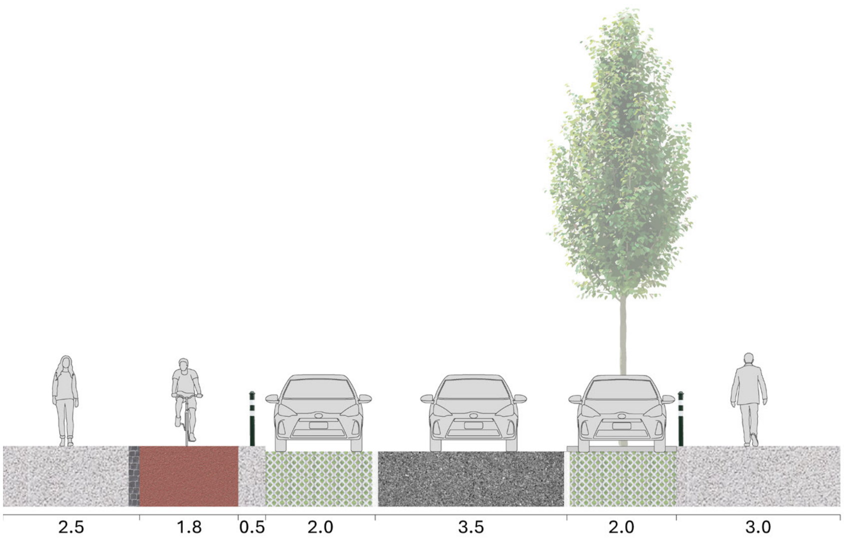

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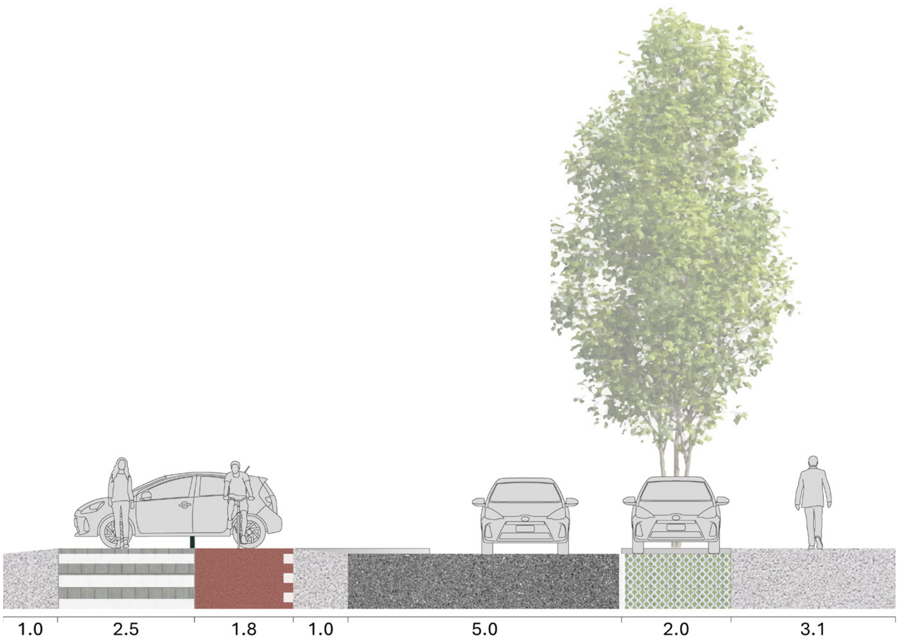

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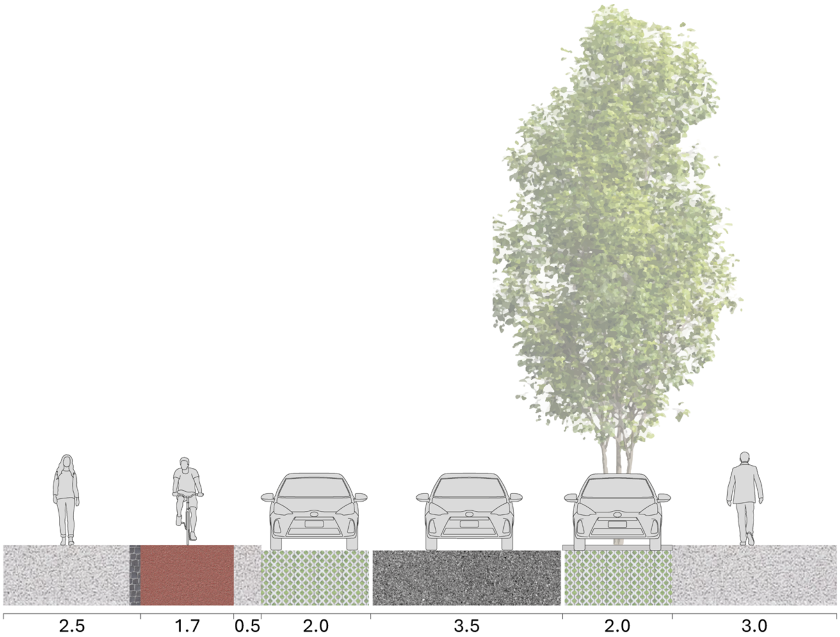

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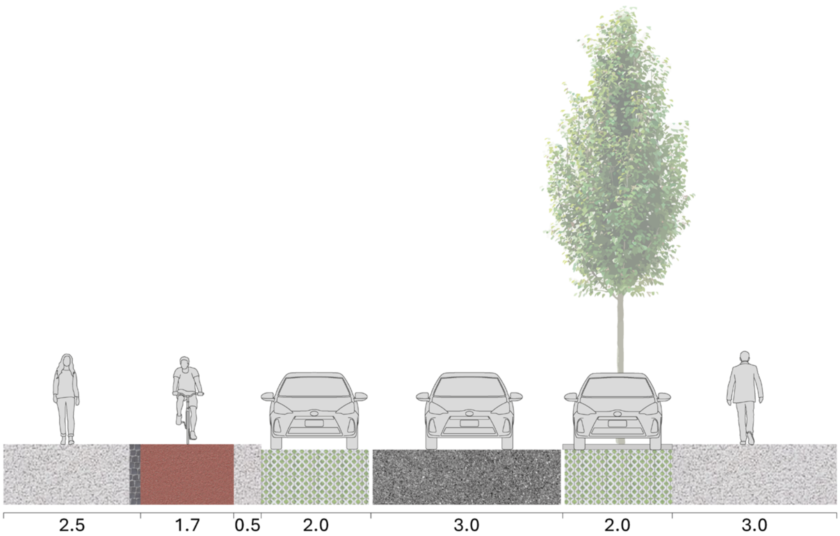

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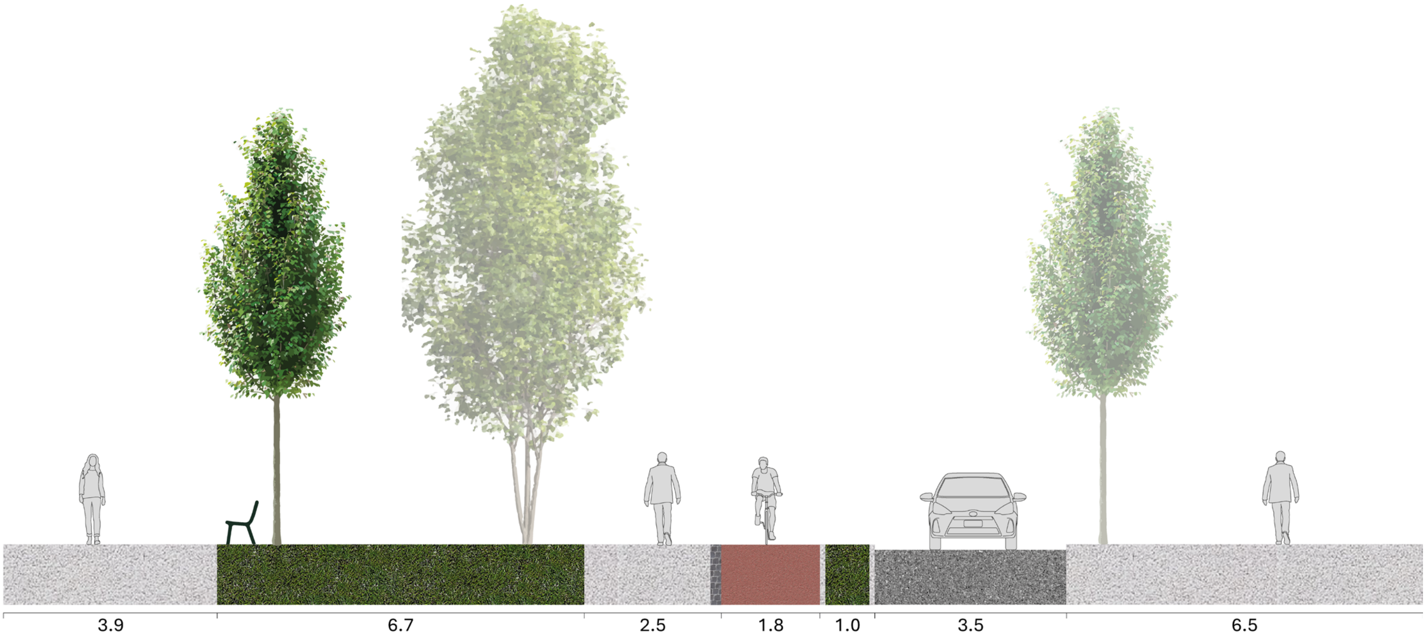


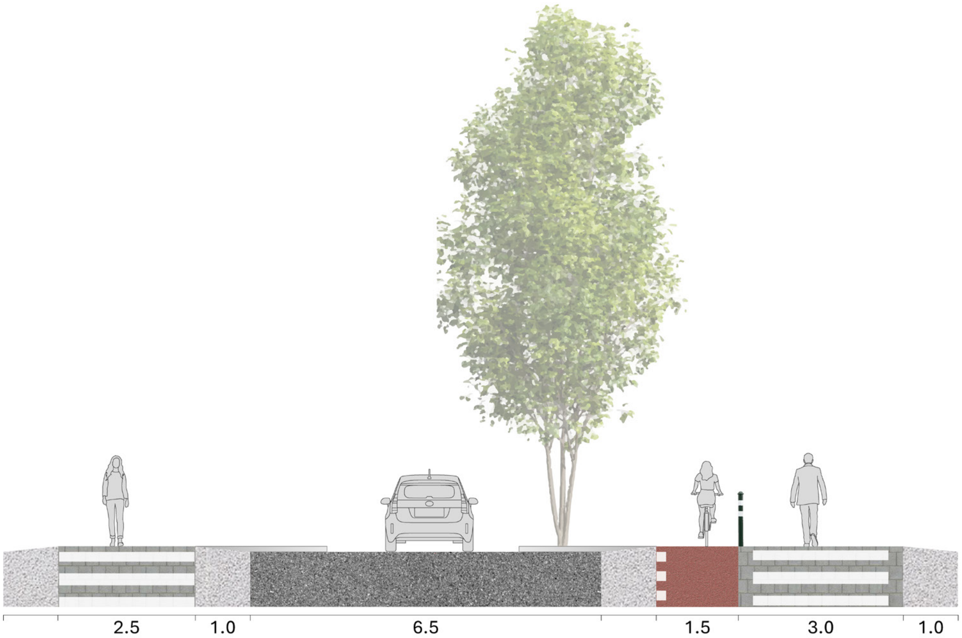
Scenario PR. The scenario is similar to the previous one, with the introduction of raised intersections. Similar comments to the scenario GR can be made about the redundancy of the two traffic calming measures.

Scenario PR

1
2
3
5
6
7
BUS
BUS
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
BUS
4
8
9
m 5 10

Section 1



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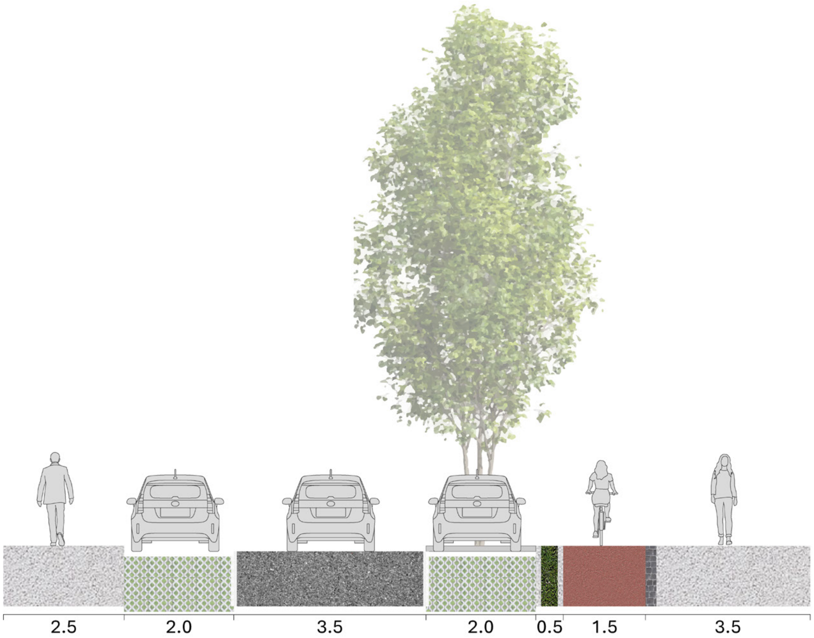

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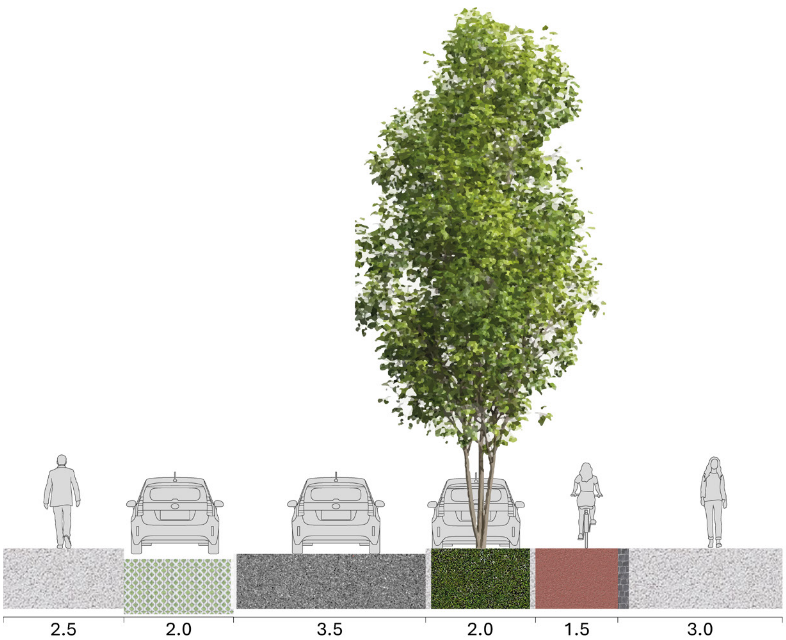

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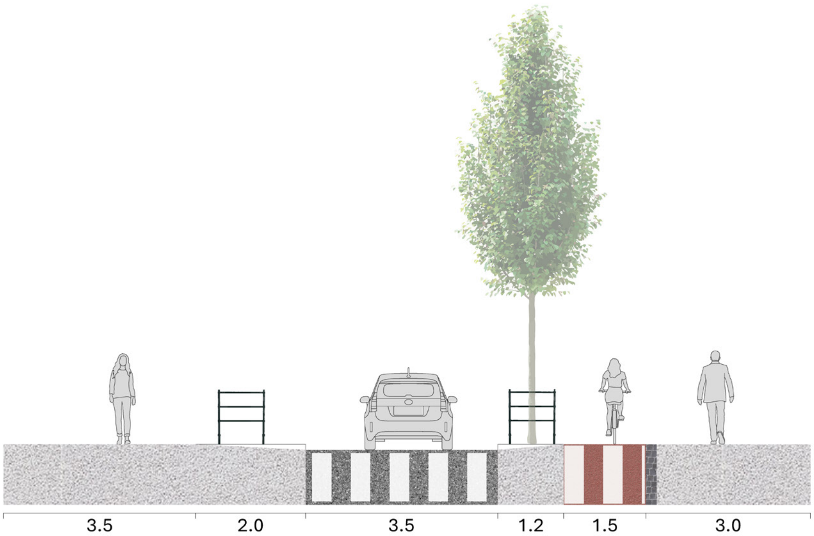

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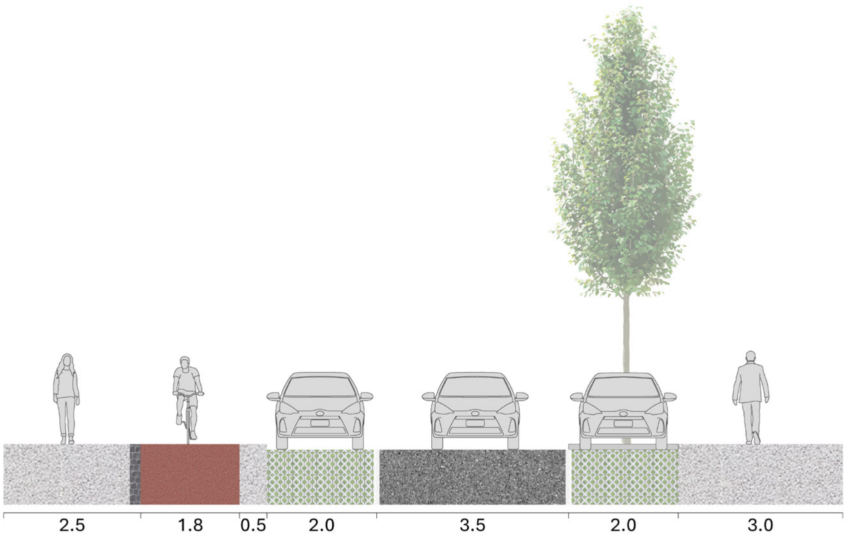

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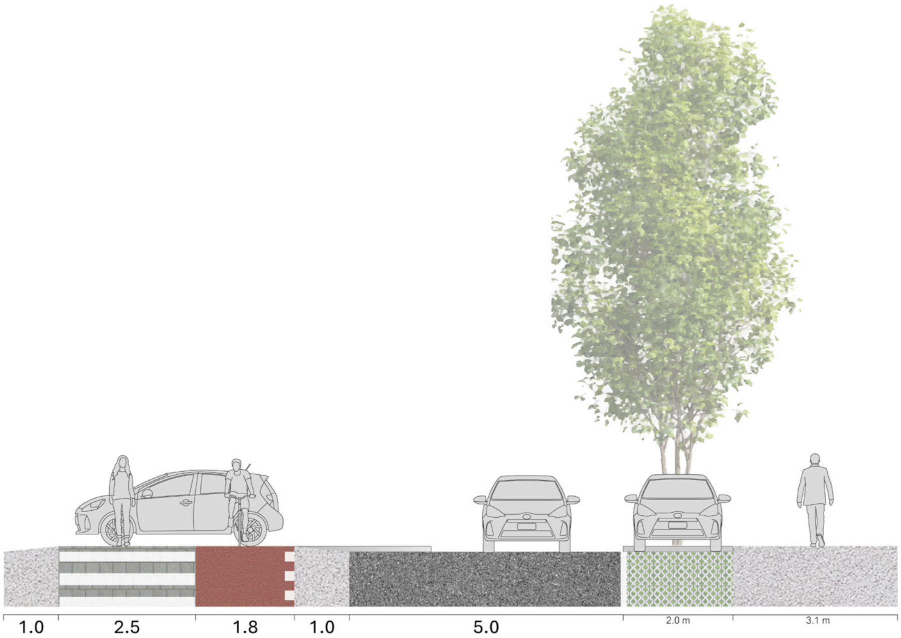

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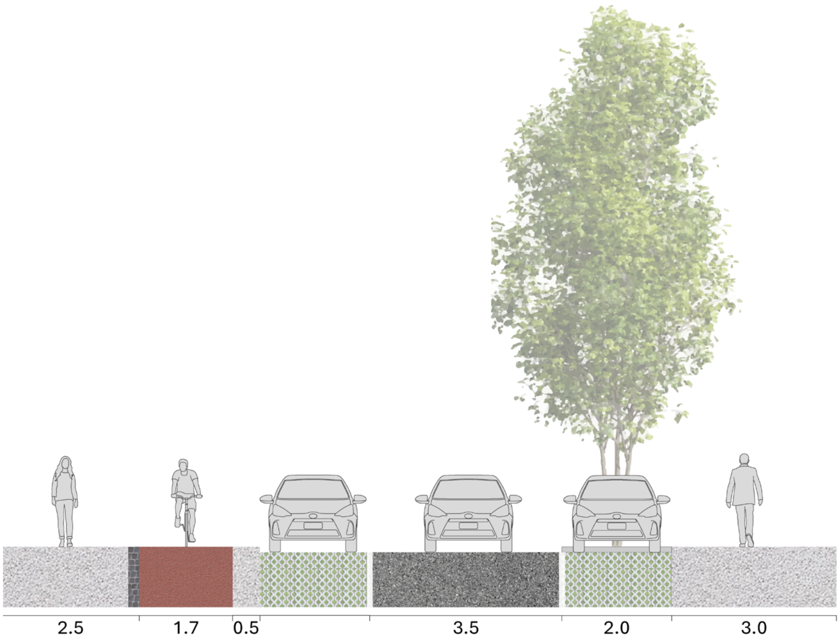

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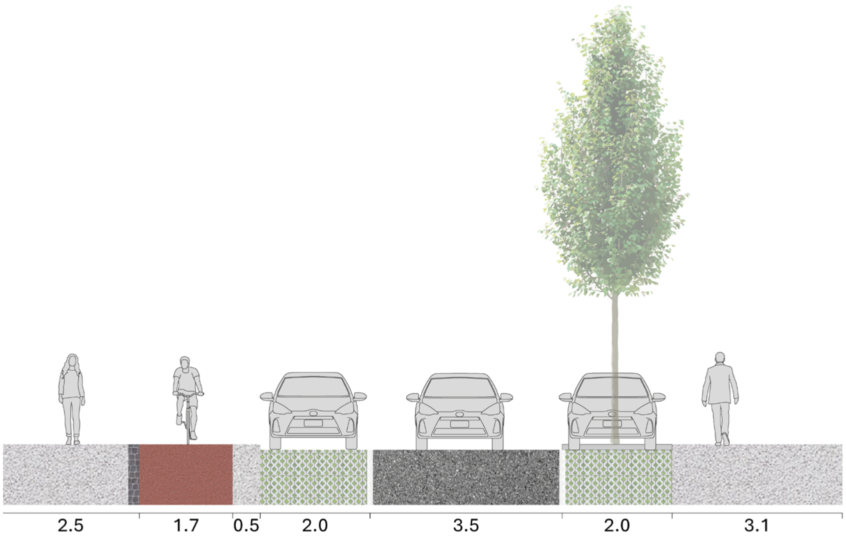


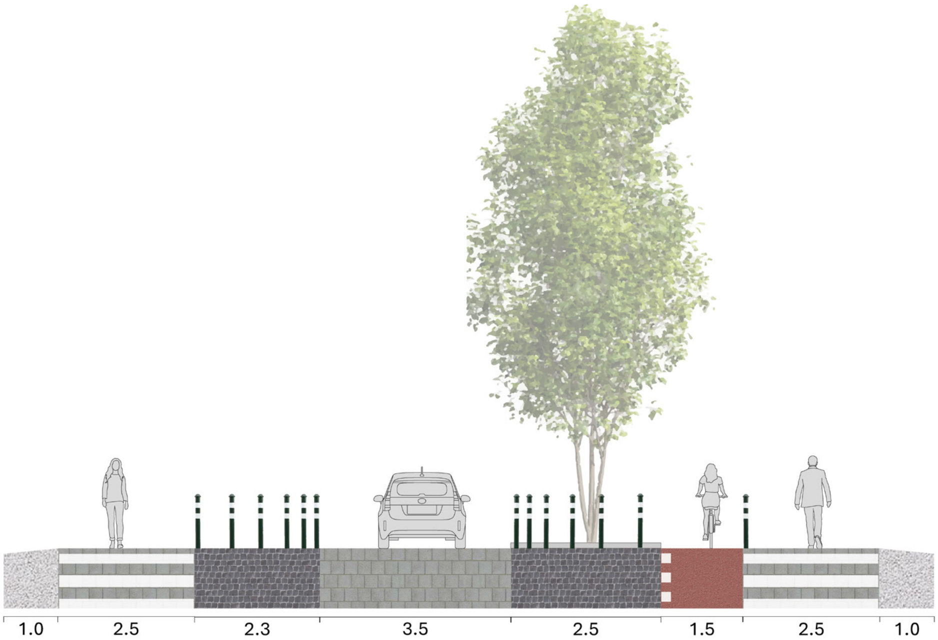
Section 9

Scenario PS. Similarly to the previous cases, the scenario combines the previous configurations with a raised surface.


Scenario PS
1
2
3
5
6
7
Vehicular space
Pedestrian space
Permeable parking
Raised intersection
Bicycle path
Green space
Tree (II category)
Tree (III category)
Shrub


N
4
8
9
m 5 10

Section 1



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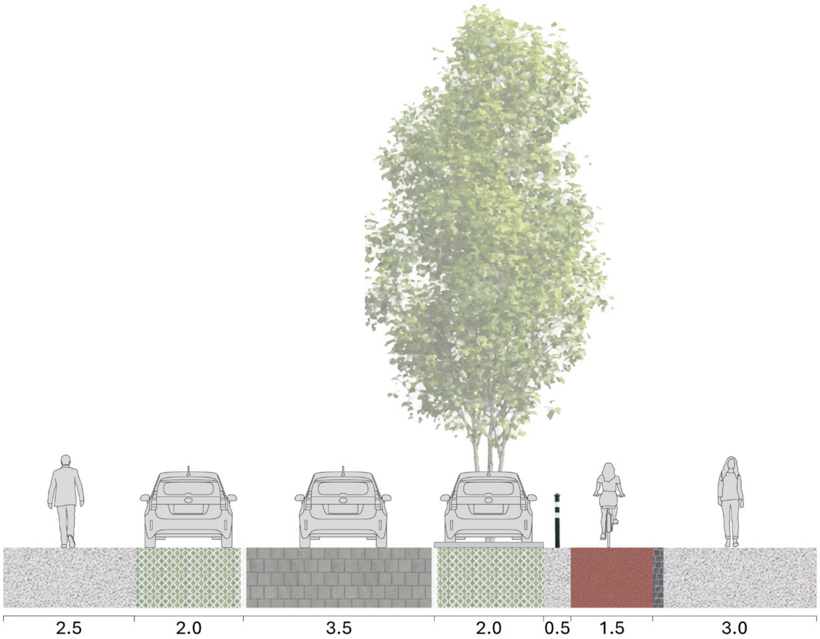
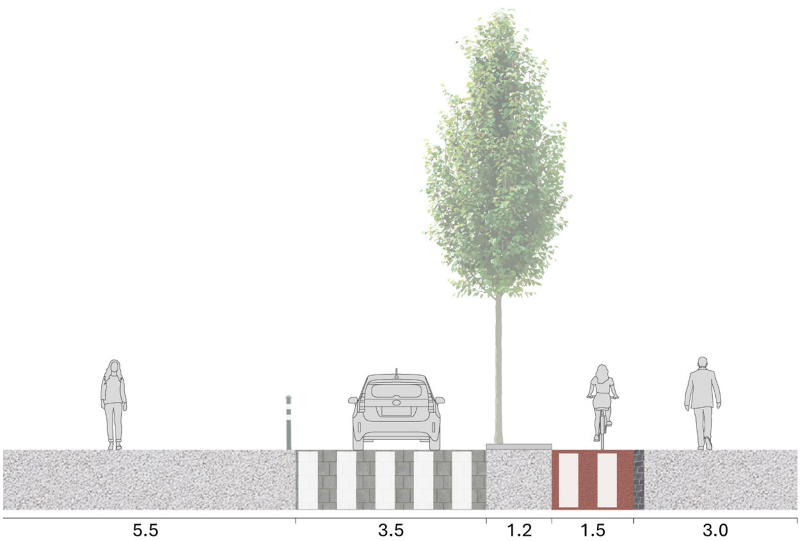


Section 3

Section 4



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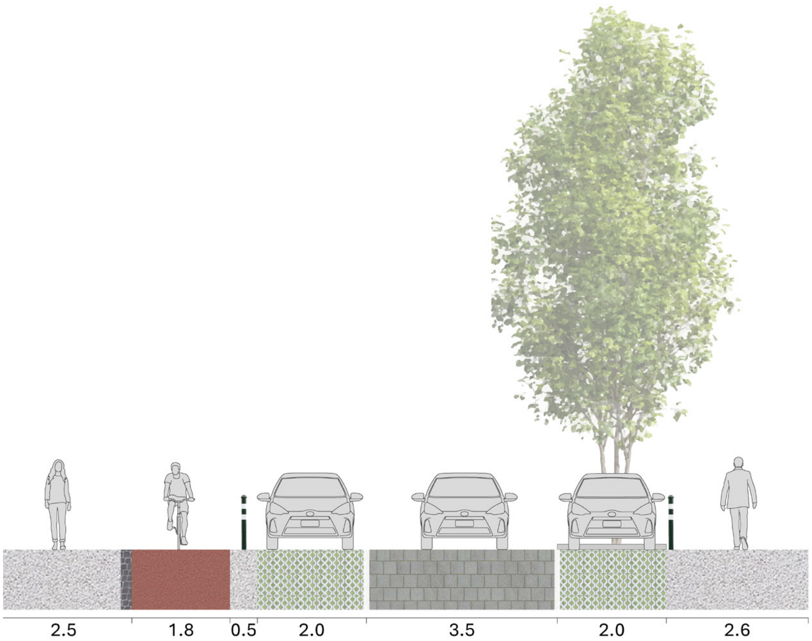

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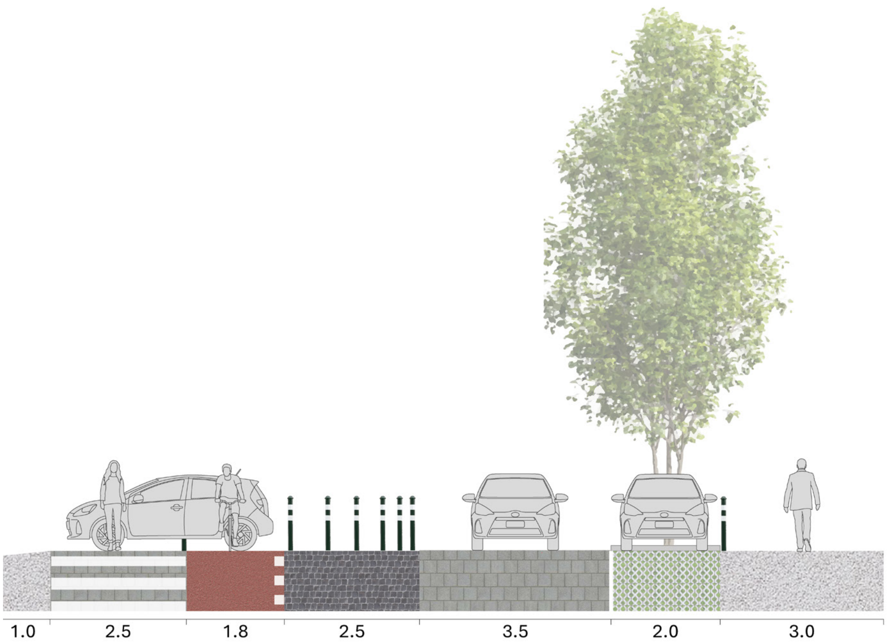

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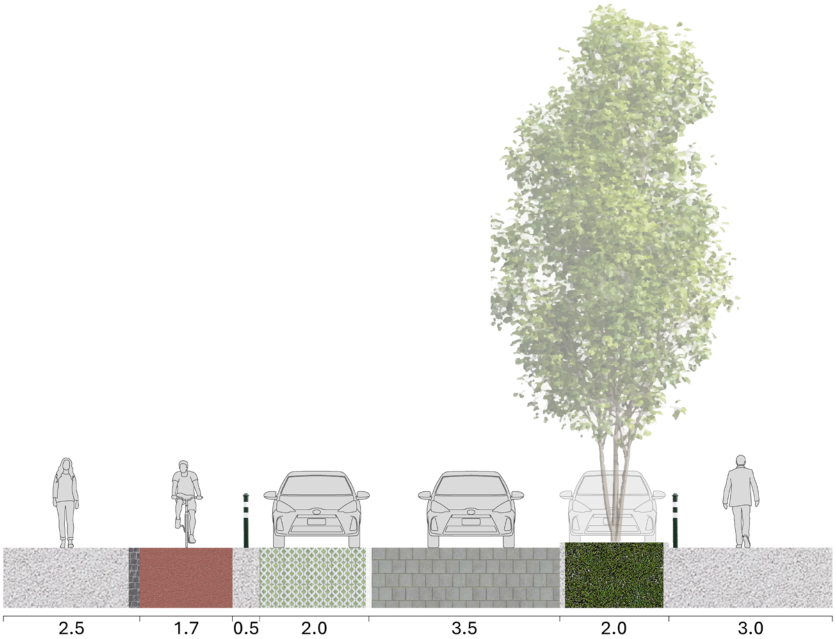

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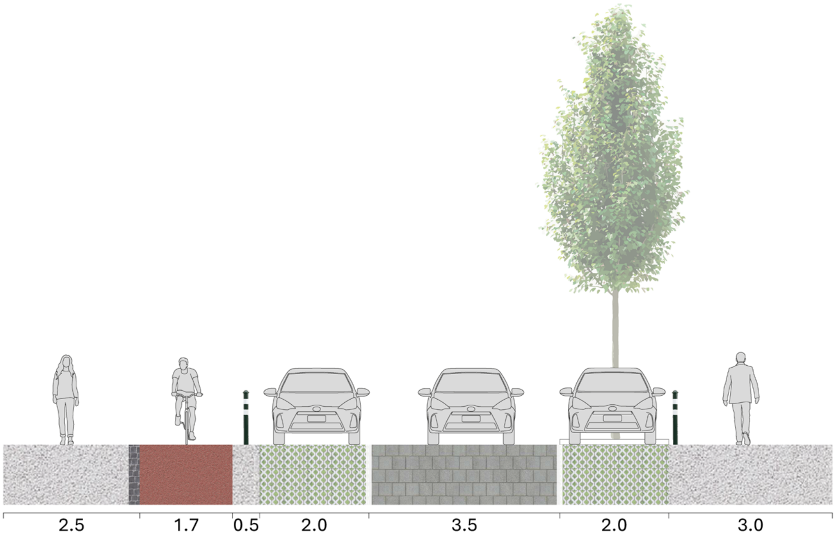


Section 9

As it can be observed, the scenarios combine different features of the organization of space, by maintaining the minimum requirements in all cases and by providing additional space to the elements considered as a priority in each scenario. In this context, it can be noted that the general scheme, with the bicycle path on the right side of the street, and the trees placed on the northern side of the vehicular lane, is not varied. Along via Carrera, the possibility to place the trees between the bicycle path and the sidewalk was studied, in order to prioritise shading on the sidewalk, however, the constraints linked with the distances of trees from the buildings did not allow the placing of trees, due to the limited width of the sidewalk of via Carrera and the necessity to locate the parking stalls with a distance of 0,5 m from the bicycle path, leading to discard the scenario, due to the absence of shading which would result from this organization. It can be seen, therefore, that the compromises between the functions can lead to the creation of conflicts, especially due to the availability of space and to the regulations linked to it: For example, the decision to increase green space and to allow higher trees to be planted results in most cases in a reduction of space for cars, and, in particular, parking stalls: an estimation of this reduction for each scenario was conducted, showing how the G scenarios highly impact the parking offer, compared to the P scenarios, where the reduction is limited, despite necessary in all cases. By observing the table, the L scenarios, allowing larger trees to be planted along via Asinari di Bernezzo, are slightly more impacting than the other G scenarios, meaning that their application would be preferable, due to the hypothesis that larger trees allow improved conditions for thermal comfort. Because of this element, it was hypothesised that the GLT scenario could be the best performing in terms of thermal comfort, due to its highest capacity to provide shading. The scenario was therefore evaluated through a second simulation, with the objective of assessing the effectiveness of the selected measures in terms of thermal comfort. Moreover, a third simulation was performed on the scenario PH. The objective in this case was the comparison between two different design proposals: the scenario maximising thermal comfort is compared to the one of the scenario combining thermal comfort objectives to the maintenance of parking stalls, in order to evaluate the effectiveness of the trade-off solution. In order to perform the second and third simulations, the same criteria and data were used, by choosing the configurations and materials proposed in the two design scenarios.

	Carrera	Asinari	Total	Reduction
Current	110	89	199	
GH	30	40	70	-64.8%
GR	30	40	70	-64.8%
GS	30	40	70	-64.8%
GLT	30	30	60	-69.8%
GLRT	30	30	60	-69.8%
GLS	30	30	60	-69.8%
PH	90	74	164	-17.6%
PR	90	74	164	-17.6%
PS	90	74	164	-17.6%

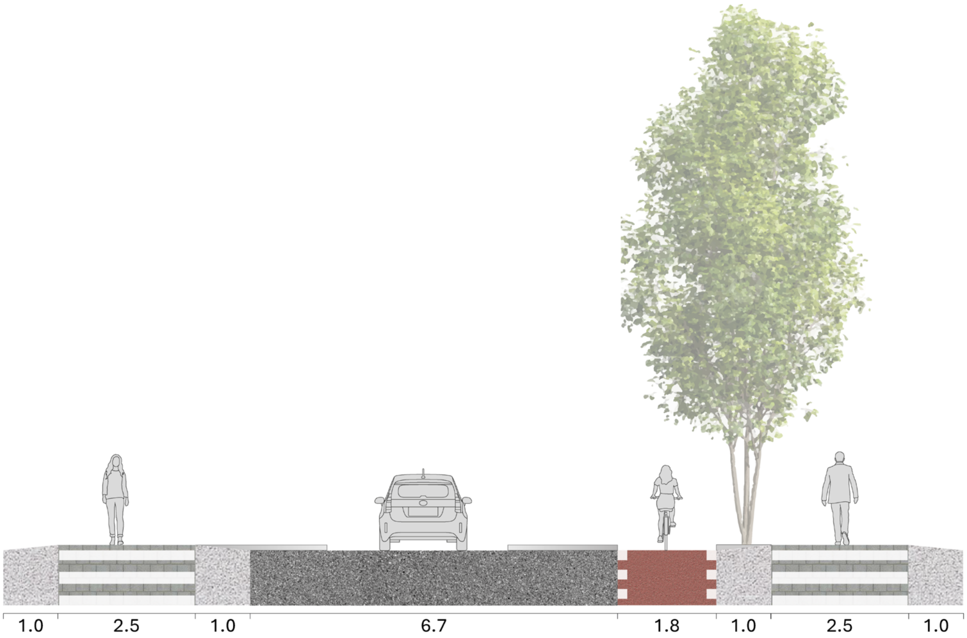
7. Discussion

7.1. Comparison of the results of the simulations

The results of the simulations related to the design scenarios are obtained with the same tools presented previously. In order to allow the comparison, the same parameters were selected.

7.1.1. Simulation scenario GLT

Section 1



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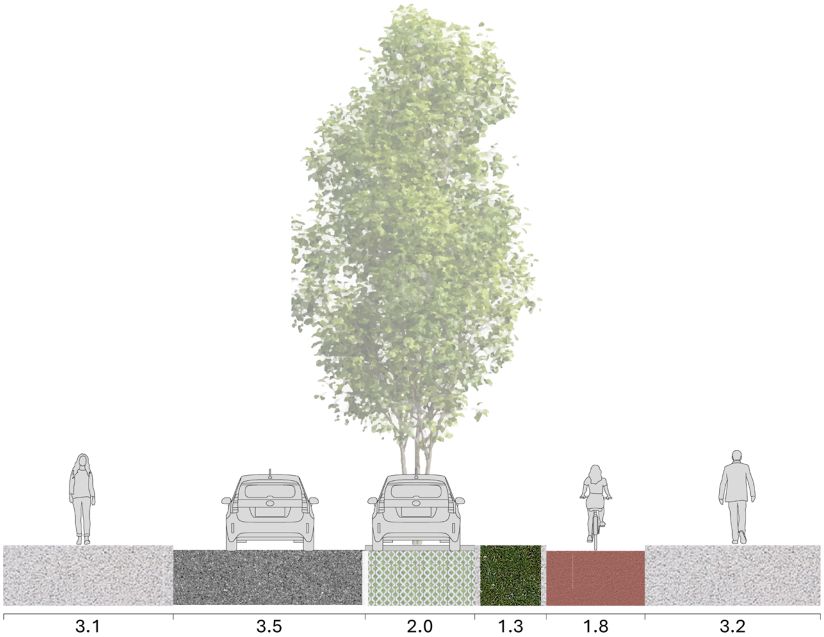

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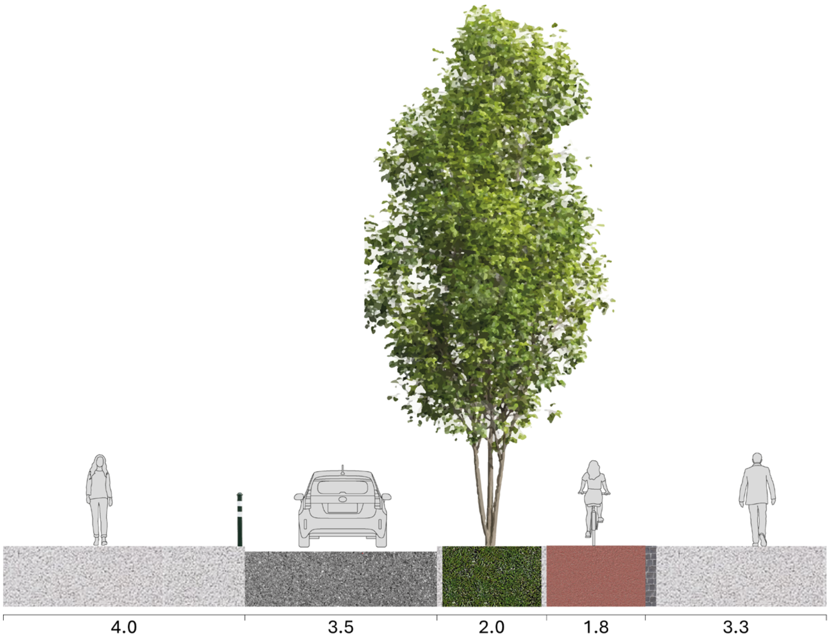

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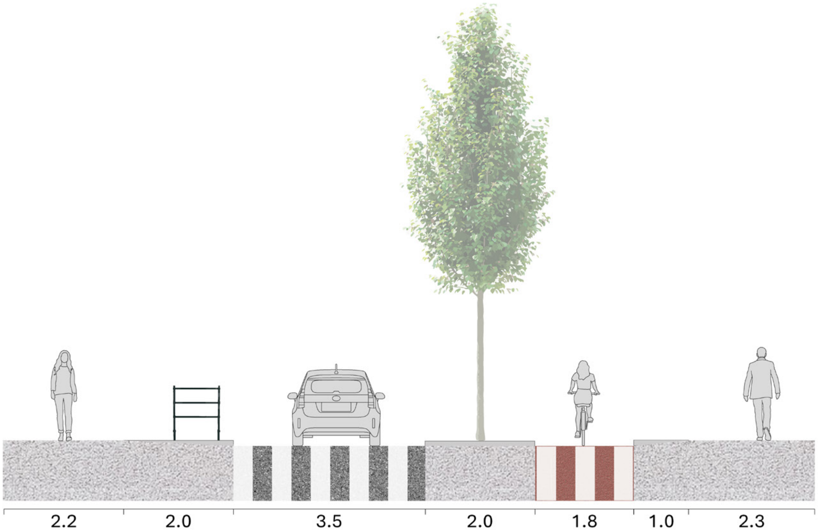

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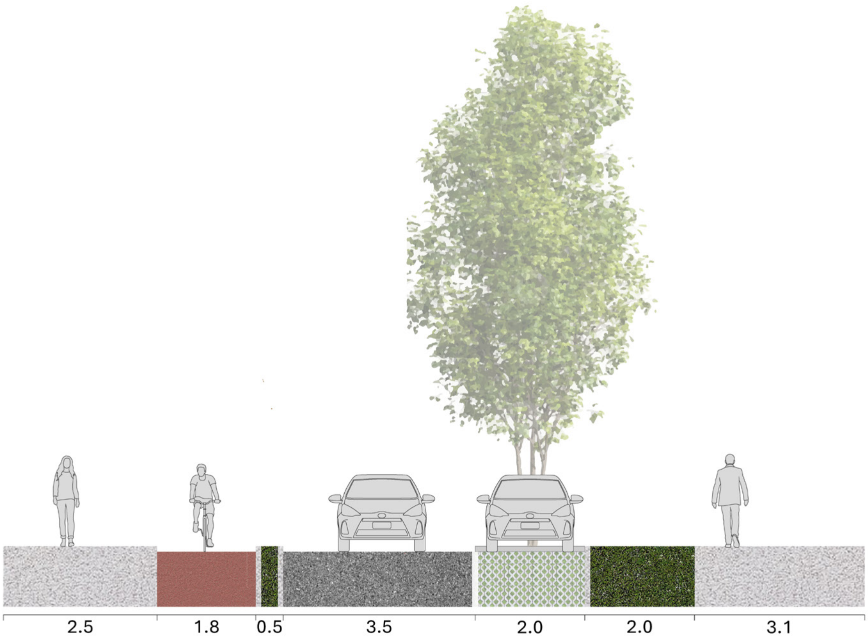
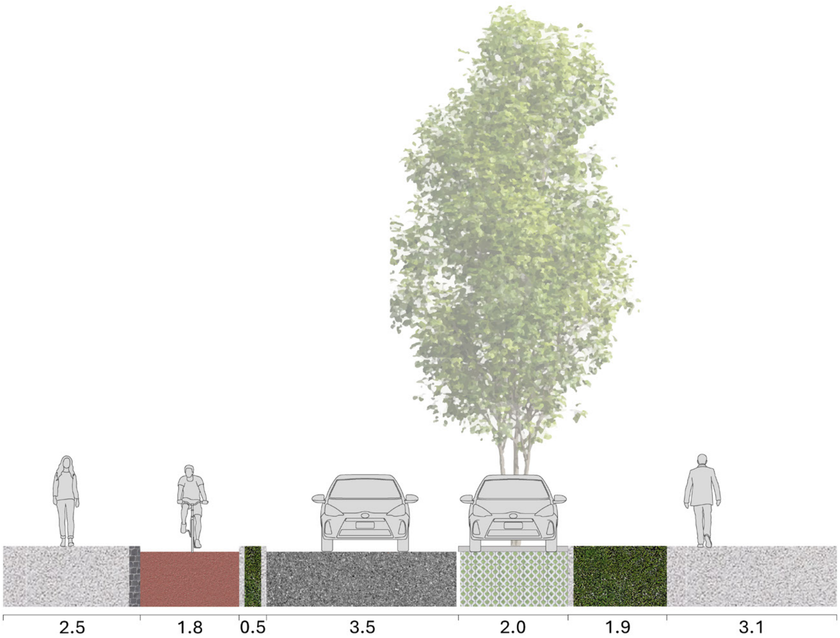


Section 6

Section 7

Section 8



Section 9

Single variable analysis

The analysis of the direct component of solar radiation allows to observe the shading pattern of the design scenario, in particular the effect of the trees. A first element of attention, as previously observed, is the difference between the shadows provoked by buildings and by trees. The shading effect on pedestrian comfort can be evaluated throughout the day. As it will be explained, the effectiveness of shading produced by plantings during the first morning hours is limited, due to the direction of radiation. Starting from 09:00, the shadows gradually rotate, and the shading effect of the buildings on the southern sidewalks is combined with the one of the trees on the northern sidewalks. As previously mentioned, the effect is more homogeneous on the southern side, while on the northern side it is affected by the size of the trees, their shape and the density of their crown. However, an almost continuous shaded path is created on both sides of the two streets, in comparison with the current state. The interruptions of the shadows in correspondence with the intersections are still evident, however, while some blocks along the streets are discontinuous and generate more interruptions in the shading, the planting allows more continuity. Especially between 09:00 and 15:00, therefore, the shading effect of trees on the sidewalks appear to be effective. Starting from 17:00, most of the surface of the streets is shaded, due to the combined effect of the trees and the buildings along the northern side. Along via Capelli, between 12:00 and 13:00, the western sidewalk facing the school is not sufficiently shaded.

As shown by the results of the first simulation, surface temperature is strictly linked with direct radiation, with lower values on the shaded surfaces. Given the dense presence of trees along the streets, a more varied distribution of surface temperatures can be observed. The hourly analysis will demonstrate that the measures included in the design provoke a reduction of surface temperature. As previously observed, the lower temperature of grass surfaces is evident as well as the one of surfaces with higher albedo. Apart from the garden Coggiola and the concrete courtyard, this simulation allows to notice the lower values of the sidewalks with the granit material selected by the project and the green strips and grass surfaces inserted to plant trees in the proposed design. These lower surface temperatures are particularly evident on the intersection between via Asinari di Bernezzo and via Mogadiscio. After the sun stops radiating directly the streets, a homogeneity can be observed, although the lower temperatures of the grass surfaces are particularly evident along the axes.

As for surface temperature, the distribution of humidity values is slightly more varied compared to the one of the current state simulation. At 07:00 higher values are registered not only in correspondence with the garden Coggiola, but also on some other portions of via Carrera and via Asinari di Bernezzo. During the rest of the day, the distribution are more similar to the current state, however, higher humidity is registered in correspondence with shaded areas.

The distribution of potential air temperature is highly variable throughout the day, and linked especially to shading. Differently than in the previous simulation, however, the impact of the new plantings is evident, especially along via Asinari di Bernezzo, for example between 09:00 and 12:00. During afternoon hours, the values are more homogenous in the area.

As in the previous simulation, wind speed and direction are rather constant throughout the day. However, compared to the current state, a difference is observed, since higher speeds appear especially along via Carrera and on the southern side of the street. This might be the result of the plantings, located on the northern side. The same effect is not registered with the same intensity along via Asinari di Bernezzo.

Similarly, PET index is linked especially with direct radiation, therefore, the first factor of influence on thermal comfort introduced by the project which can be observed is constituted by the trees. They produce an important effect in the reduction of the values of the index, as it will be measured more in detail with the hourly analysis. Due to the relevance of the shading provoked by trees, it is difficult to discern the effect of the high-albedo materials on the PET. An overall reduction of the PET index is observed on the two axes, especially on the northern sidewalks during the central hours of the day, and with a noticeable effect on the intersection between via Asinari di Bernezzo and via Mogadiscio.

Hourly analysis

07:00. The sun radiates with an east-west orientation, the shadows are generally parallel to the sidewalks, shading mostly the green spaces or the parking stalls. The effect on the sidewalks, however, is not negligeable, especially along via Asinari di Bernezzo, due to its slightly different orienation. The southern side of the streets is mostly radiated. Due to its perpendicular direction, the planting along via Capelli extends the shadow generated by the buildings, by completing the effect on the whole surface of the street. The increased shading along the two axes is a key factor in the reduction of surface temperature. Compared to the first simulation, where the surfaces showed a rather homogeneous temperature mostly ranging between 34° and 35°, a general reduction can be observed in the second simulation. The shaded areas show temperatures ranging between 22° and 25°, with the effect of the trees being especially visible along via Asinari di Bernezzo. Warmer surfaces (29° to 34°) are observed where the plantings are interrupted, such as at the intersections or at the bus stops. Surface temperatures, however, are also influenced by the changes in materials: the northern sidewalks, especially along via Carrera, despite not being completely shaded, show temperatures between 27° and 29°. The lower temperatures of the green strips and areas dedicated to plantings are also evident. Particularly low temperatures (between 21° and 25°) are observed on the square facing the church. A general effect of the measures introduced in the design can be observed with the potential air temperature. In the current state, the temperature ranges between 29° and 30°, with values reaching 31° along via Carrera to the east of via Capelli. The transformation scenario modifies the distribution, decreasing in general air temperature of about 1°. Along via Carrera, the temperature ranges between 28° and 29°. Along via Asinari di Bernezzo, the temperature is always lower than 29°, except from two areas, corresponding to the intersection with via Baveno and to the backyard of the kindergarten. It must be noted that, differently than surface temperatures, air temperature is less strictly identifiable as the result of a single measure. The pattern of potential air temperature is similar to the one of relative humidity, with a slight increase in the same areas where the temperature diminishes. At 07:00, few modifications can be observed to the wind speed and direction. Especially due to the effect of shading, the PET along the two axes is particularly different. While in the current state the values mostly range between 43° and 45°, although some cooler areas are present, these values are verified in the project scenario only on the areas exposed to the sun, mostly corresponding to the southern sides of the streets. The surfaces completely shaded, either by the buildings or by the trees, show values between 32° and 33°. The surfaces covered by the external edges of the shadows produced by the trees show slightly higher values, comprised between 33° and 35°. As it was mentioned, due to the orientation of the sun, some portions of the sidewalks are not completely shaded, with resulting higher PET values. These correspond especially to the northern sidewalks of via Carrera.

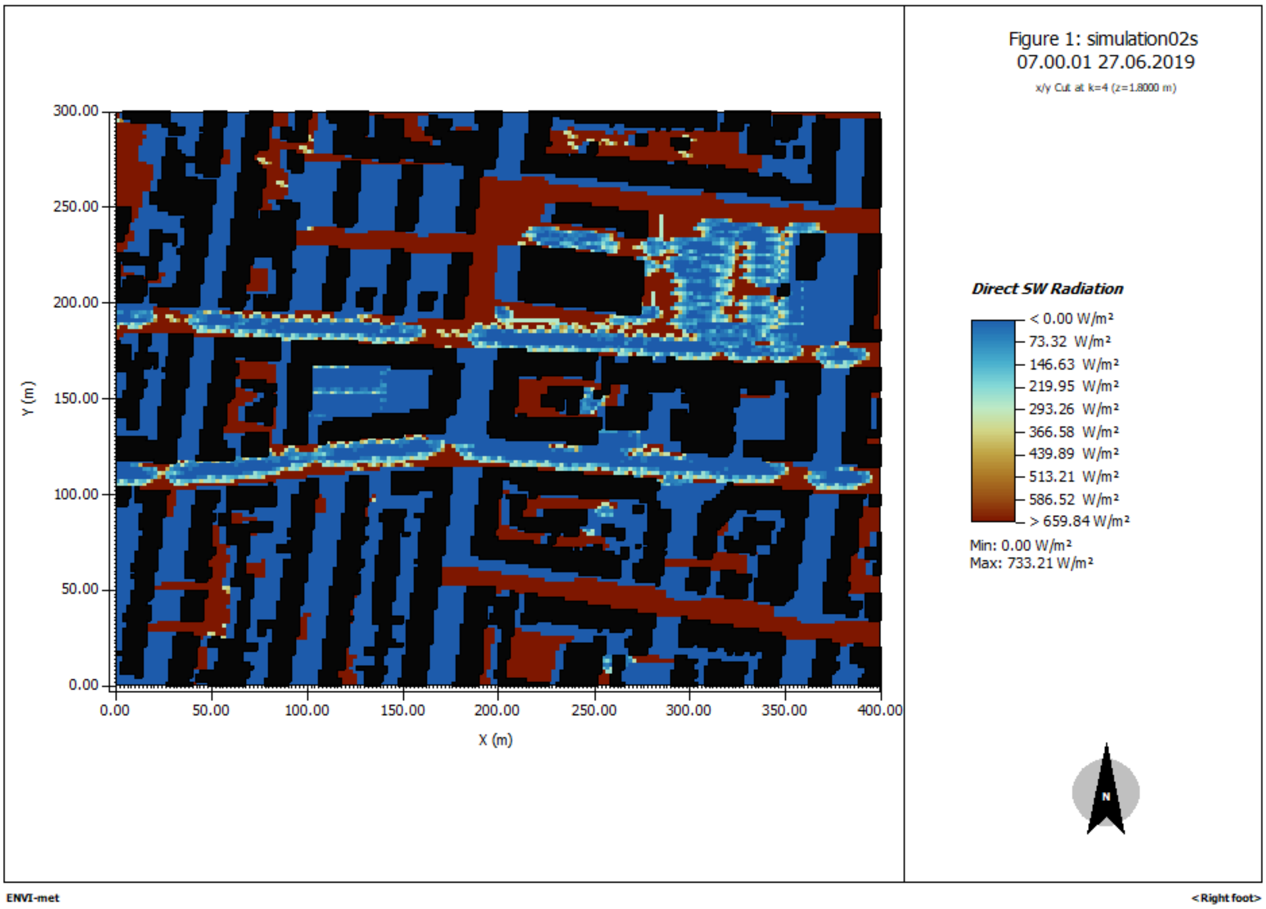


Figure 76. Direct radiation, scenario GLT, 07:00

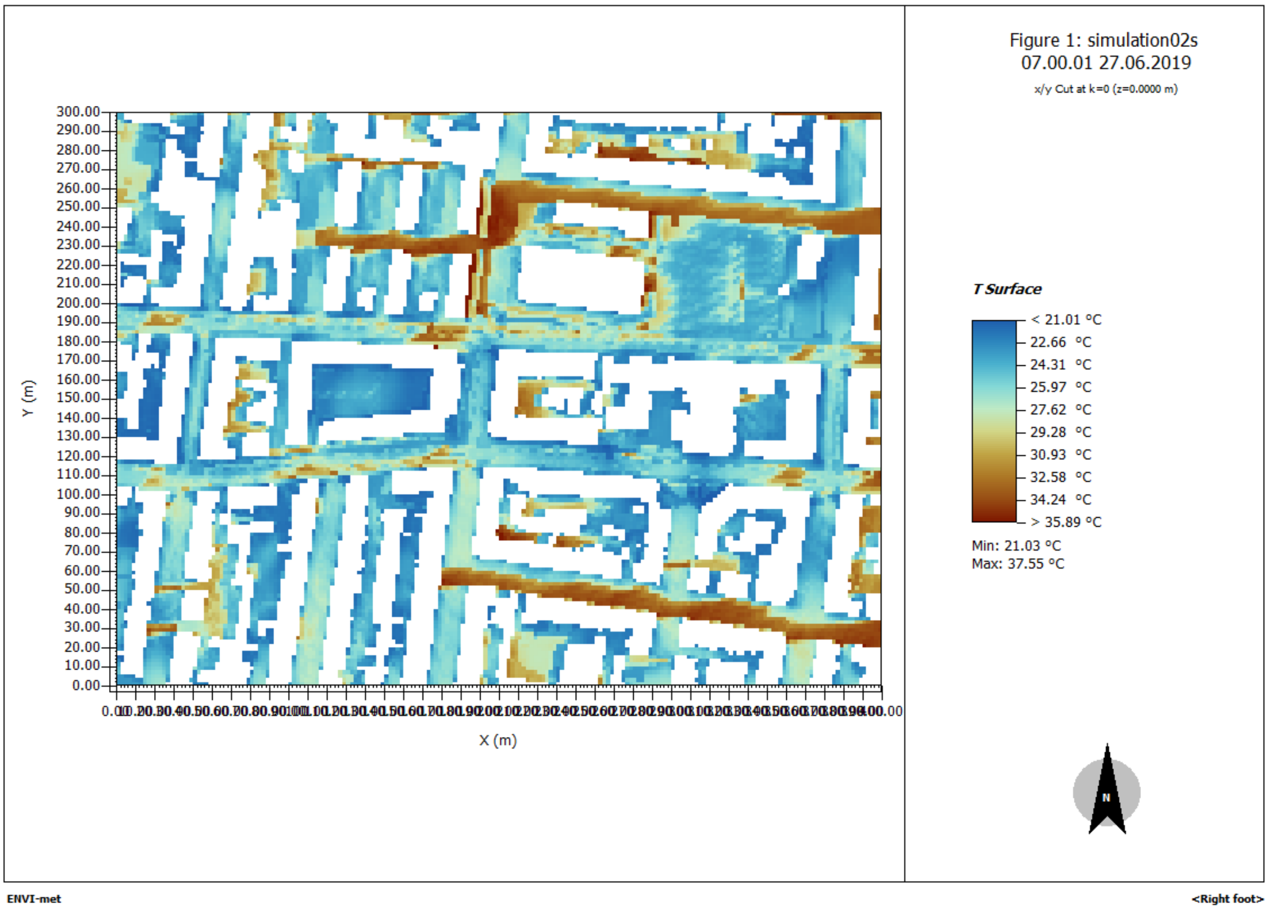


Figure 77. Surface temperature, scenario GLT, 07:00

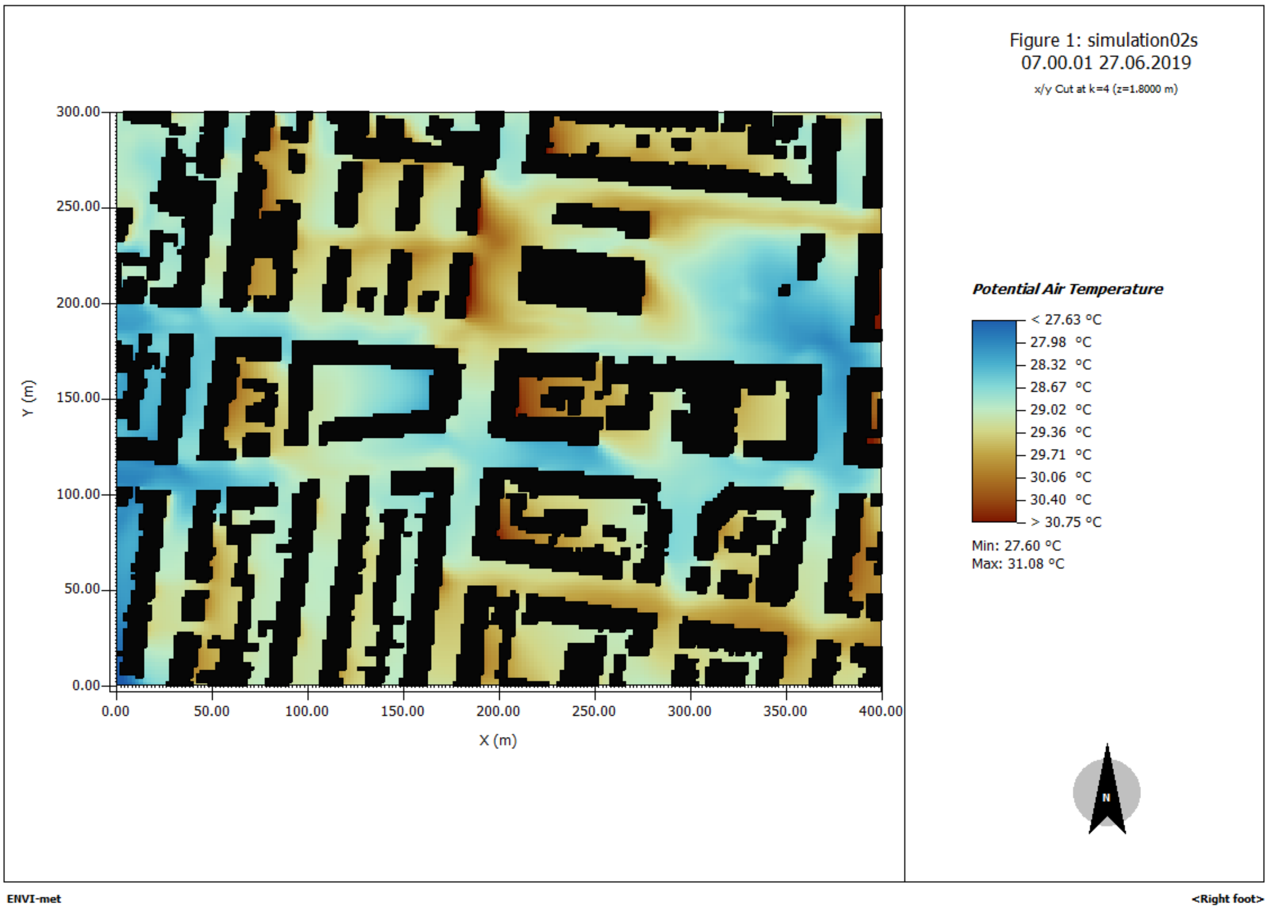


Figure 78. Potential air temperature, scenario GLT, 07:00

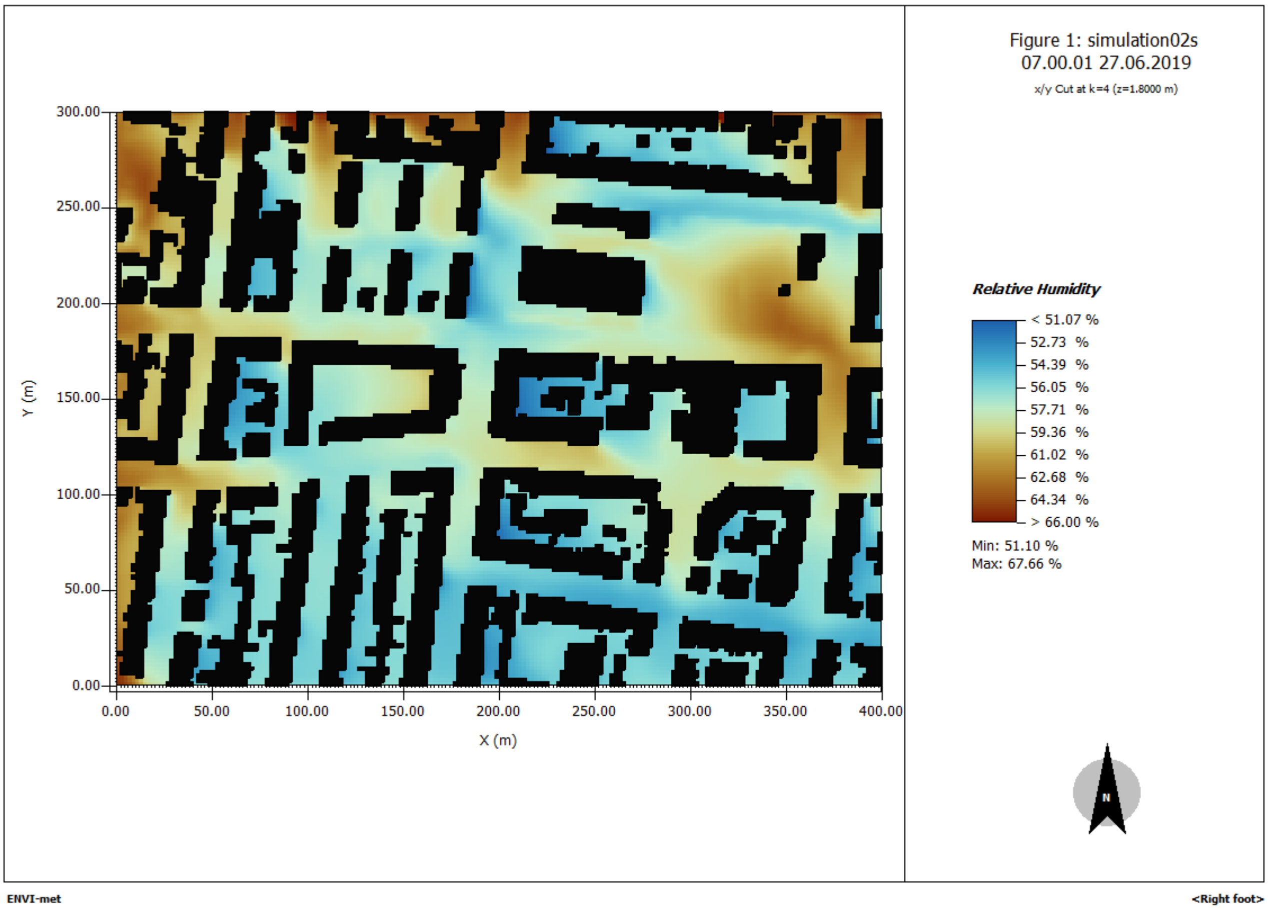


Figure 79. Relative humidity, scenario GLT, 07:00

Figure 80. Wind speed and direction, scenario GLT, 07:00

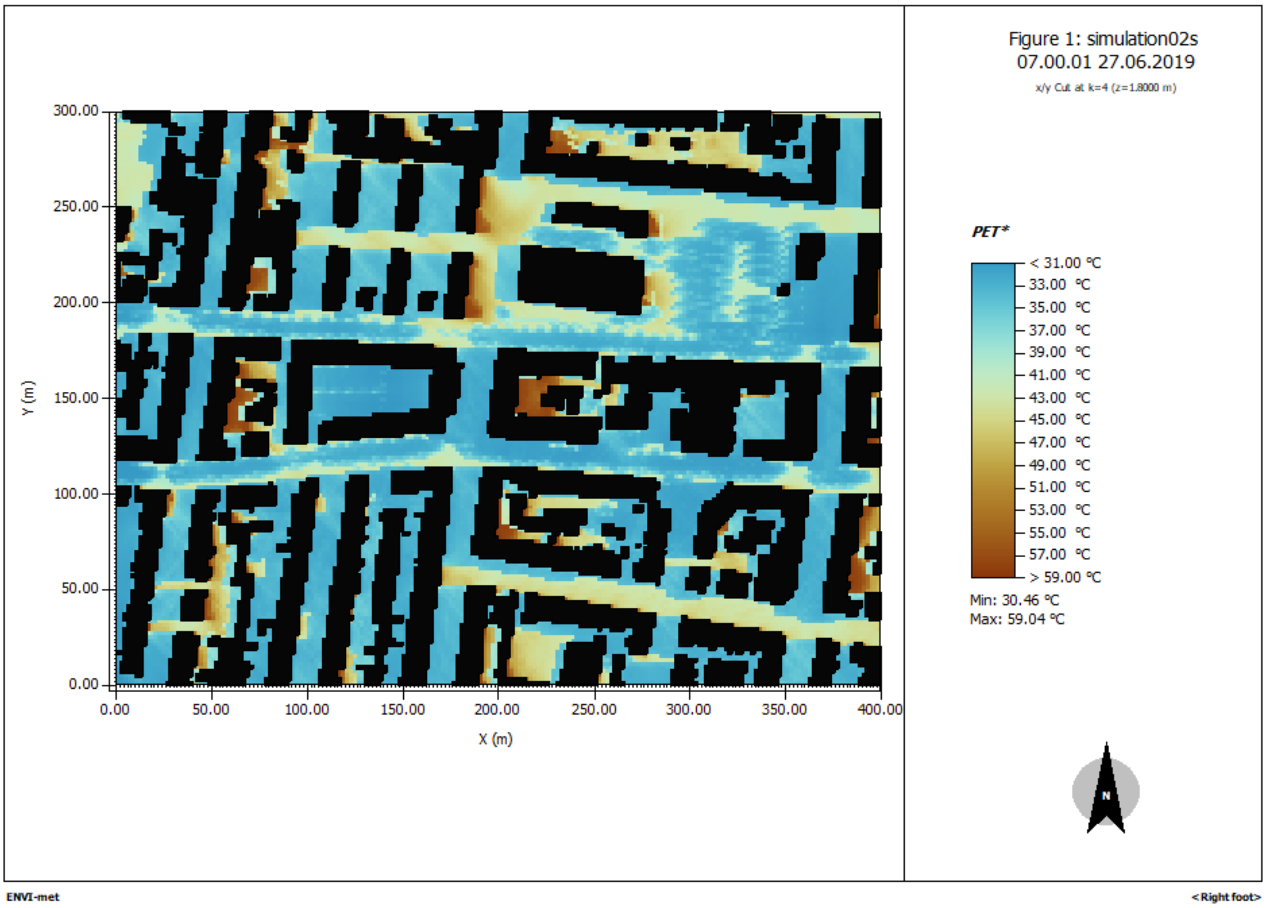


Figure 81. PET, scenario GLT, 07:00

12:00. The observation of the distribution of direct radiation at 12:00 allows to observe the most clearly the effect of the trees. Although the shadow length is limited, its effect is visible on the northern sidewalks, while the southern sidewalks are already shaded by the buildings, where there is continuity in the facades. Along via Capelli, the effect is limited, due to the perpendicular direction of the planting. The effect of shading is evident on surface temperature. Compared to the current state, a general reduction of the temperature is evident. In the current state, the northern sidewalks show temperatures ranging between 50° and 55°, while in the project scenarios the temperatures mostly range between 30° and 35°. Regarding the sidewalks, the temperature reduction is also the result of the higher albedo materials, since lower temperatures are also shown on the radiated portions of the sidewalks, such as the one corresponding to the bus stops along via Carrera. As in the previous cases, the reduction of temperature is also verified on green areas. An important difference between the scenarios is noticeable with the comparison of potential air temperature. Regarding the current state, the reported temperatures range between 35° and 37°, while for the project scenario they are comprised between 33° and 35. In general, a 1° reduction of the temperature is reported. Humidity. As in the previous case, the wind pattern does not show important changes. Finally, the PET is modified especially due to the different conditions of shading. Along the southern sidewalks, shaded by the buildings, the values range between 40° and 42°, while the same surfaces in the current state showed values between 41° and 43°: despite the unchanged shading conditions, it can be hypothesized that the overall transformation of the street might have influenced some of the parameters considered in the PET. The surfaces shaded by the trees are associated with the values between 43° and 46°, while in the current state the values ranged between 53° and 54°. These mostly correspond to the northern sidewalks, although along via Carrera the condition of shading is reduced, leading to higher values, reaching 48°. Moreover, low conditions of thermal comfort along the sidewalks are registered where the shadows are interrupted, reaching 53°. The higher values in correspondence with these areas could be associated not only to the absence of shading, but also to the high albedo of the materials chosen, which, as it was seen, might be detrimental to thermal comfort.

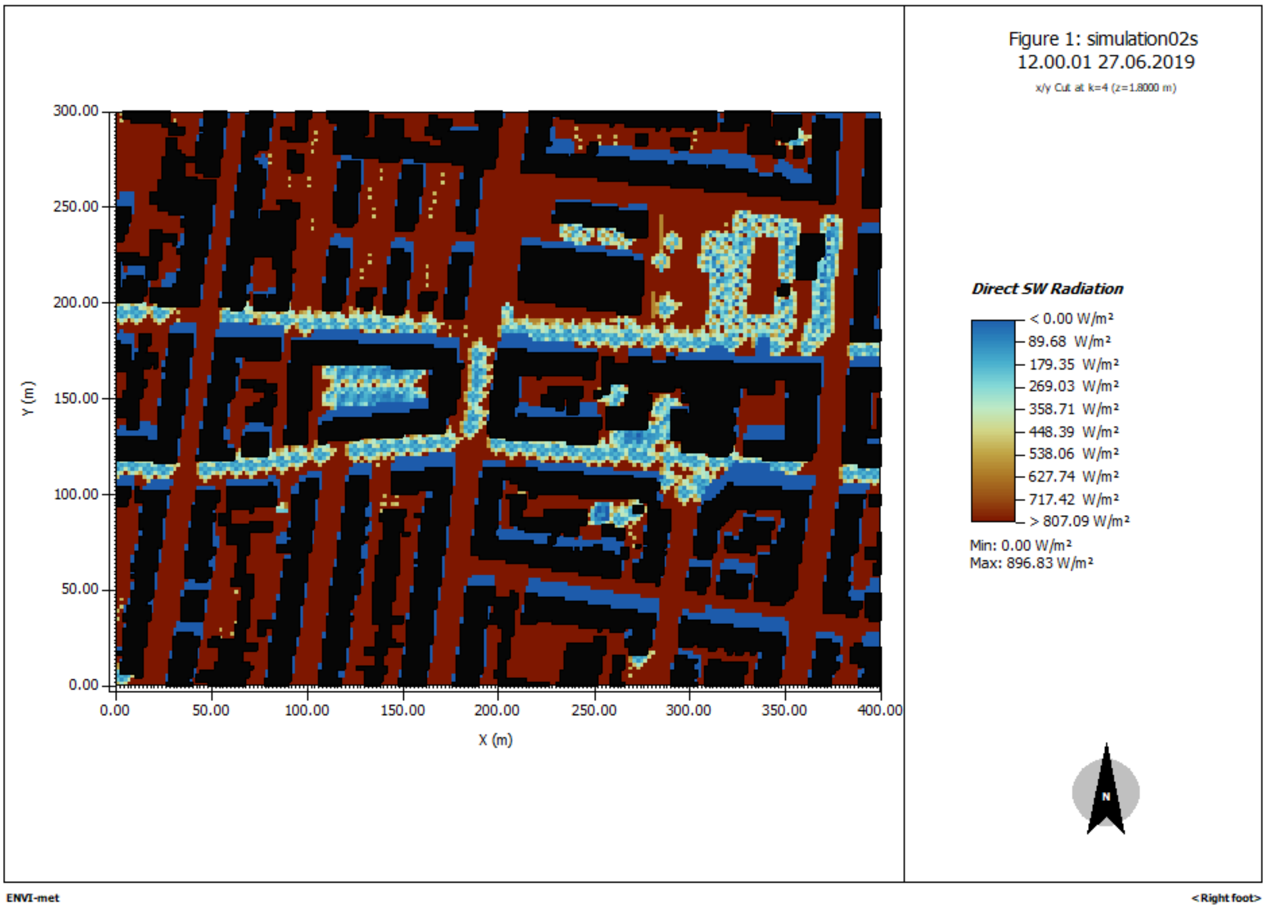


Figure 82. Direct radiation, scenario GLT, 12:00

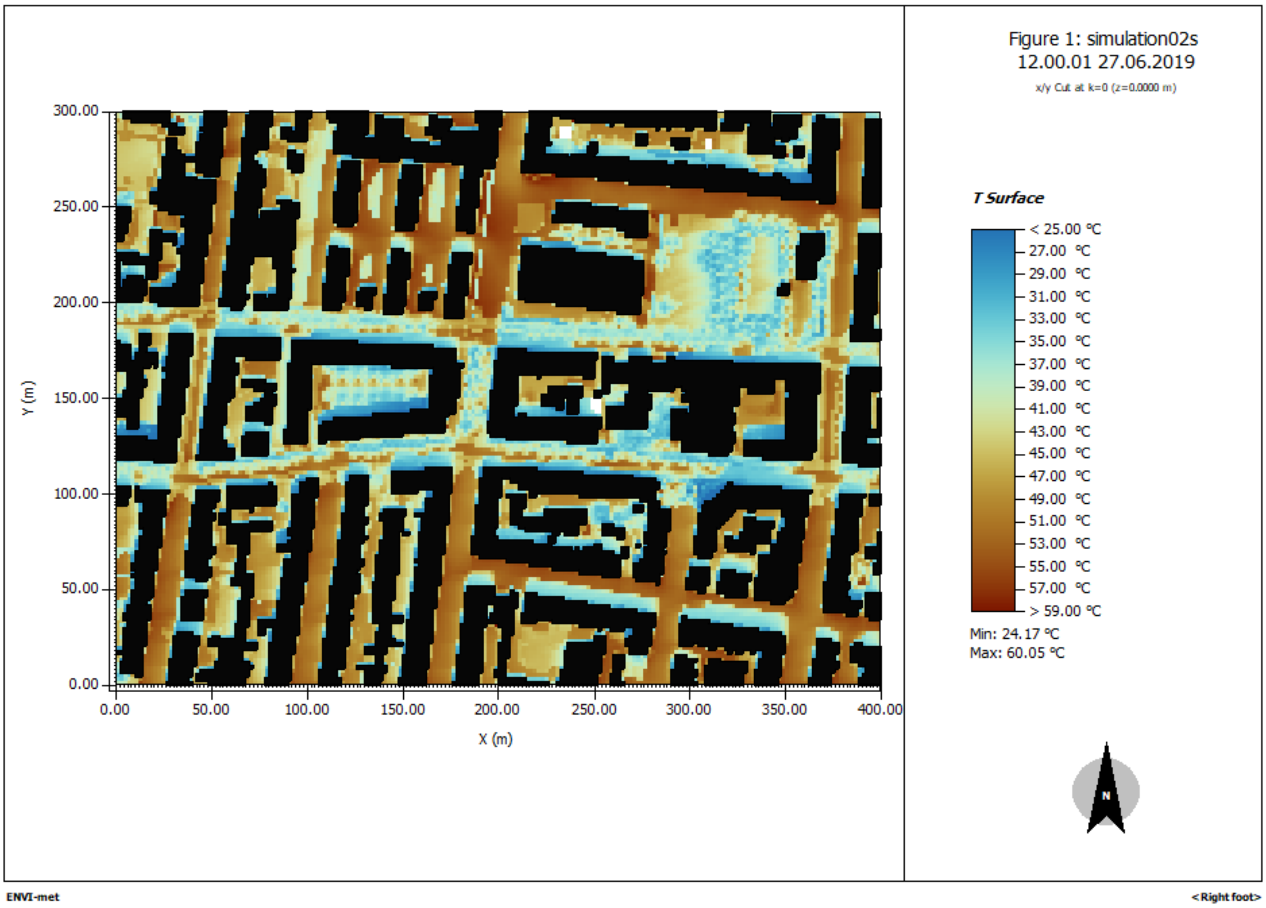


Figure 83. Surface temperature, scenario GLT, 12:00

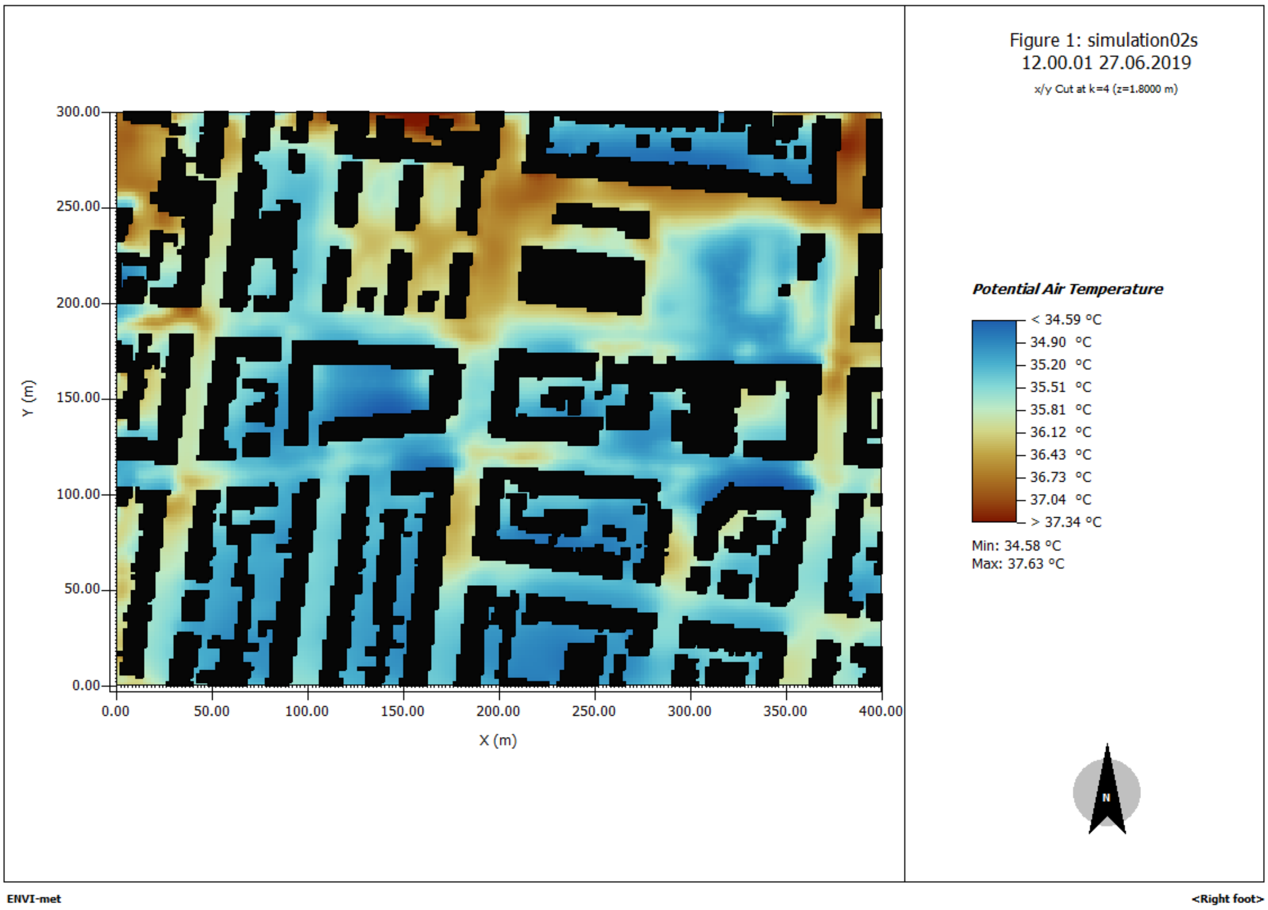


Figure 84. Potential air temperature, scenario GLT, 12:00

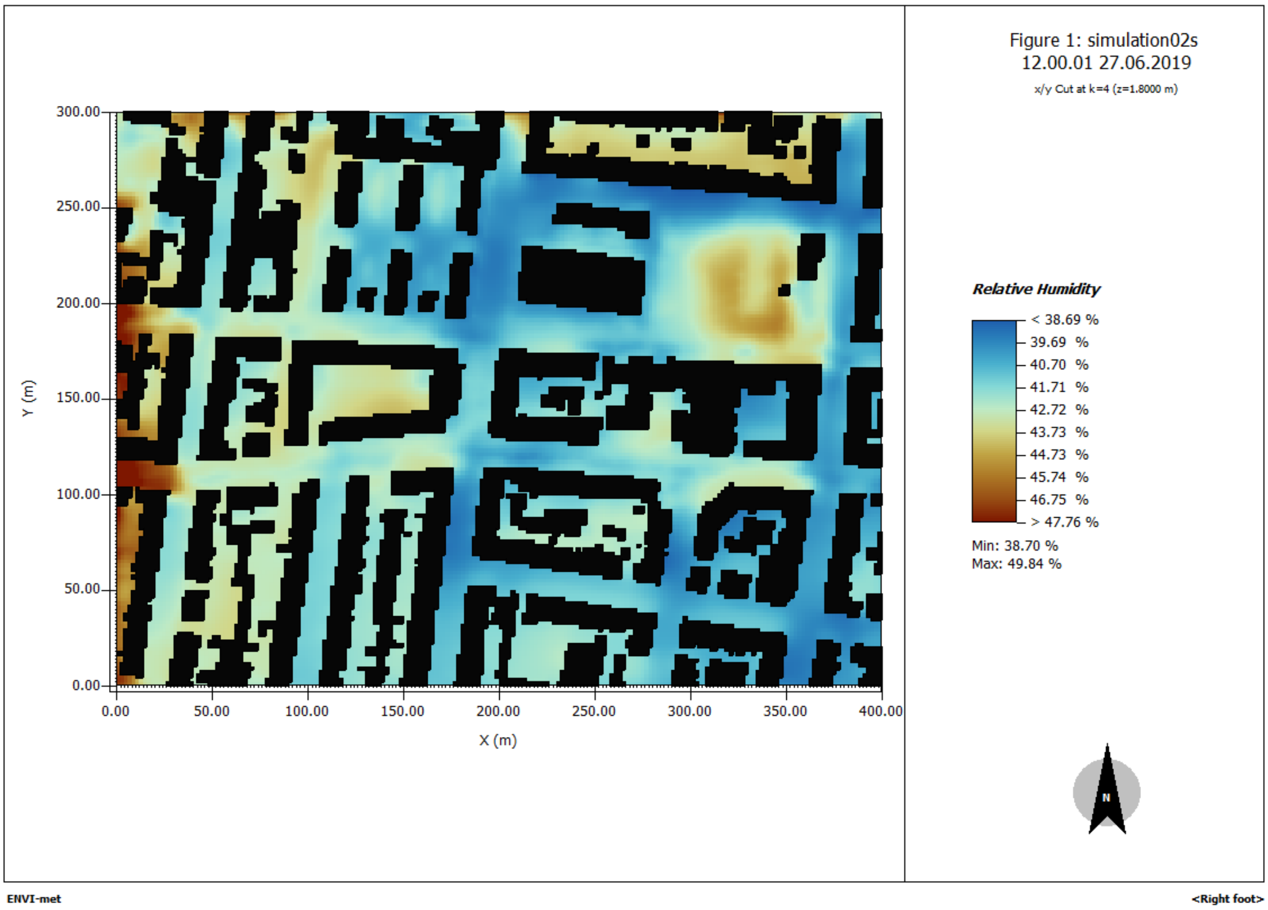


Figure 85. Relative humidity, scenario GLT, 12:00

Figure 86. Wind speed and direction, scenario GLT, 12:00

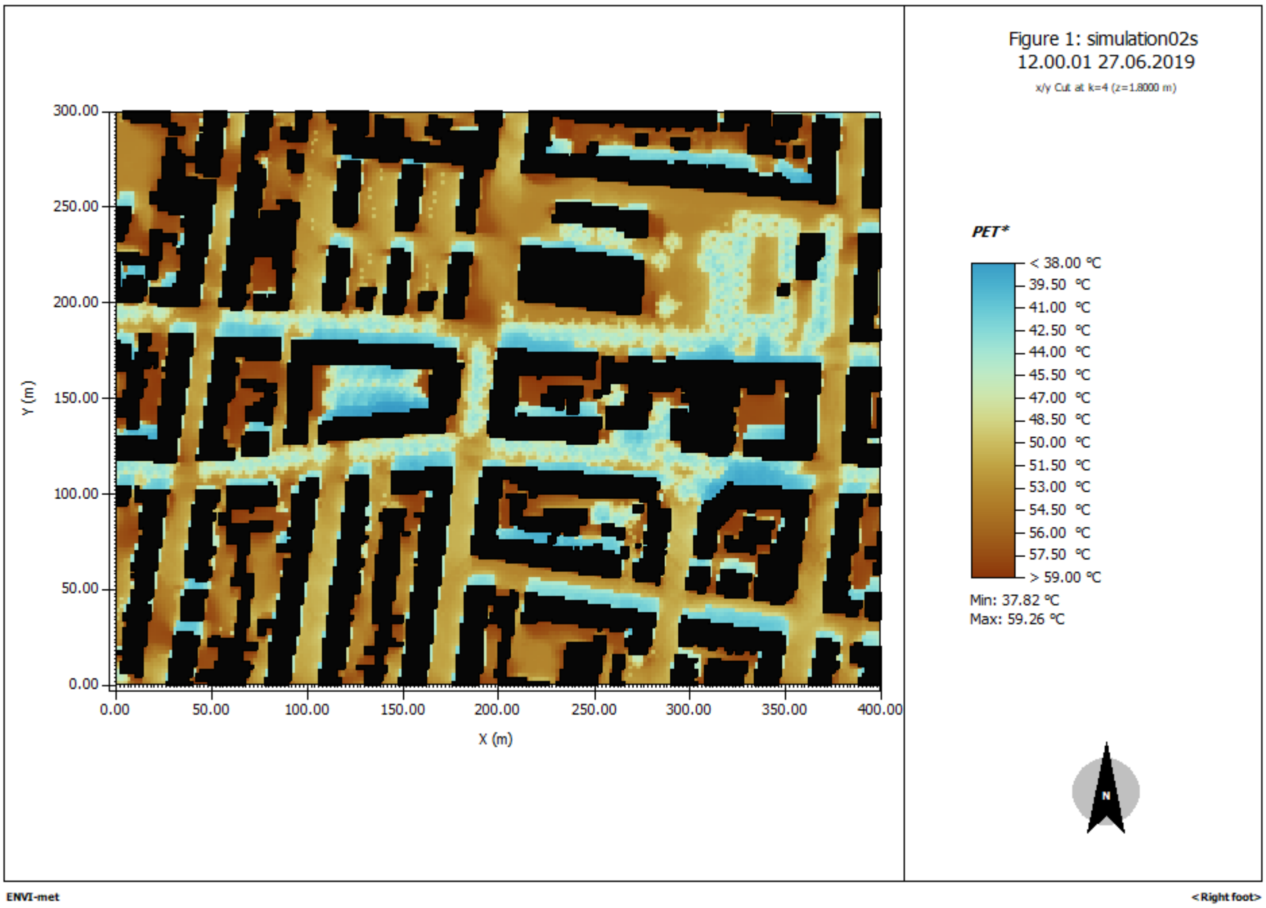


Figure 87. PET, scenario GLT, 12:00

15:00. Regarding direct solar radiation, similar observations can be made to the ones expressed for 12:00. The northern sidewalks are mostly shaded by the trees, while the southern ones are, at least partially, shaded by the buildings. The entire surface of via Capelli, between via Carrera and via Asinari di Bernezzo, is shaded by the combined effect of the building of the school and the trees. Almost the entire area of the intersection facing the church is shaded. The distribution of the values of surface temperature is similar to the ones of 12:00. However, the temperatures are slightly higher, such as the ones of the sidewalks ranging between 35° and 39°, while in the current state they are comprised between 50° and 55°. The non-shaded asphalt surfaces reach temperatures higher than 50°, while the coloured asphalt and the granit pavements show lower temperatures (between 36° and 38°) due to the higher albedo, despite being exposed to the sun. As in the previous cases, a reduction of potential air temperature of about 1° is registered, with values changing from 37°-38° to 36°-37°. The increase in humidity is probably linked with the vegetation, as it can be observed from the distribution of the higher values along the streets. An important decrease in the PET is observed. In the current state, the index ranges between 53° and 54° an almost all surfaces of the two streets, with values between 42° and 43° along part of the southern sidewalks, and a peak of 58° on the intersection between via Asinari di Bernezzo and via Mogadiscio. In the scenario of transformation, with the shading produced by trees, the PET index along the northern sidewalks reachers 41° to 43°, although the portions closest to the northern edge are less homogeneously shaded, with resulting higher values, reaching 49°. The vehicular surfaces, as well as the pedestrian crossings where the shading is interrupted, show similar values to the current state. The critical area at the intersection between via Asinari di Bernezzo and via Mogadiscio is more comfortable, with values between 42° and 45°, mostly thanks to the trees.

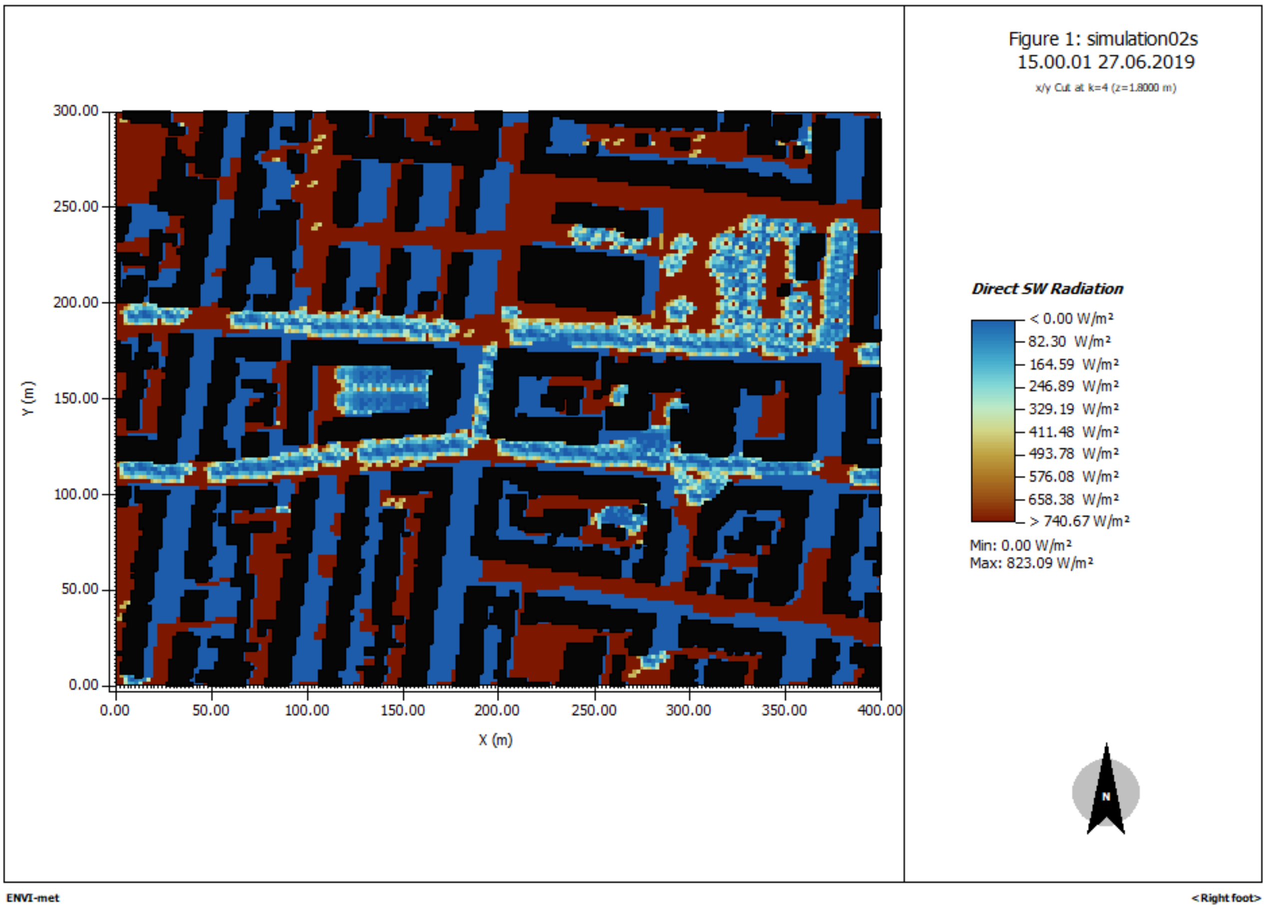


Figure 88. Direct radiation, scenario GLT, 15:00

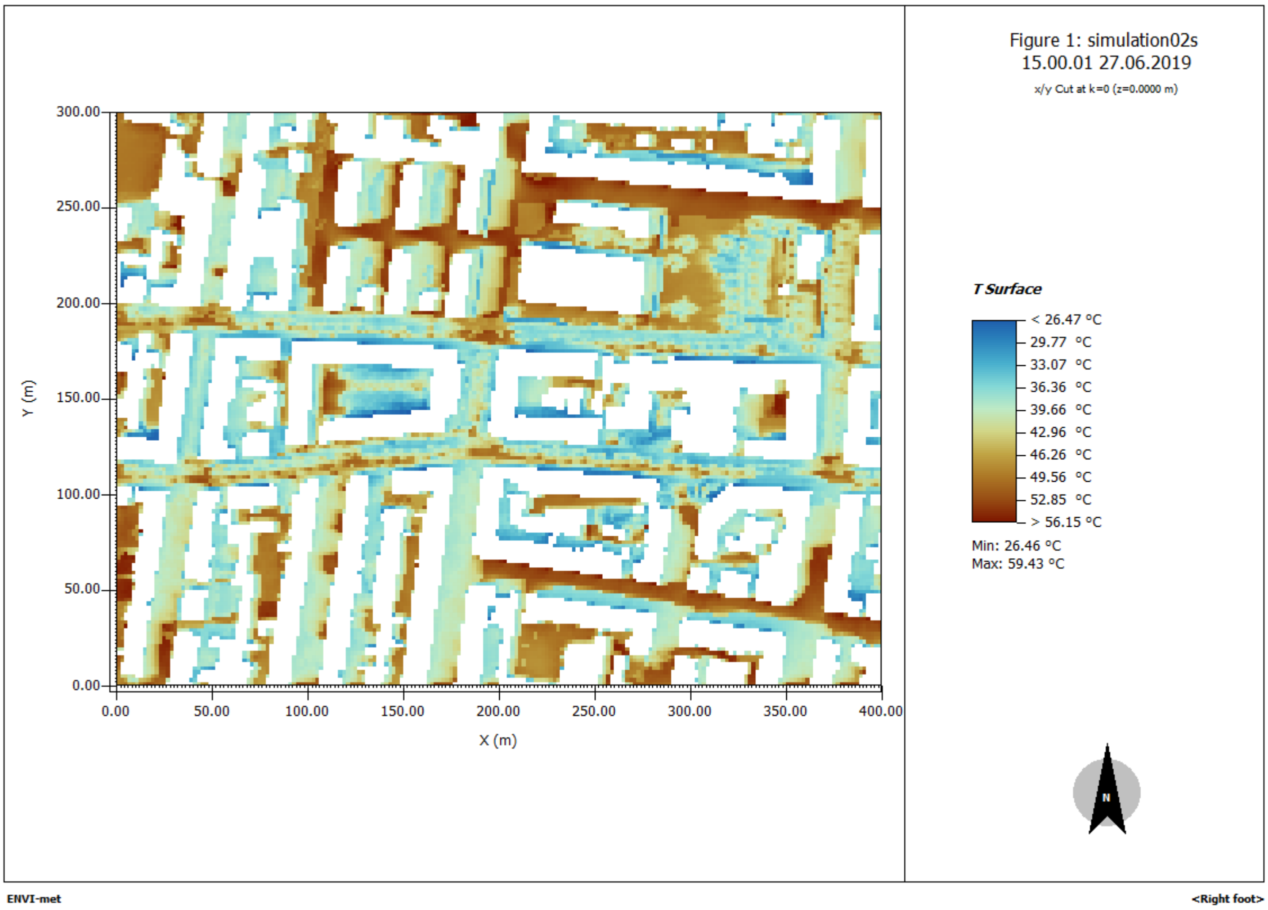


Figure 89. Surface temperature, scenario GLT, 15:00

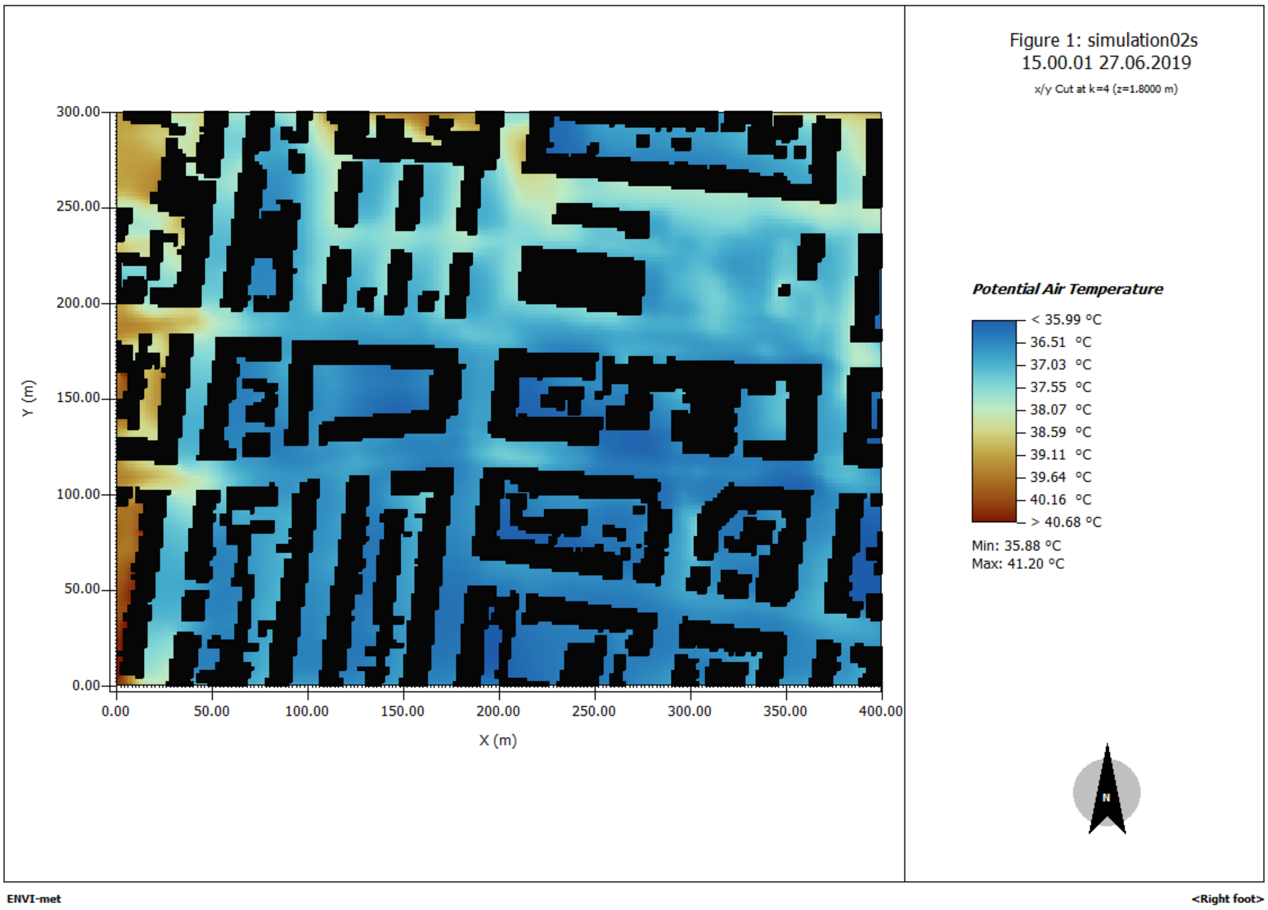


Figure 90. Potential air temperature, scenario GLT, 15:00

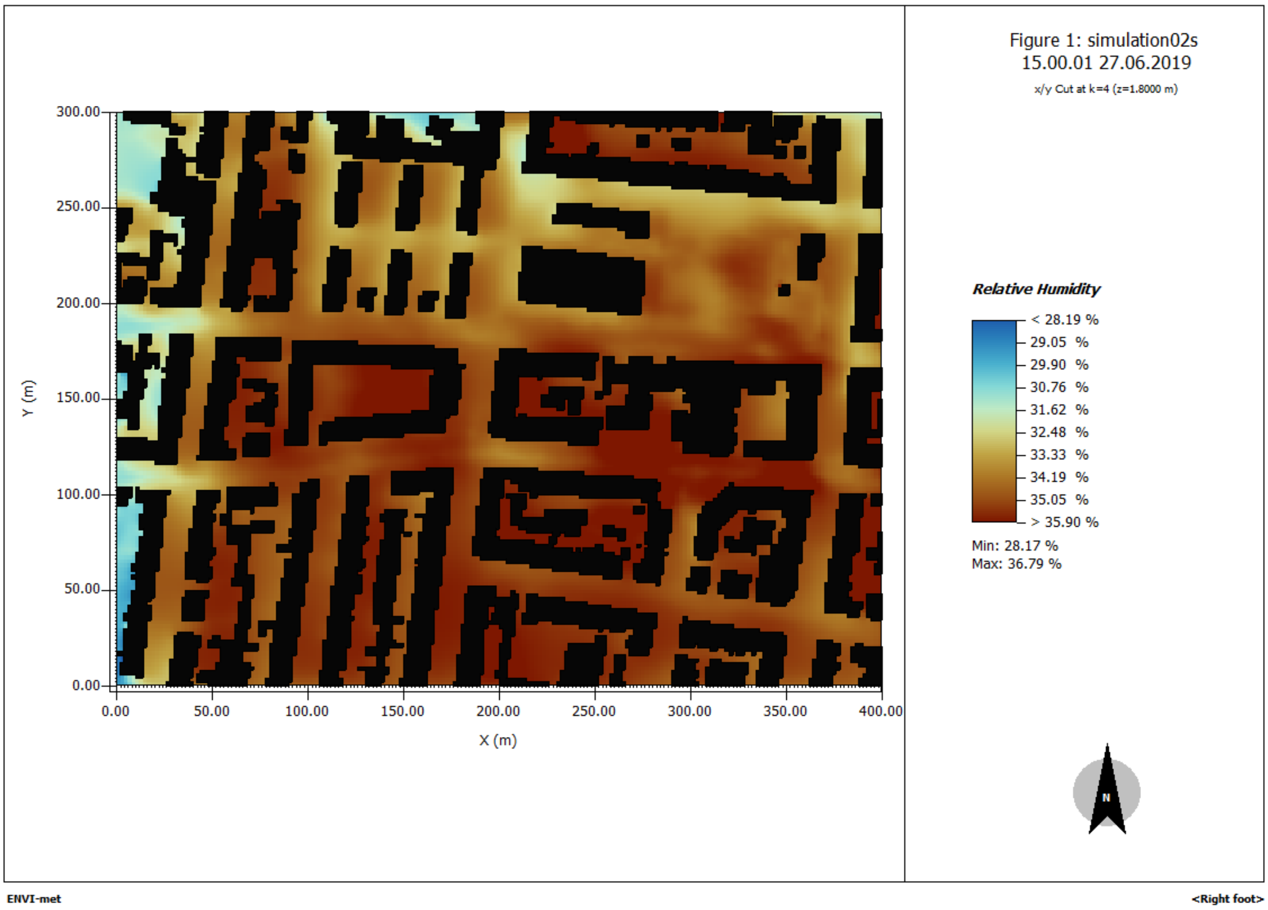


Figure 91. Relative humidity, scenario GLT, 15:00

Figure 92. Wind speed and direction, scenario GLT, 15:00

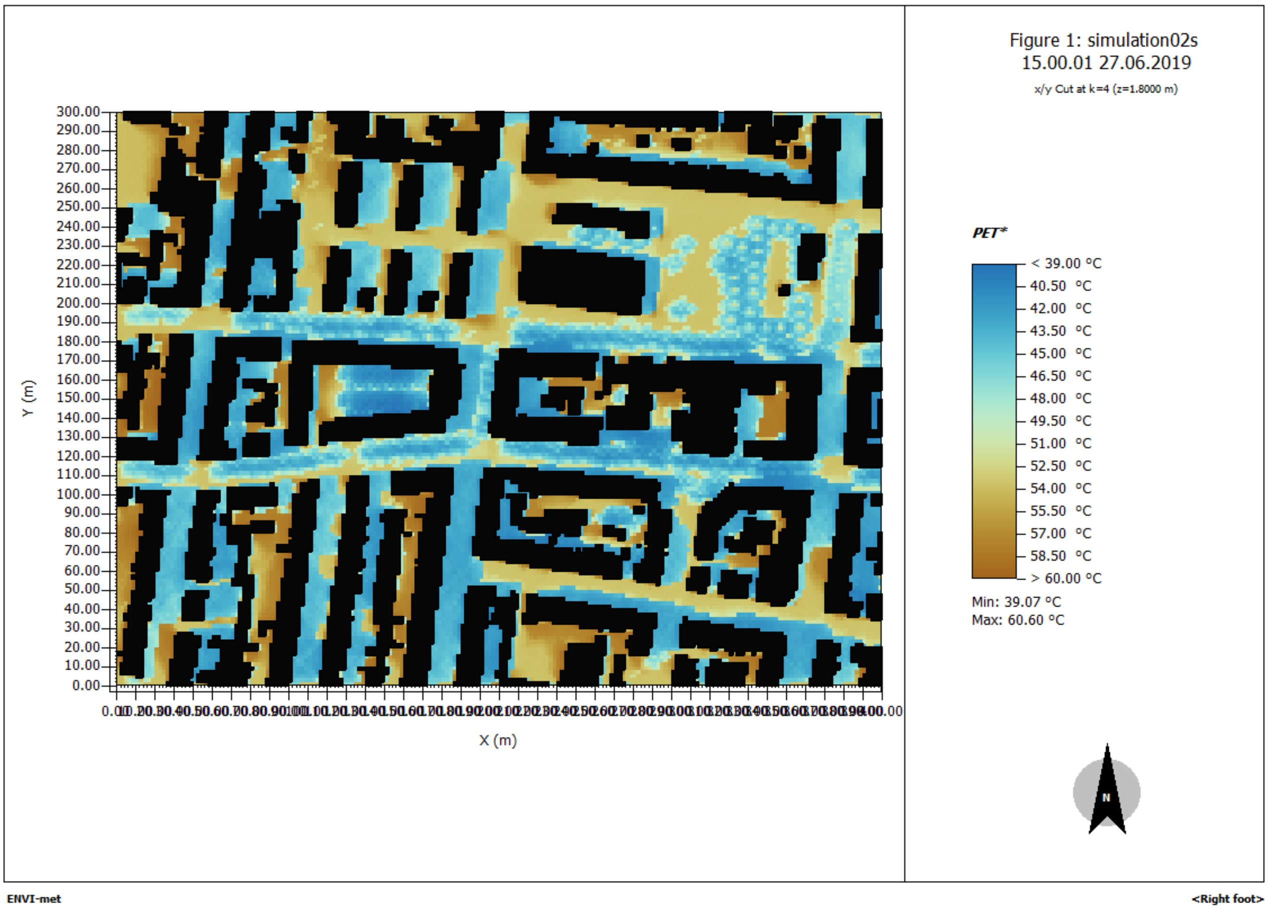


Figure 93. PET, scenario GLT, 15:00

18:00. As mentioned, at 18:00 only small portions of the area are directly radiated by the sun. Compared to the previous timeslots, surface temperature appears to be rather homogenous along the streets, mostly comprised between 34° and 36°, with values around 32° on the high albedo sidewalks of via Carrera. In the current state, the surface temperature ranges between 37° and 41° By comparing with the other streets in the area, the temperature appears to be lower, and especially along the northern sides of via Asinari di Bernezzo, where the temperature is lower in correspondence with higher albedo materials. Potential air temperature is lowered of about 1°, with values ranging between 34° and 35°. An increase in humidity is observed, especially in the eastern portions of the two axes. Given the homogeneity of shading conditions, a similar pattern is observed with the analysis of the PET. In the current state, the values mostly range between 39° and 40°, except from the limited portions where direct radiation is still observed. In the project scenario, the values range between 37° and 39° in most cases.

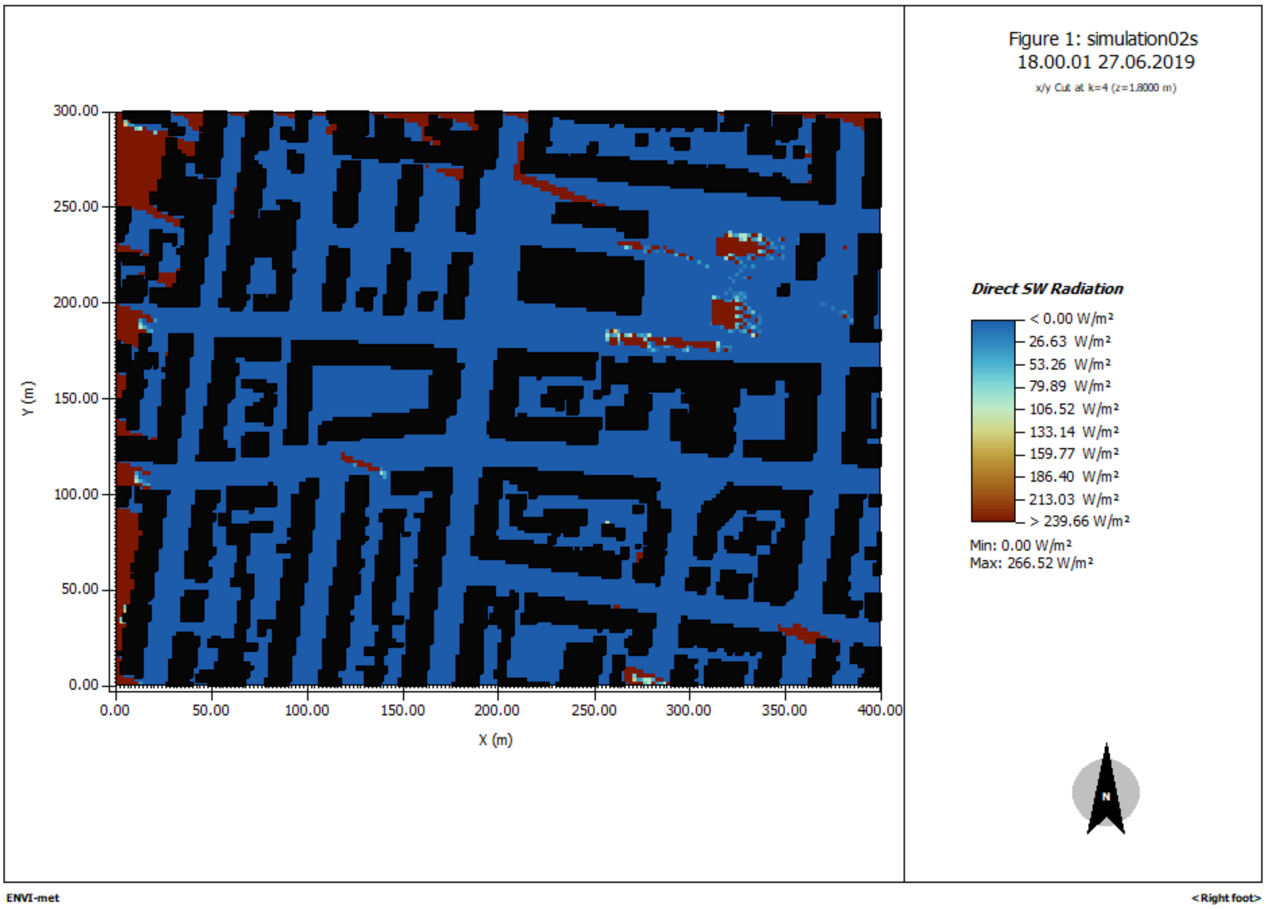


Figure 94. Direct radiation, scenario GLT, 18:00

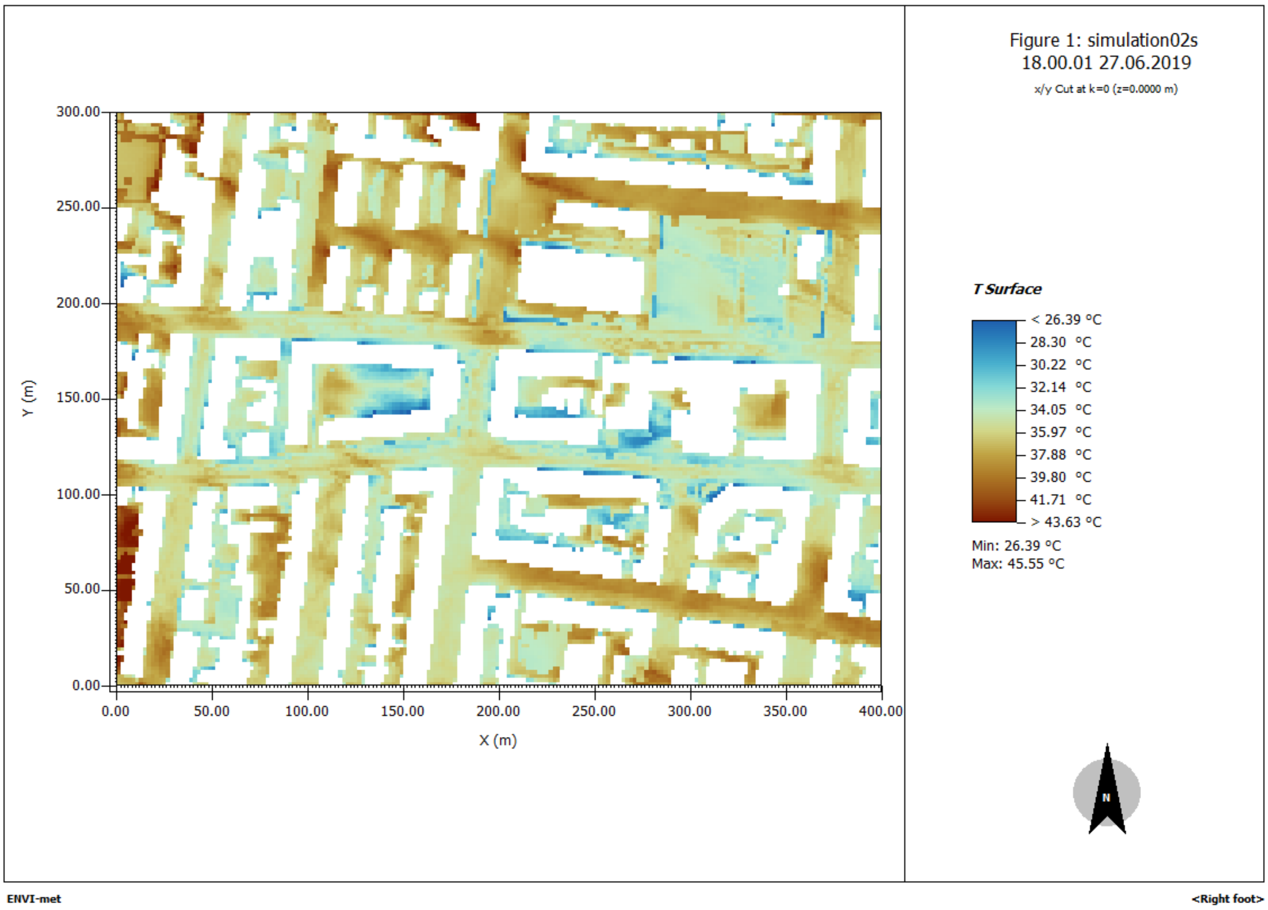


Figure 95. Surface temperature, scenario GLT, 18:00

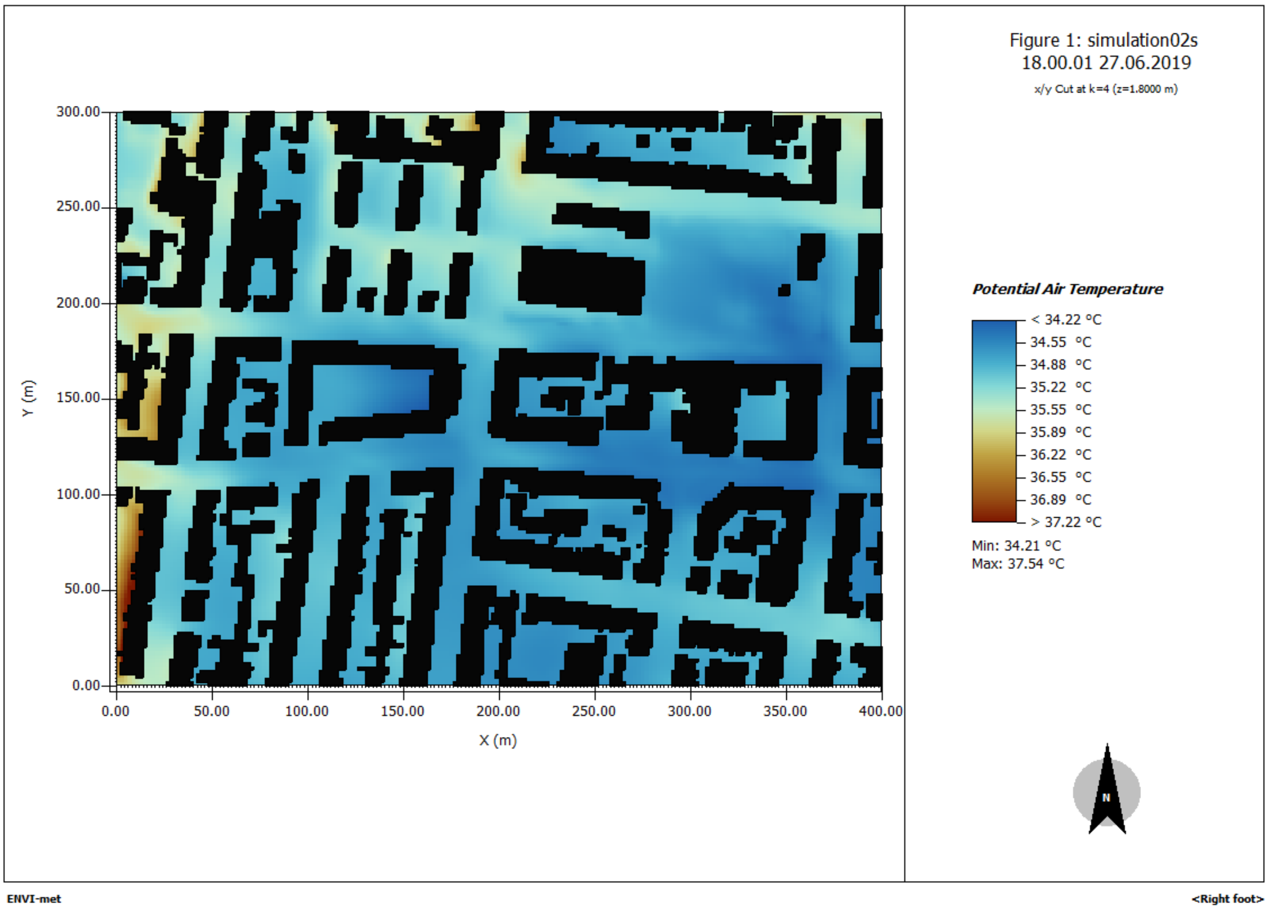


Figure 96. Potential air temperature, scenario GLT, 18:00

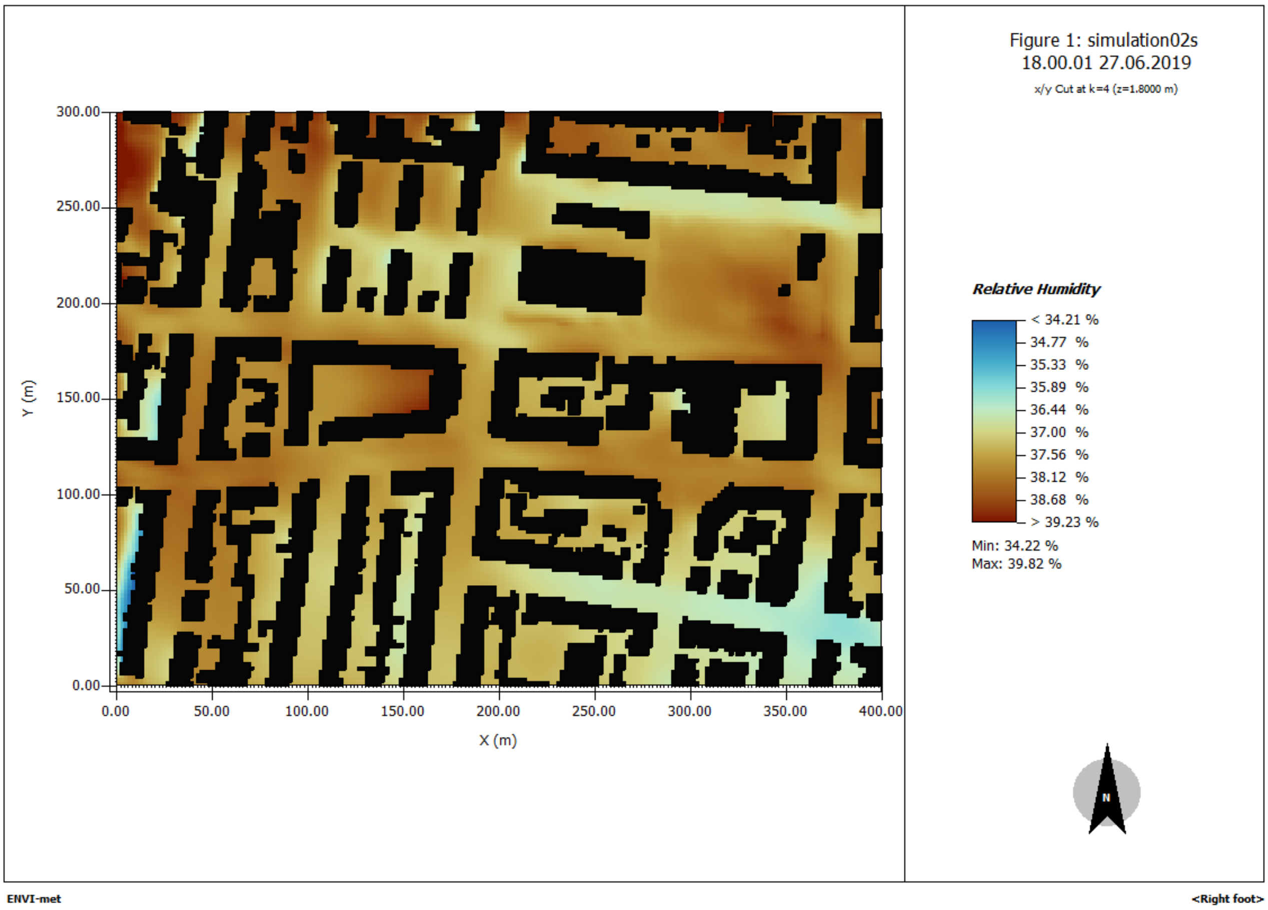


Figure 97. Relative humidity, scenario GLT, 18:00

Figure 98. Wind speed and direction, scenario GLT, 18:00

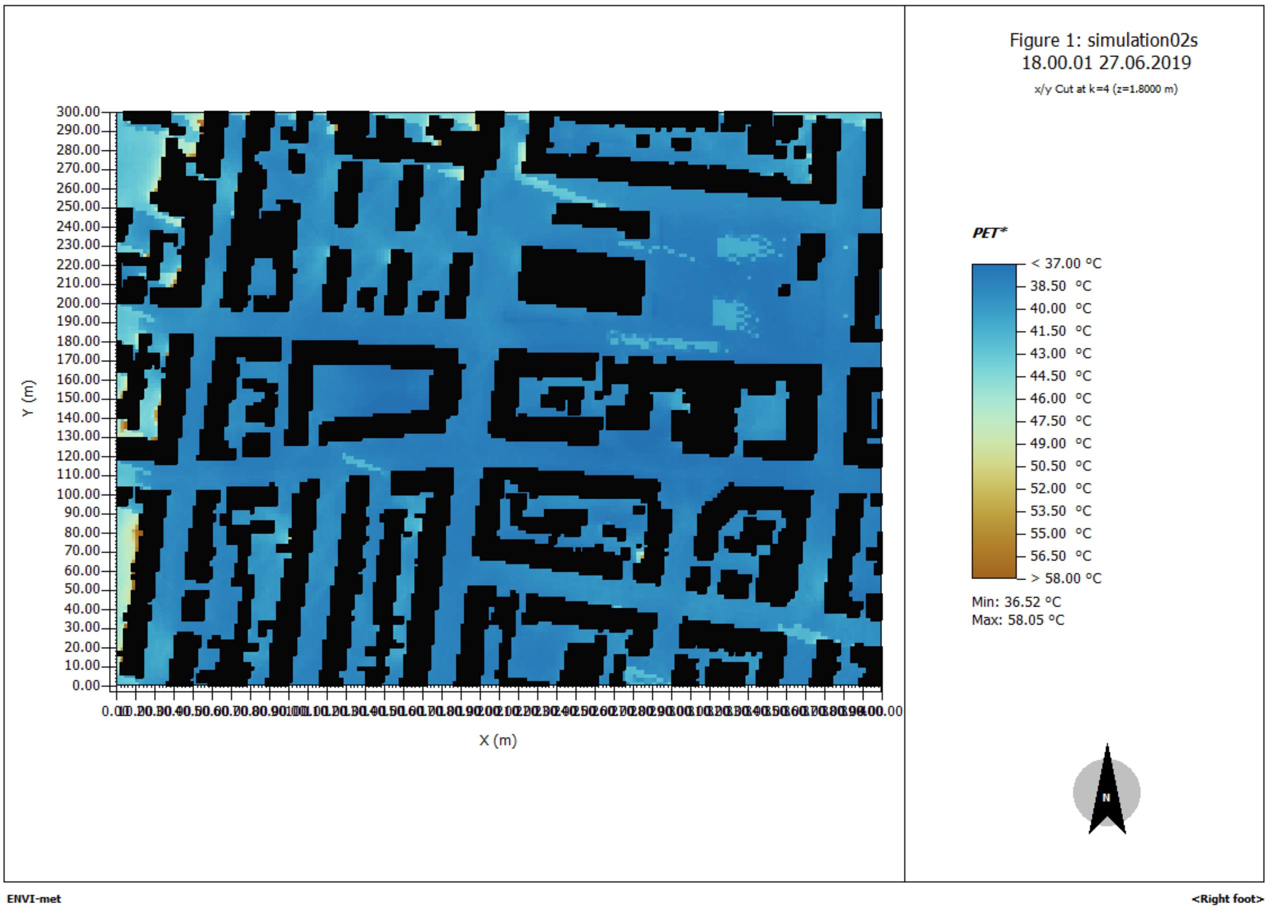
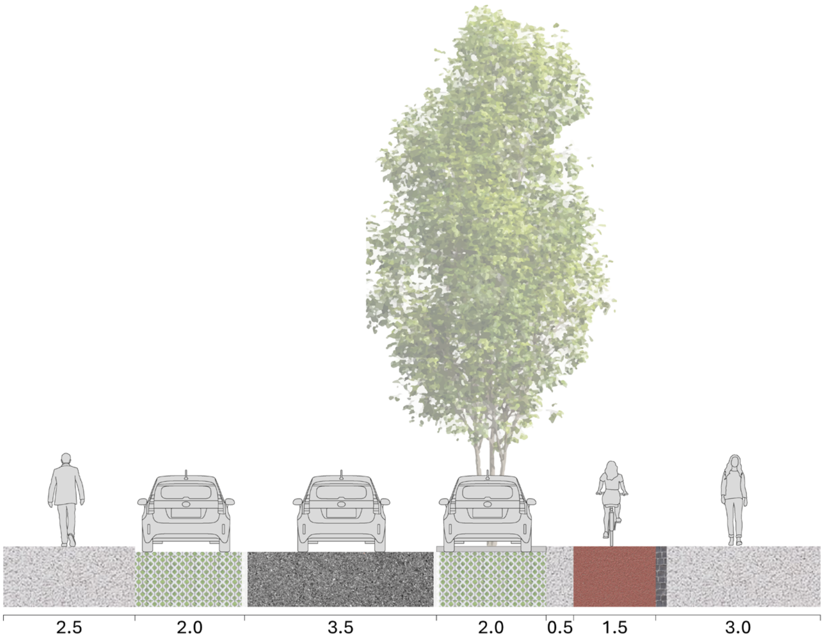


Figure 99. PET, scenario GLT, 18:00

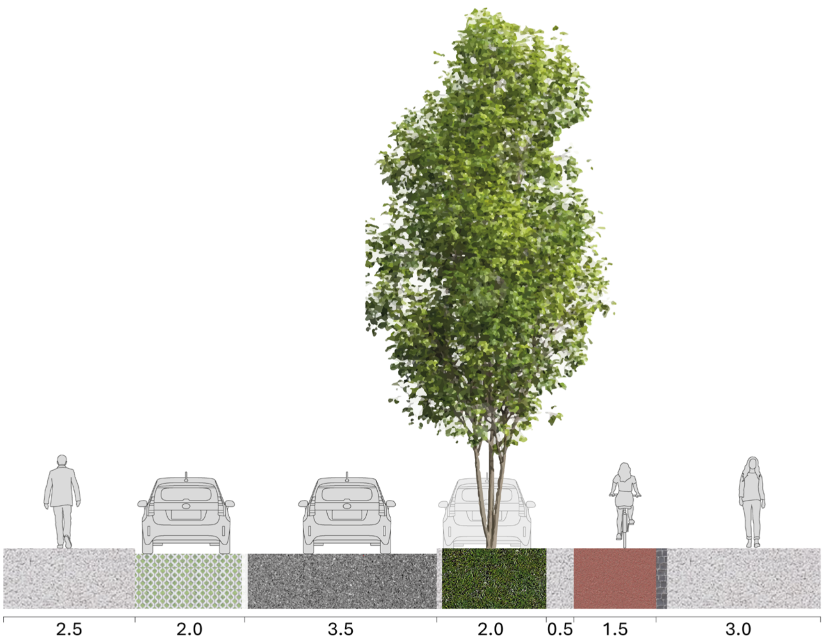
7.1.2. Simulation scenario PH

Section 1

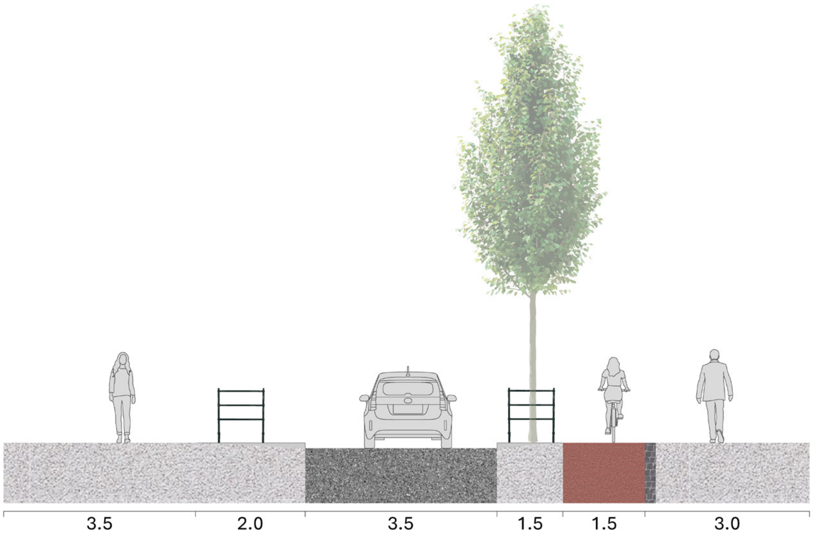
Section 2



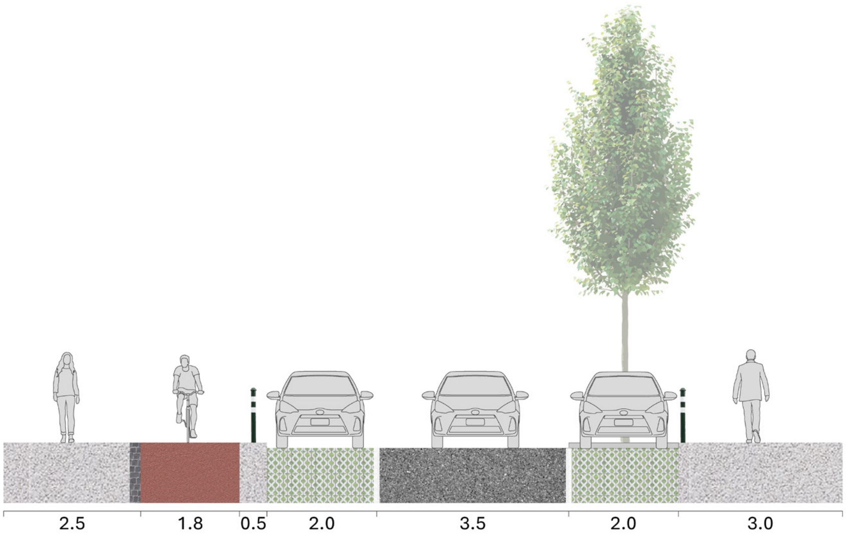
Section 3



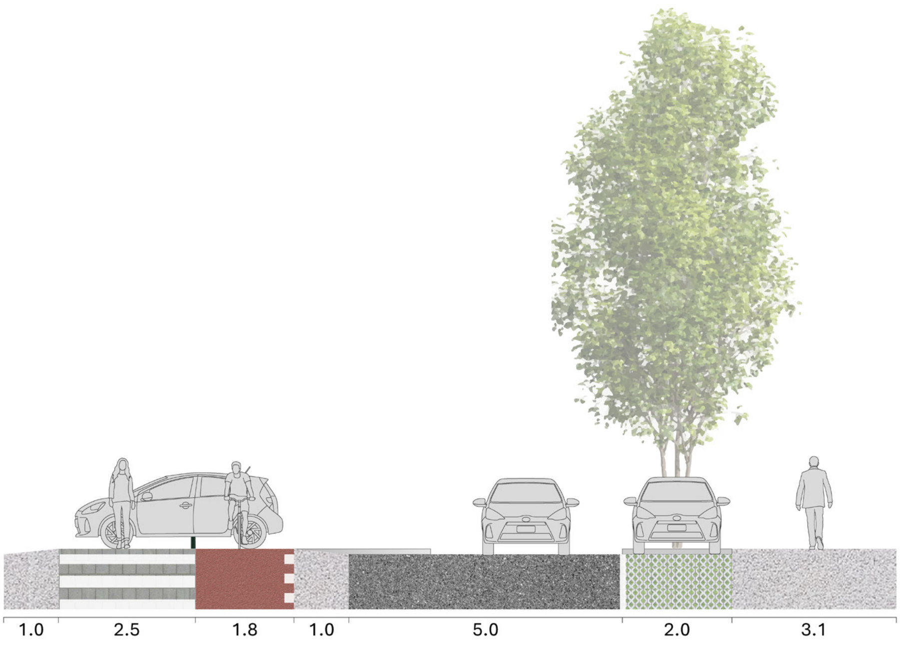
Section 4



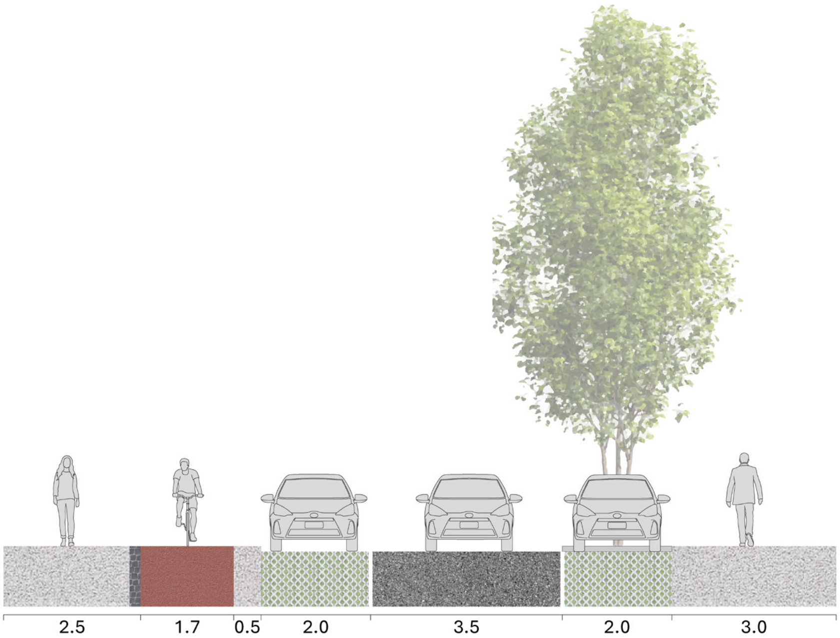
Section 5



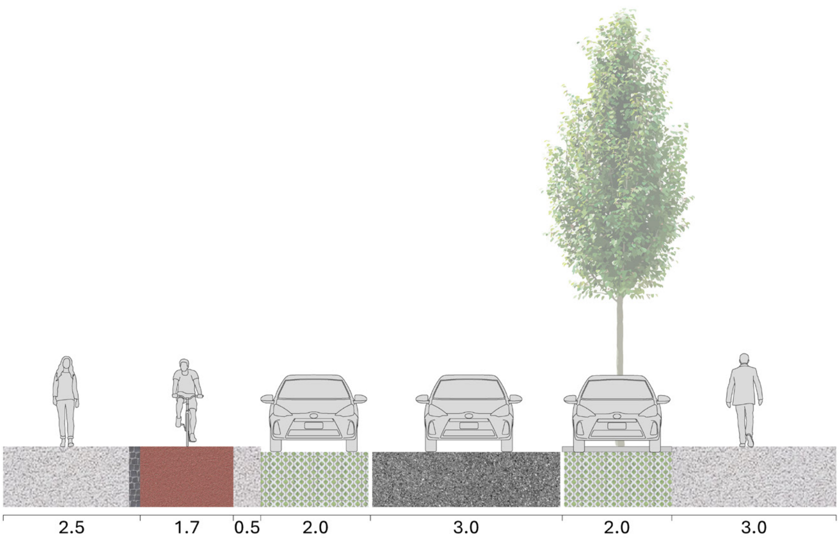
Section 6



Section 7



Section 8



Section 9

Single variable analysis

The results of the simulation for this scenario are mainly impacted by the lower size of the trees along via Asinari di Bernezzo. The shading pattern is therefore different from the other scenario. While no changes can be observed along via Carrera and via Capelli, a reduction in the effect of shading can be observed along via Asinari di Bernezzo. These trees belong to the third category, and they were set in the model as 5 m high. Although further detail in the choice of the species and the dimensioning could be added, this shows the relevance of the size of the trees in the contribution to shading and, therefore, to thermal comfort. Differently than the higher trees, which allow an almost continuous shading of the northern sidewalks, the smaller trees only provide a punctual effect.

The difference of size of the trees, through the impact on shading, affects the surface temperatures. The maps referred to this scenario show clearly the difference between the two axes, via Carrera with higher trees and via Asinari di Bernezzo with lower trees. However, the minimum impact on shading caused by the lower trees allows to observe more precisely the difference provoked by the materials, since, for example, pedestrian aeras appear cooler than the vehicular asphalt lane. Despite the low effect caused by trees, moreover, the green areas contribute to a reduction in surface temperature.

The difference between the streets is also evident by comparing the maps of scenario 2 and 3 referred to potential air temperature. Potential air temperature can be related to vegetation, since smaller trees have a limited evapotranspiration effect and contribute less to blocking direct solar radiation.

A similar distribution can be obersved for relative humidity, with higher values along via Carrera compared to via Asinari di Bernezzo. As mentioned, this might be the result of the lower presence of vegetation.

Comparing the wind speed and direction maps, few differences can be observed between the scenarios. At the height considered, therefore, it can be hypothesised that the different size of trees has a low impact on ventilation.

Comparing the PET cartography, the main difference between the scenarios is related to shading, with higher values of PET for the third scenario along via Asinari di Bernezzo. While it was mentioned that the third scenario allows to observe more clearly the impact of the different materials on surface temperature, the same cannot be said regarding the PET, since the difference between the sidewalks and the asphalt street cannot be clearly distinguished.

Hourly analysis

07:00. The radiation is different on the two streets. On via Carrera, the parallel shadows mostly cover the green areas and the parking stalls, however, the northern sidewalks are also shaded by the trees. The southern sidewalks are not shaded. Along via Asinari di Bernezzo, the only shaded portions of sidewalks are the one on the southern side between via Exilles and via Capelli, and the one on the northern side between via Capelli and via Salbertrand, due to the orientation of the street. On the northern side, the trees have an impact, but it is very limited. The portion of via Capelli facing the elementary school is completely shaded by the eastern buildings. As a result, the difference between the axes is evident by comparing surface temperatures. Along via Carrera, the temperatures mostly range between 24° and 26°: low values (23°) are observed on the green surfaces and on the sidewalk extension in front of the kindergarten, composed by a high-albedo material. The importance of shading is confirmed by the higher temperatures verified in correspondence with bus stops (up to 34°), which interrupt the tree line. Along via Asinari di Bernezzo, the temperatures are higher. The asphalt surfaces have a temperature varying around 34°, while in the previous scenarios the temperature was varying around 26°.The radiated sidewalks show temperatures between 26° and 28°, and in some cases higher than 30°, instead of 22° to 24° in the previous case. The difference between the materials is clearly visible, as well as the effect of green areas. Due to the combined effect of the materials, green areas and the shading of the buildings, the temperatures are low on the square facing the church (21° to 25°). Despite the limited effect of the design measures along via Asinari di Bernezzo, the temperatures are still lower than the current state. Potential air temperature on via Carrera ranges between 28° and 29° with lower values especially on the southern side, similarly to the previous scenario. Values between 29° and 30° are observed along via Asinari di Bernezzo, especially on the central portion of the street. This constitutes a slight increase compared to the previous scenario, where the temperatures were ranging between 28° and 29°. A reduction in humidity is also observed on via Asinari di Bernezzo, with a decrease in some cases of 4 percentage points. The differences in the PET index are mostly evident on via Asinari di Bernezzo. While the surfaces shaded by the buildings show values between 31° and 34°, similarly to the ones of the previous scenario, the unshaded areas correspond to values between 43° and 45°. The shadows of the trees reduce the values, but they have a limited impact on pedestrian areas. The most comfortable areas are the ones shaded by the buildings, including the southern part of the square facing the church.

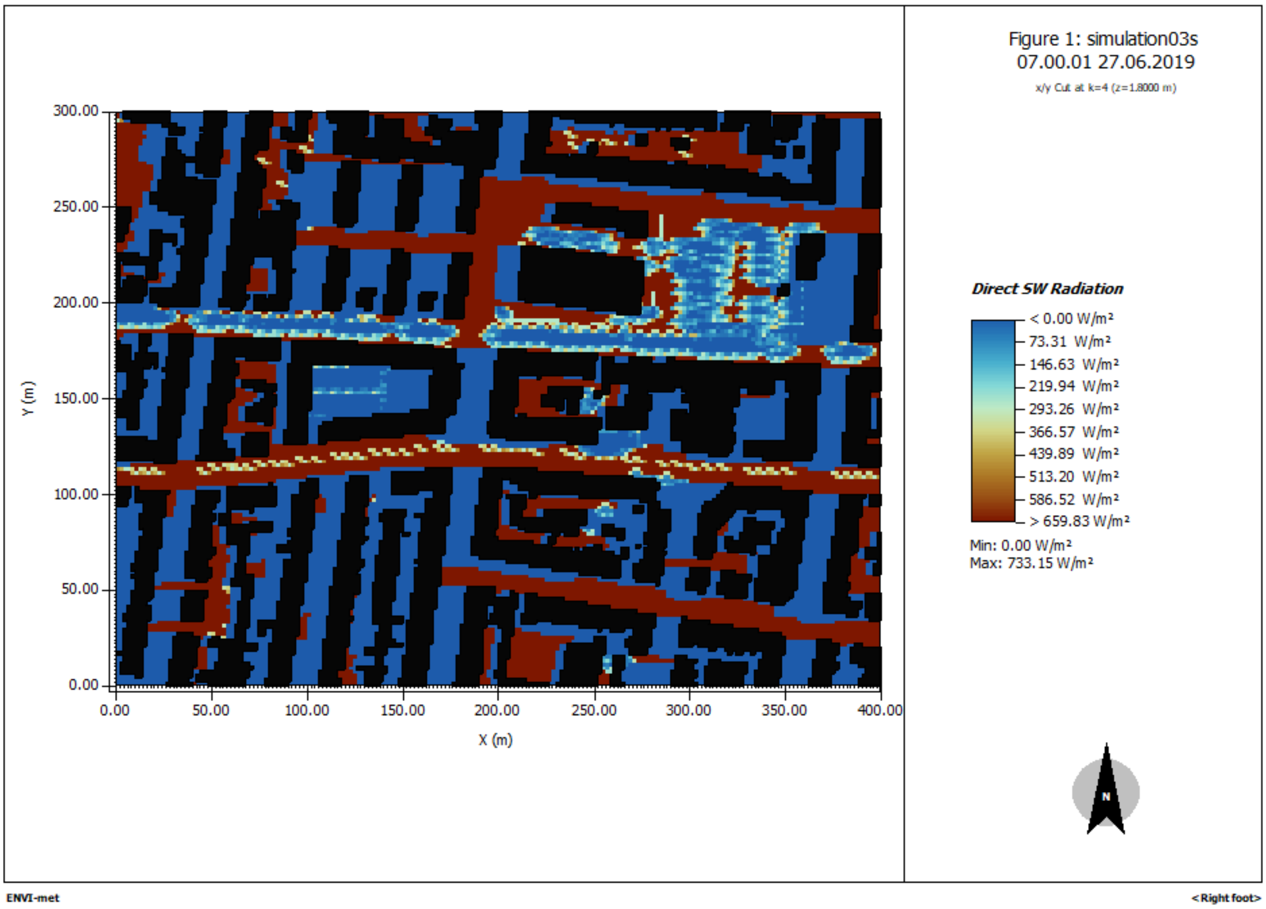


Figure 100. Direct radiation, scenario PH, 07:00

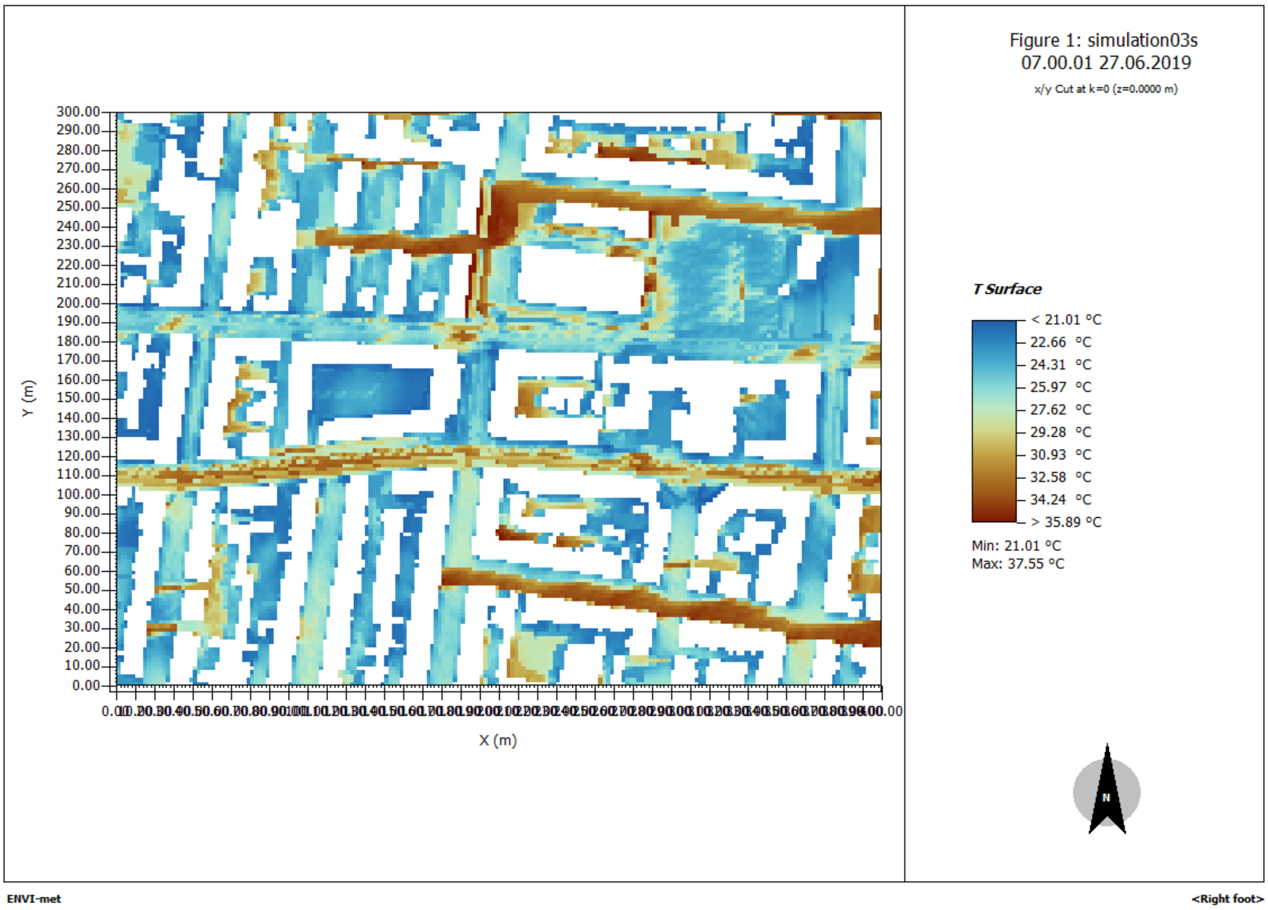


Figure 101. Surface temperature, scenario PH, 07:00

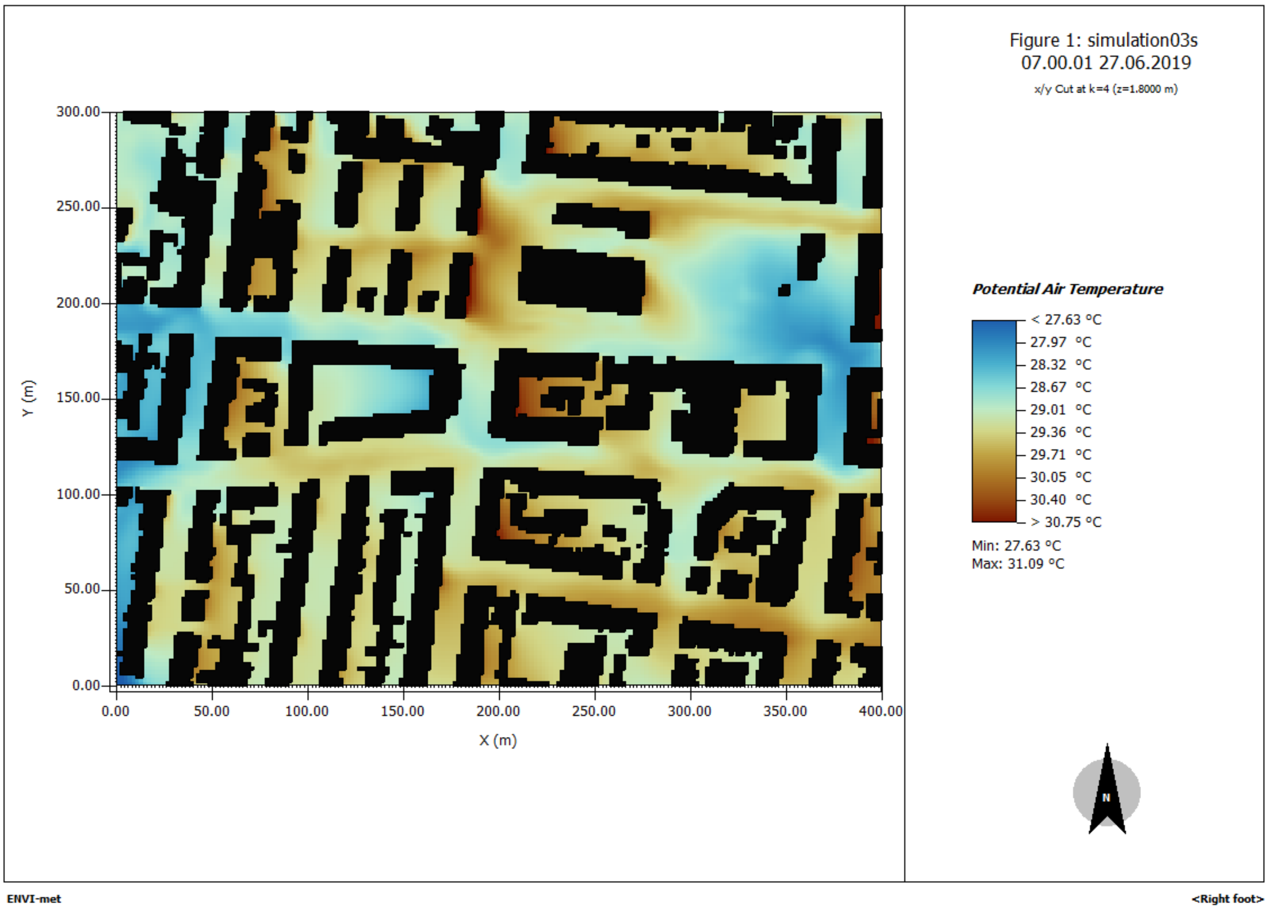


Figure 102. Potential air temperature, scenario PH, 07:00

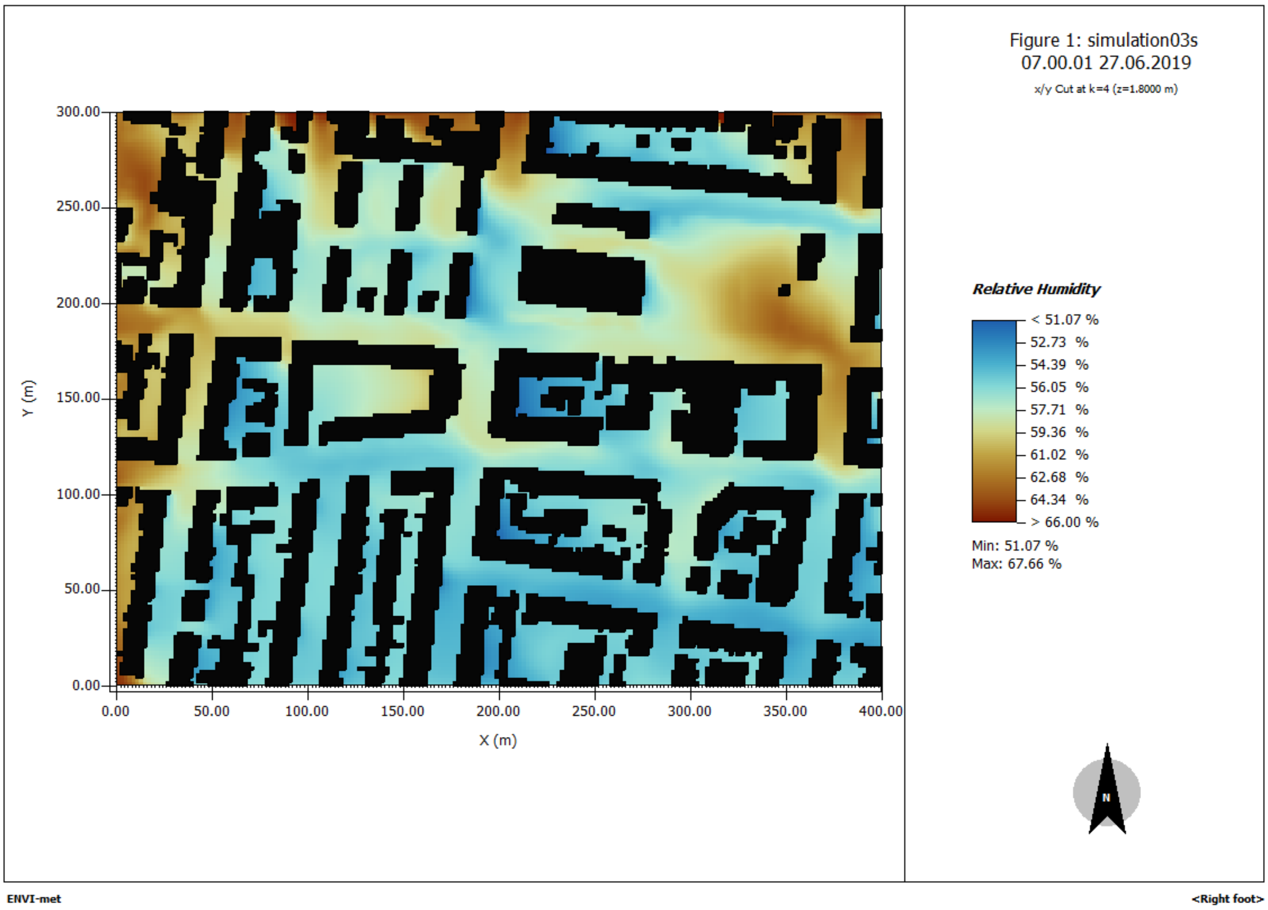


Figure 103. Relative humidity, scenario PH, 07:00

Figure 104. Wind speed and direction, scenario PH, 07:00

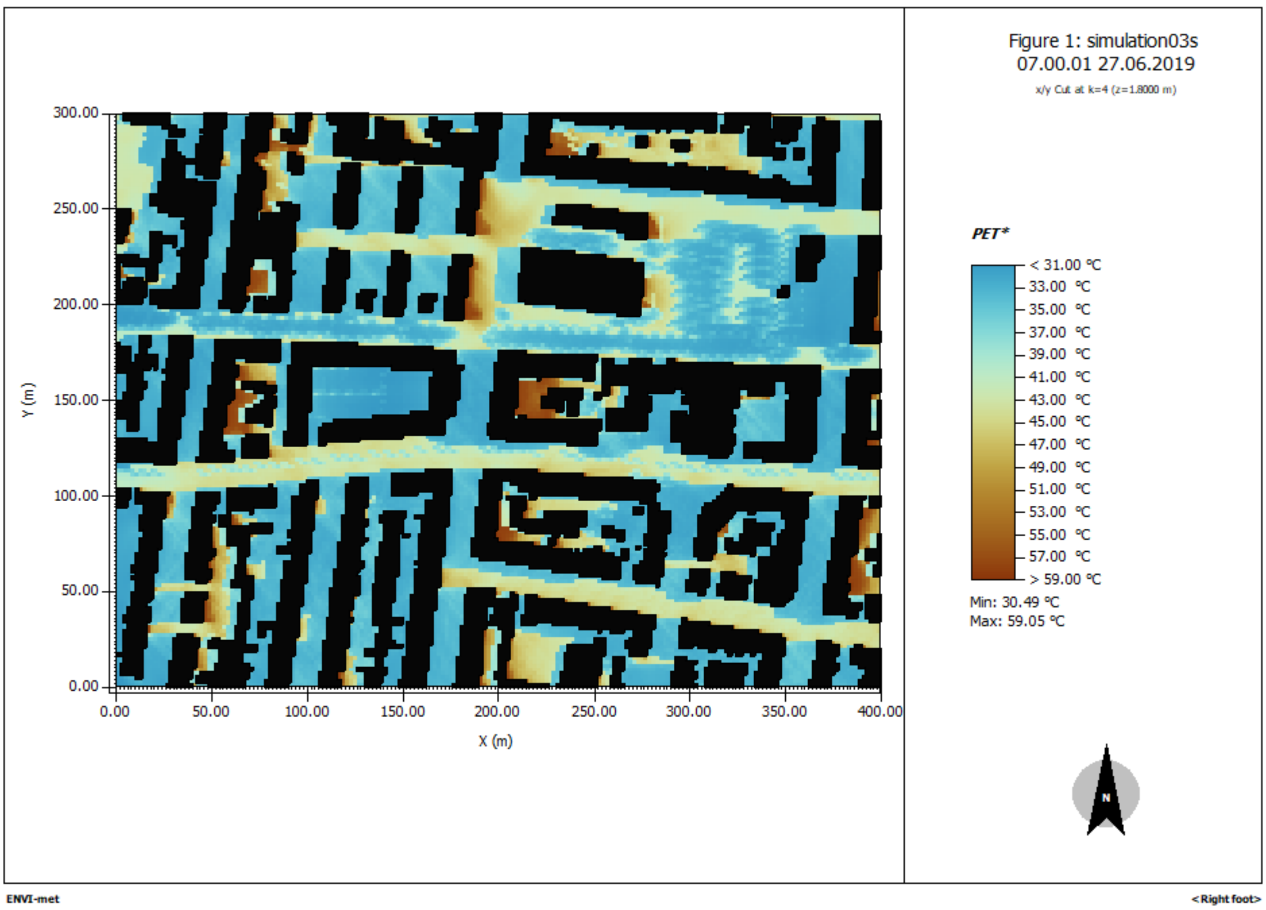


Figure 105. PET, scenario PH, 07:00

12:00. While the shading on via Carrera is similar to the one of the previous scenario, with the southern sidewalks shaded by the buildings and the northern ones shaded by the trees, the difference is highlighted along via Asinari di Bernezzo. Similar observations to the ones referred to 07:00 can be made, although in this case the southern sidewalks are shaded by the buildings, while the northern ones are mostly radiated. The pedestrian and green area of the square facing the church is mostly shaded. Similarly, regarding surface temperatures, a similar situation can be observed for via Carrera, while higher values are registered along via Asinari di Bernezzo. Shaded surfaces show values between 31° and 35°. The asphalt surfaces show values ranging between 50° and 55°, while lower temperatures are registered for the higher albedo surfaces. The main difference is highlighted between asphalt and higher-albedo materials, but it is difficult to perceive the difference between granit, coloured asphalt, and concrete. This allows to confirm that the difference in materials contributes to the reduction of surface temperatures, but shading constitutes a more important factor. The difference in size of trees has an limited effect on potential air temperature, as it can be observed by comparing the two transformative scenarios on via Asinari di Bernezzo. On the portion between via Capelli and via Mogadiscio, a warm area is created, reaching 37°. A decrease of humidity can be noticed, similar to the one observed at 07:00. As a result, the values of PET are higher along via Asinari di Bernezzo. The areas shaded by the buildings are the ones showing the lowest values, between 41° and 43°. The square facing the church, where larger trees are introduced, shows values between 40° and 46°. Higher values are observed on the northern sidewalks, mostly between 54° and 56°. This shows how the previous scenarios was more suitable in order to improve thermal comfort, thanks to the shading provoked by the plantings.

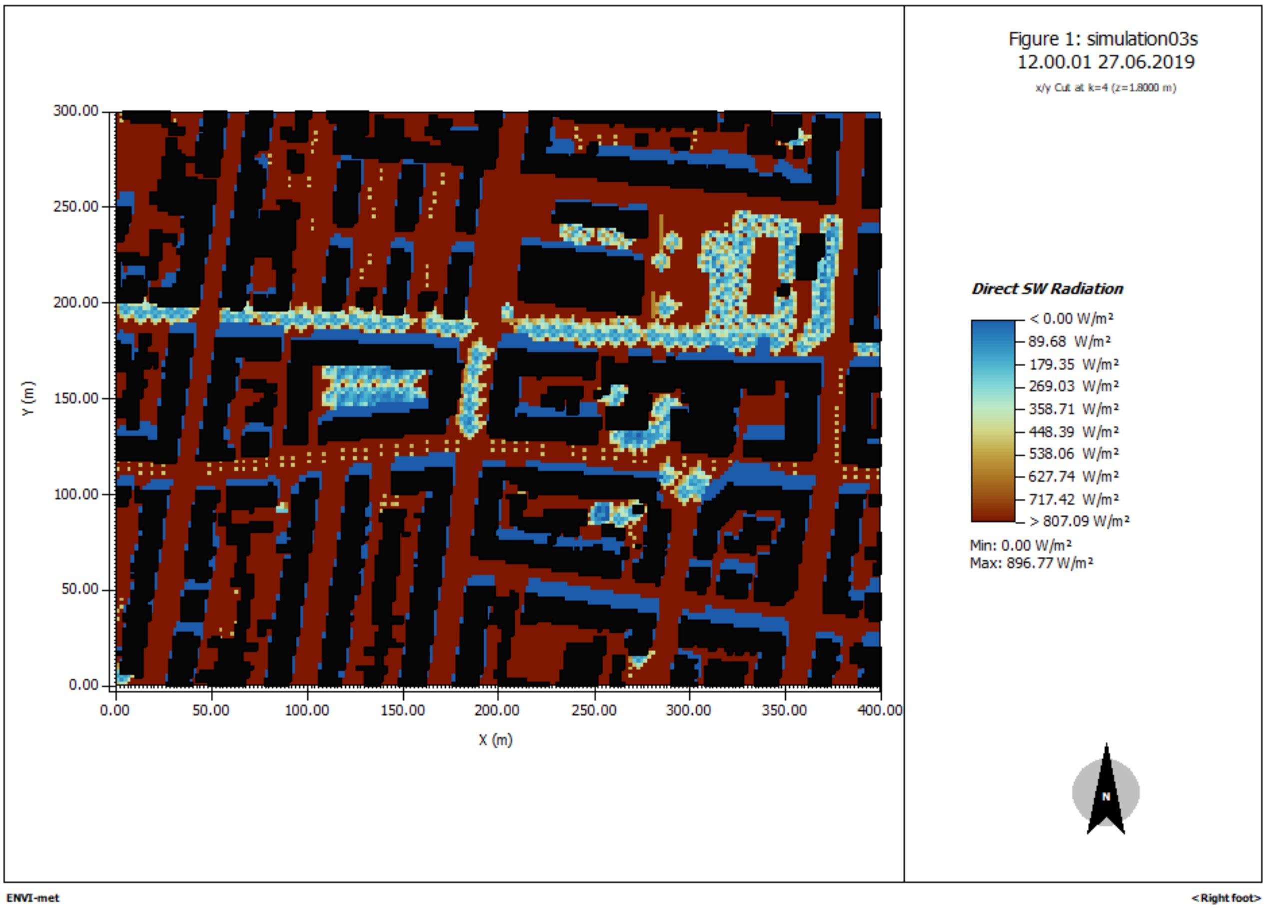


Figure 106. Direct radiation, scenario PH, 12:00

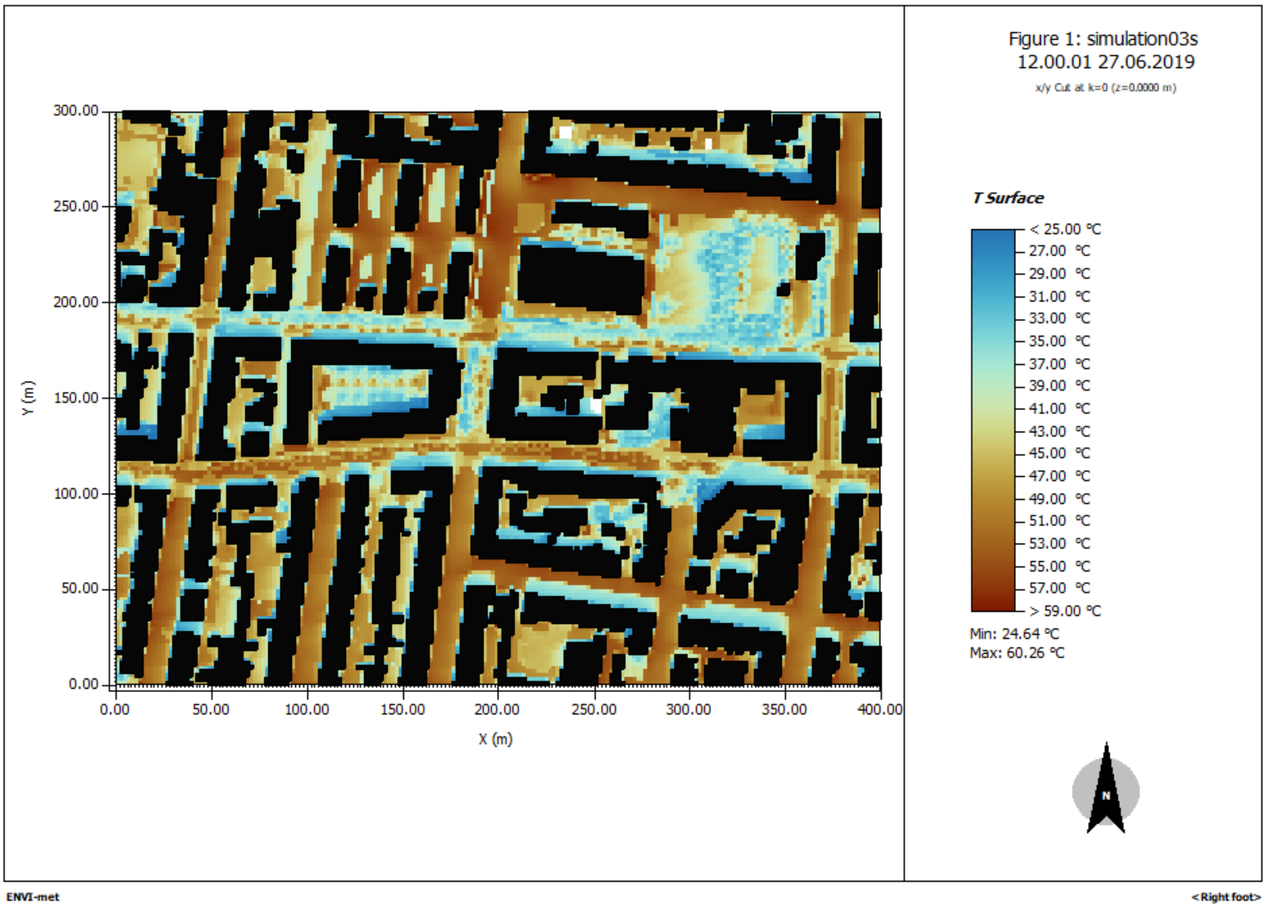


Figure 107. Surface temperature, scenario PH, 12:00

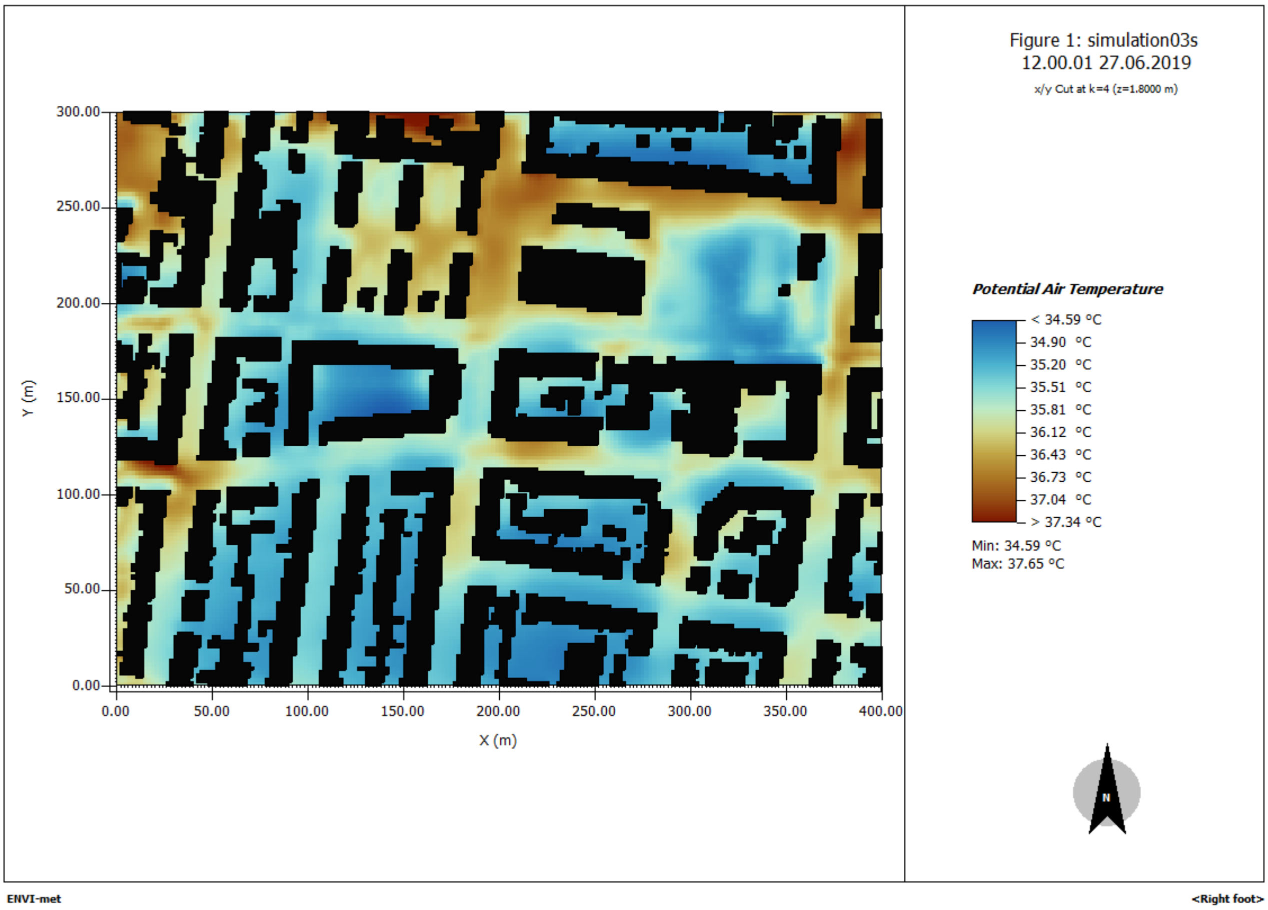


Figure 108. Potential air temperature, scenario PH, 12:00

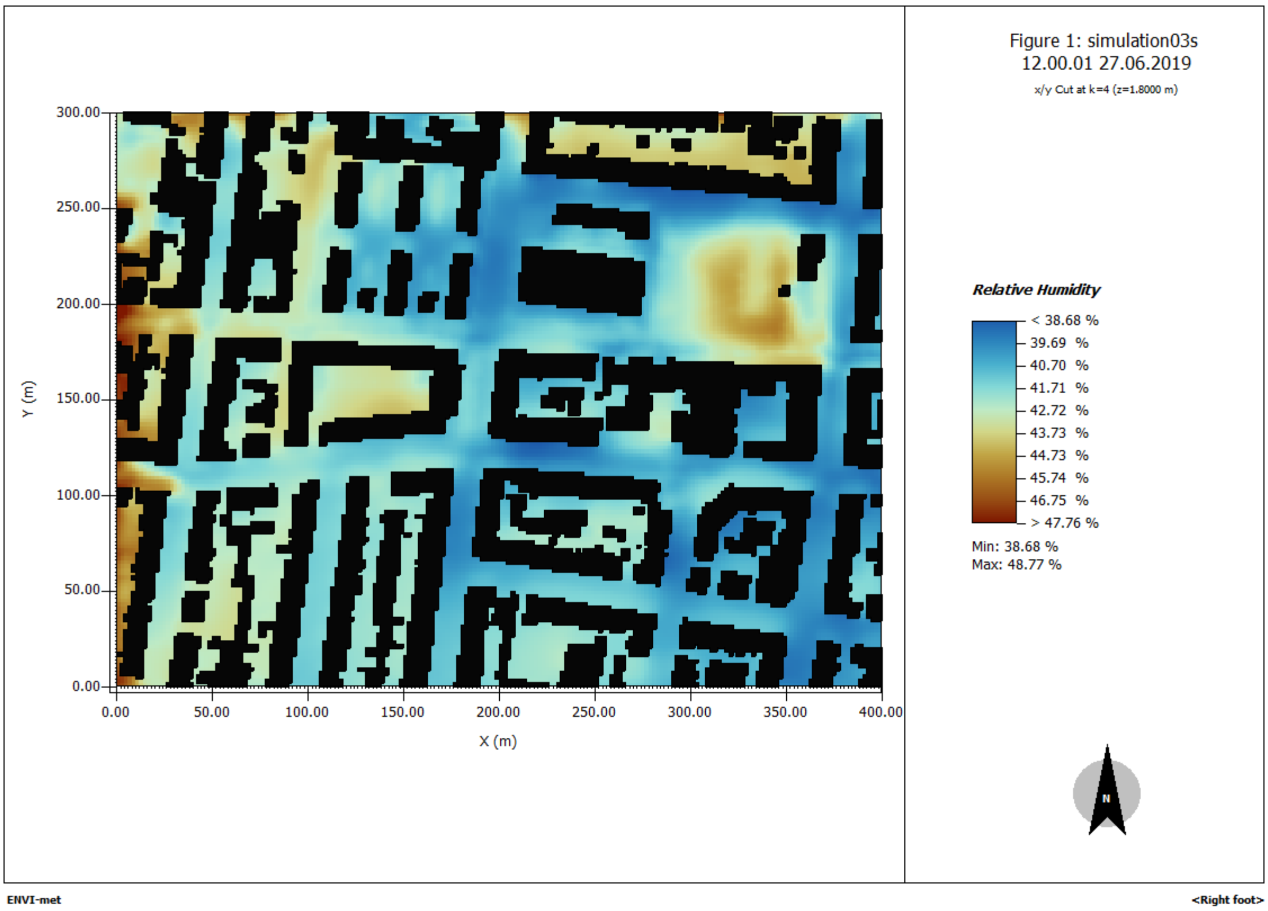


Figure 109 Relative humidity, scenario PH, 12:00

Figure 110. Wind speed and direction, scenario PH, 12:00

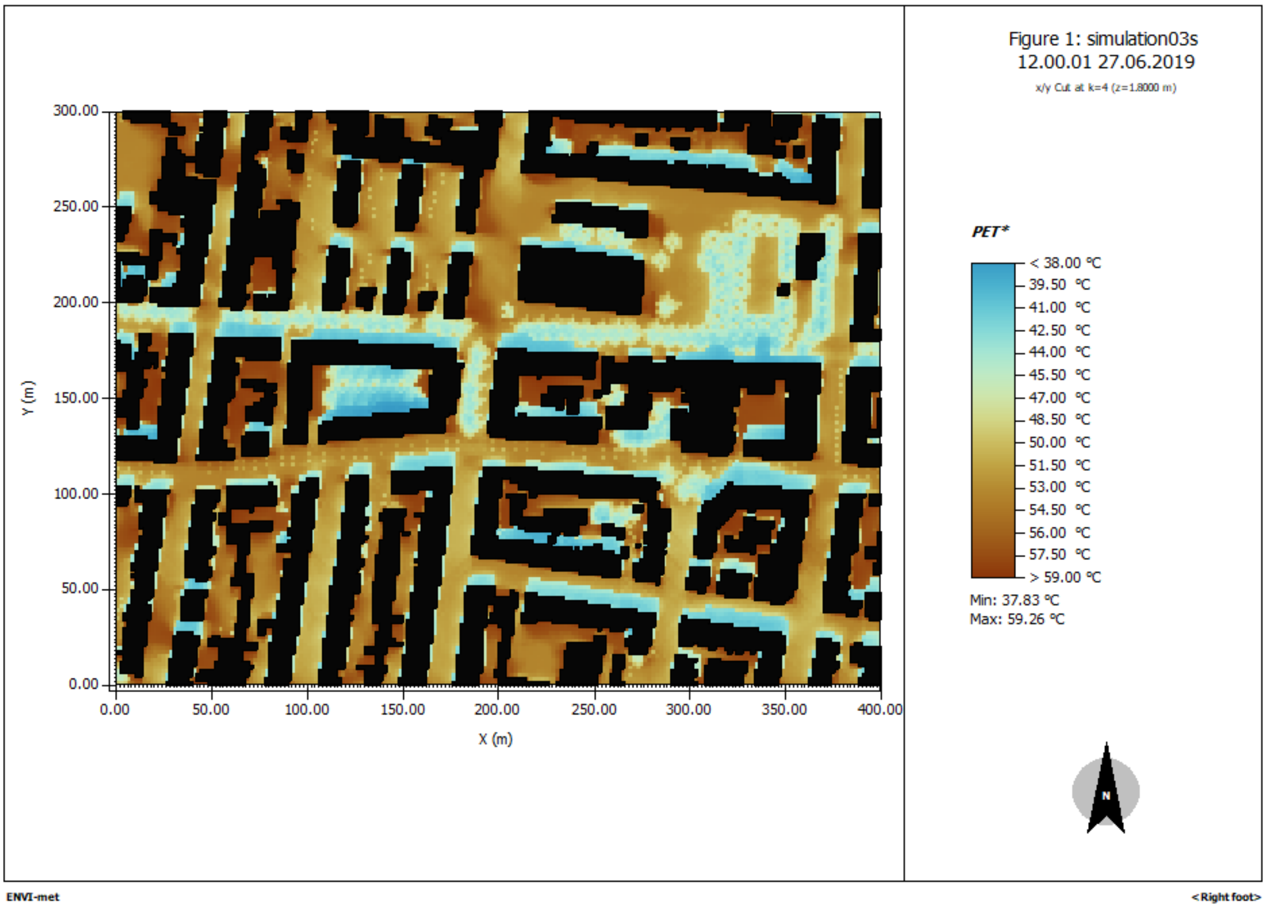


Figure 111. PET, scenario PH, 12:00

15:00. The direct radiation distribution is similar to the one of 12:00. The shadows of the trees of via Asinari di Bernezzo are slightly longer, meaning that they partially cover the northern sidewalks, although their effect is limited. A more important shading effect is provided by the western buildings and the larger trees in front of the church. The western portion of via Capelli is shaded by the school, while the eastern part is shaded by the trees. Similar observations to the previous scenarios can be done for via Carrera regarding surface temperature. As in the other timeslots, the surface temperatures of via Asinari di Bernezzo are higher compared to the previous scenario. The high albedo surfaces show temperatures ranging between 39° and 43°, while the asphalt area shows values higher than 47°. On the square facing the church, lower temperatures are observed for the high albedo materials (between 30° and 36°) compared to the green surfaces. Along via Asinari di Bernezzo, a slight increase in potential air temperature is observed, corresponding to about 1°, compared to the previous scenario. A reduction in humidity is linked with the reduction of vegetation, as it can be observed on the northern side of via Asinari di Bernezzo. As in the other cases, the PET is influenced especially by shading, thus the effect of the project on via Asinari di Bernezzo is limited, while the situation on via Carrera is similar to the previous scenario. Due to the smaller size of the trees, the PET along via Carrera is similar to one of the current state, ranging between 53° and 54°. Better conditions are provided by the planting on the critical area at the intersection with via Mogadiscio.

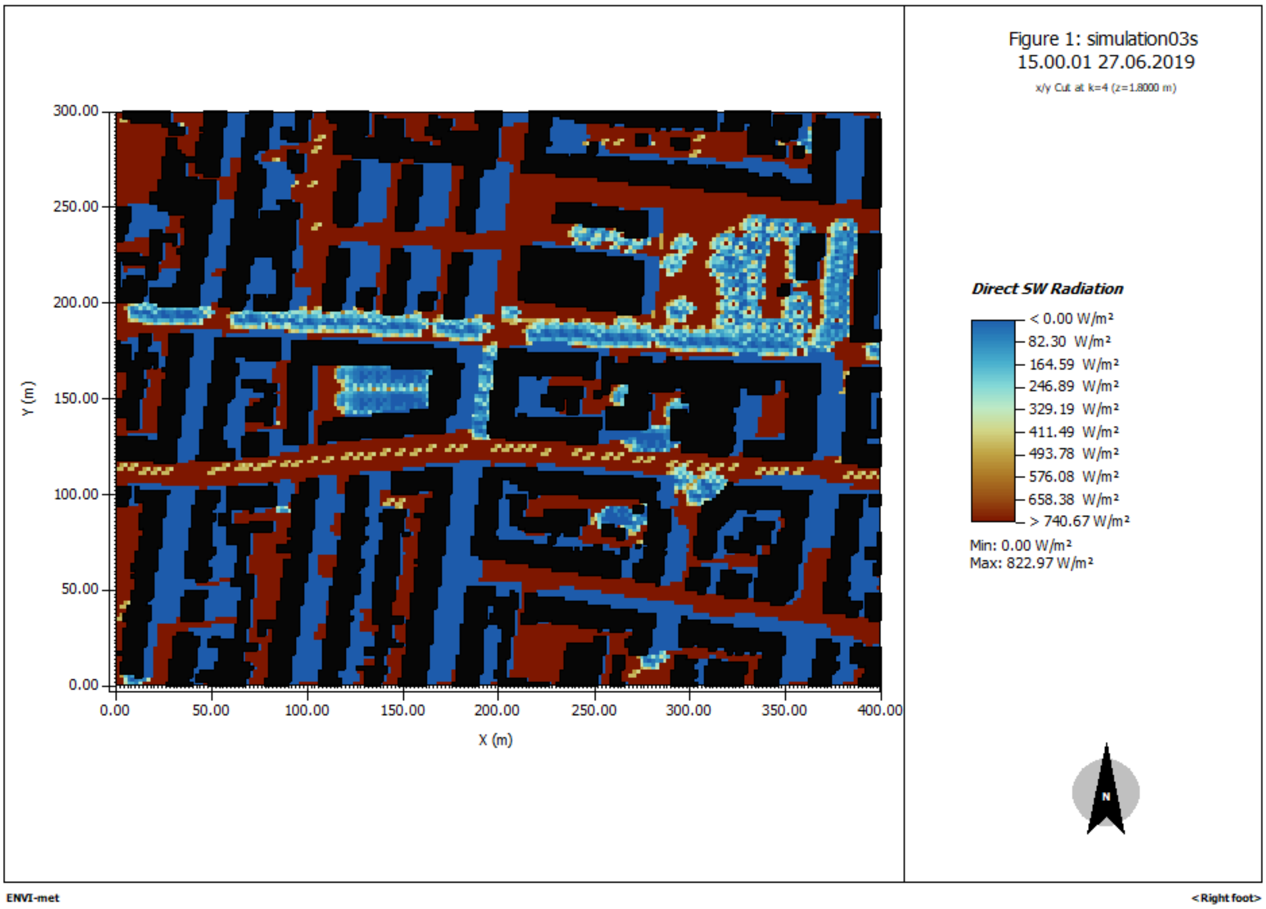


Figure 112. Direct radiation, scenario PH, 15:00

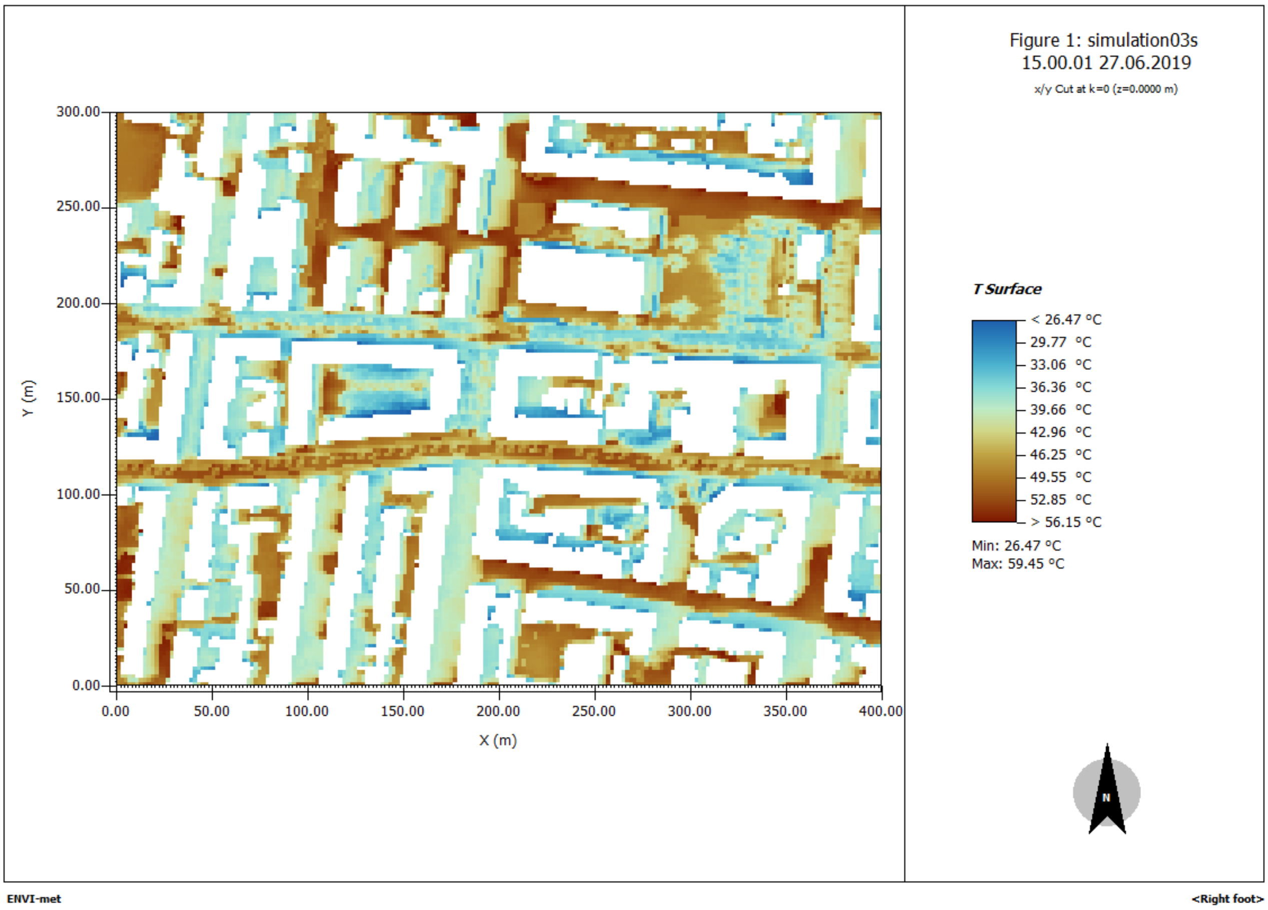


Figure 113. Surface temperature, scenario PH, 15:00

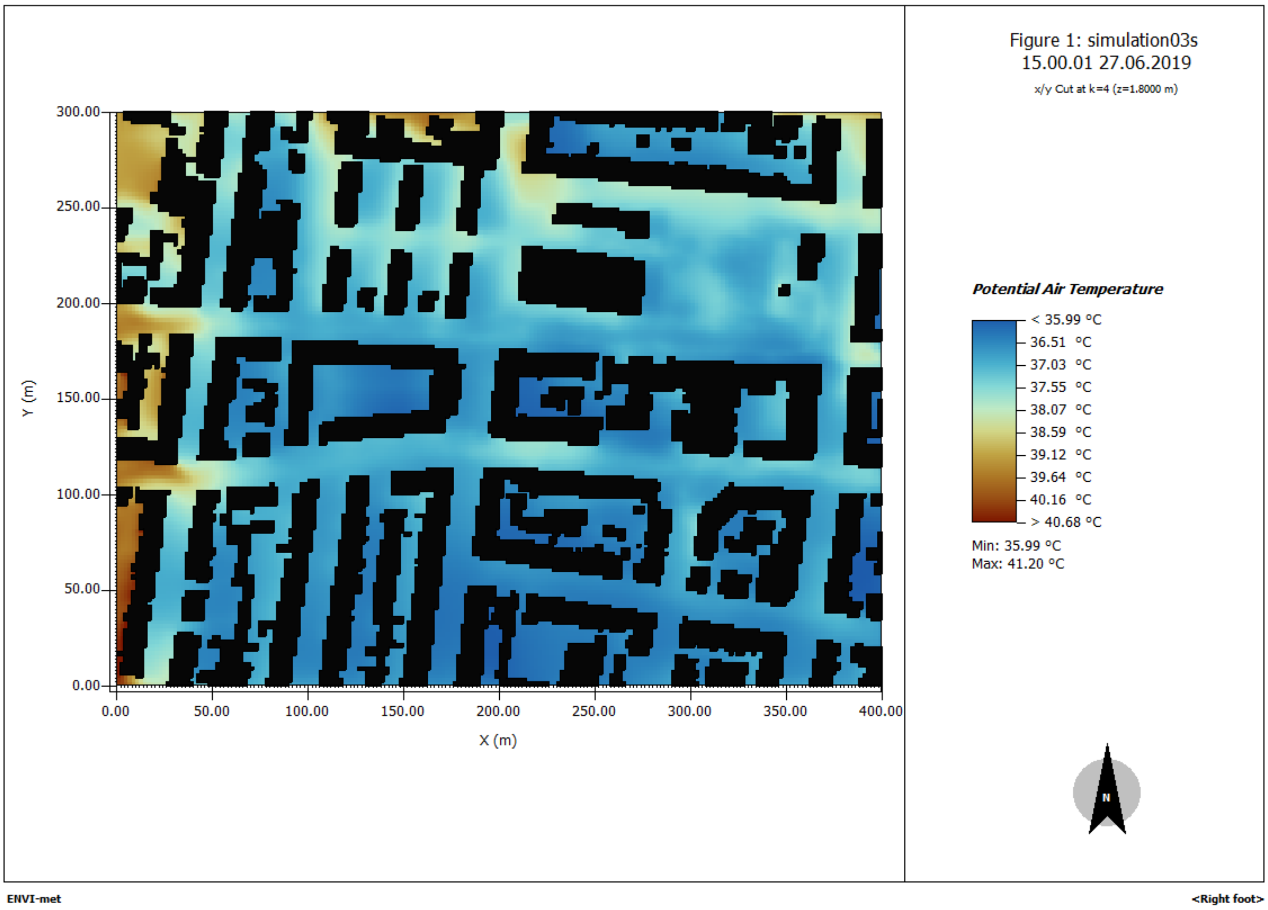


Figure 114. Potential air temperature, scenario PH, 15:00

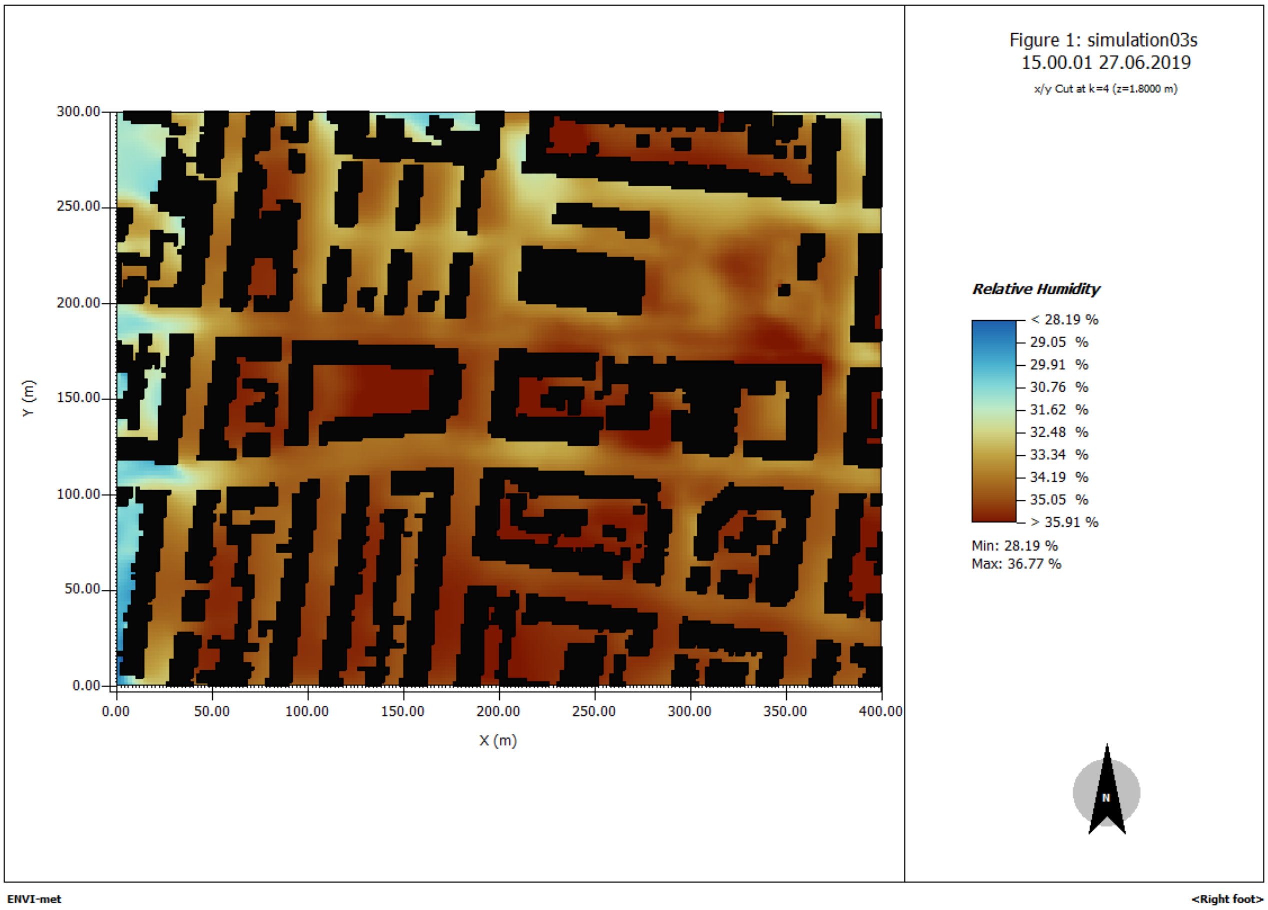


Figure 115. Relative humidity, scenario PH, 15:00

Figure 116. Wind speed and direction, scenario PH, 15:00

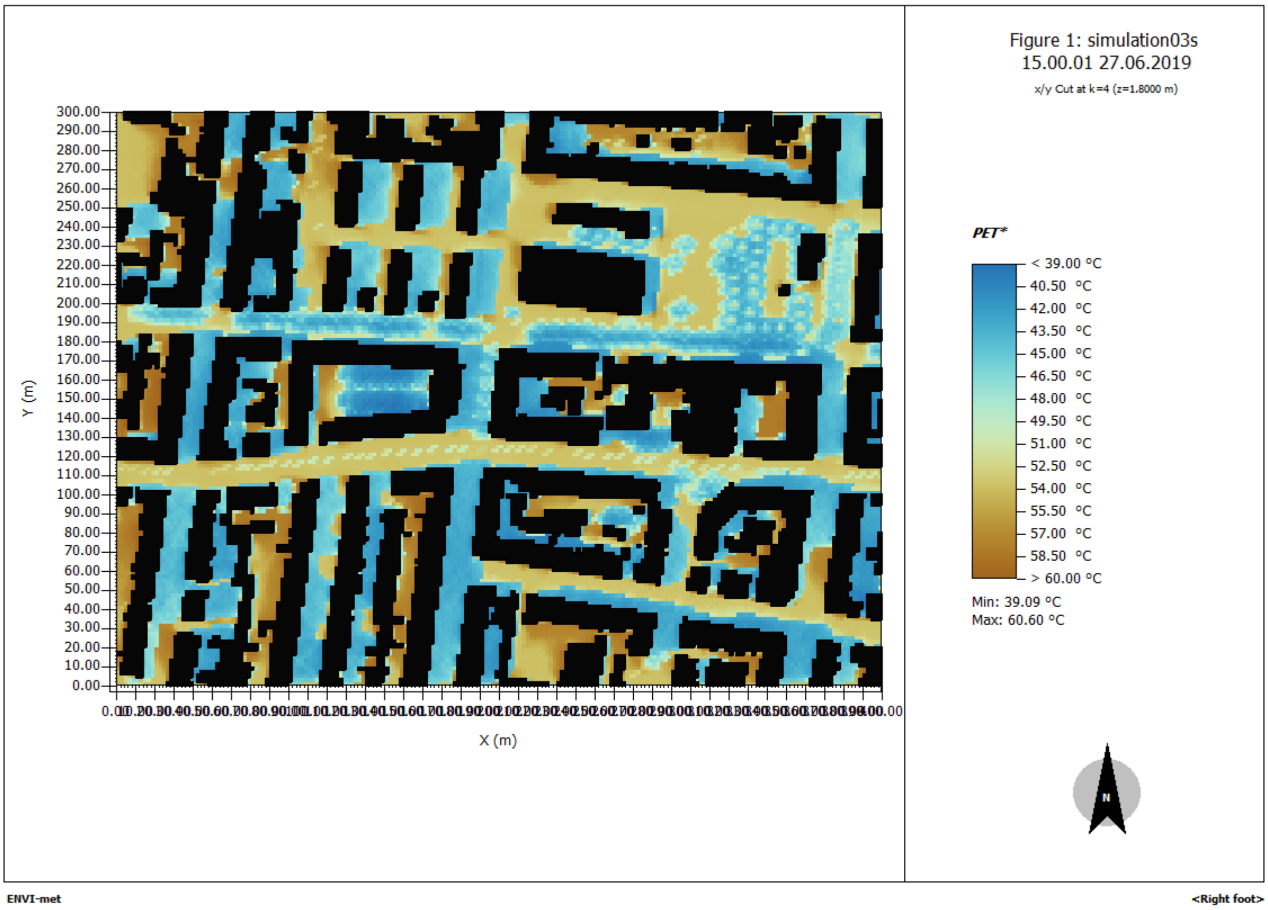


Figure 117. PET, scenario PH, 15:00

18:00. At this time, the conditions of radiation are similar for both axes, as well as for both scenarios, since the area is almost completely shaded. However, the difference in surface temperatures is persistent, possibly because of the heat gained by the surfaces during the previous hours. At 18:00, while along via Carrera the surfaces are around 34°, along via Asinari di Bernezzo these values are observed mostly along the southern sidewalks. Values between 35° and 38° are observed on the remaining portions of the street, with higher peaks to 40° on the asphalt surfaces. A more homogeneous distribution of the values was observed in the previous scenarios, with lower temperatures along the sidewalks. Despite the lack of radiation, the effect of the vegetation is observed by the extended higher temperatures along via Asinari di Bernezzo, although the difference is of about 1°. Similarly, the values of humidity are lower. Given the lack of direct radiation, the PET values referred to this scenario are similar to the ones referred to the previous one, ranging between 37° and 39°, with slightly higher values along via Asinari di Bernezzo. This confirms the prevalence of direct radiation on the contributing parameters to PET and the importance of shading as a tool to improve thermal comfort, although factors such as surface temperature, air temperature and humidity might have an importance, even if it is minor.

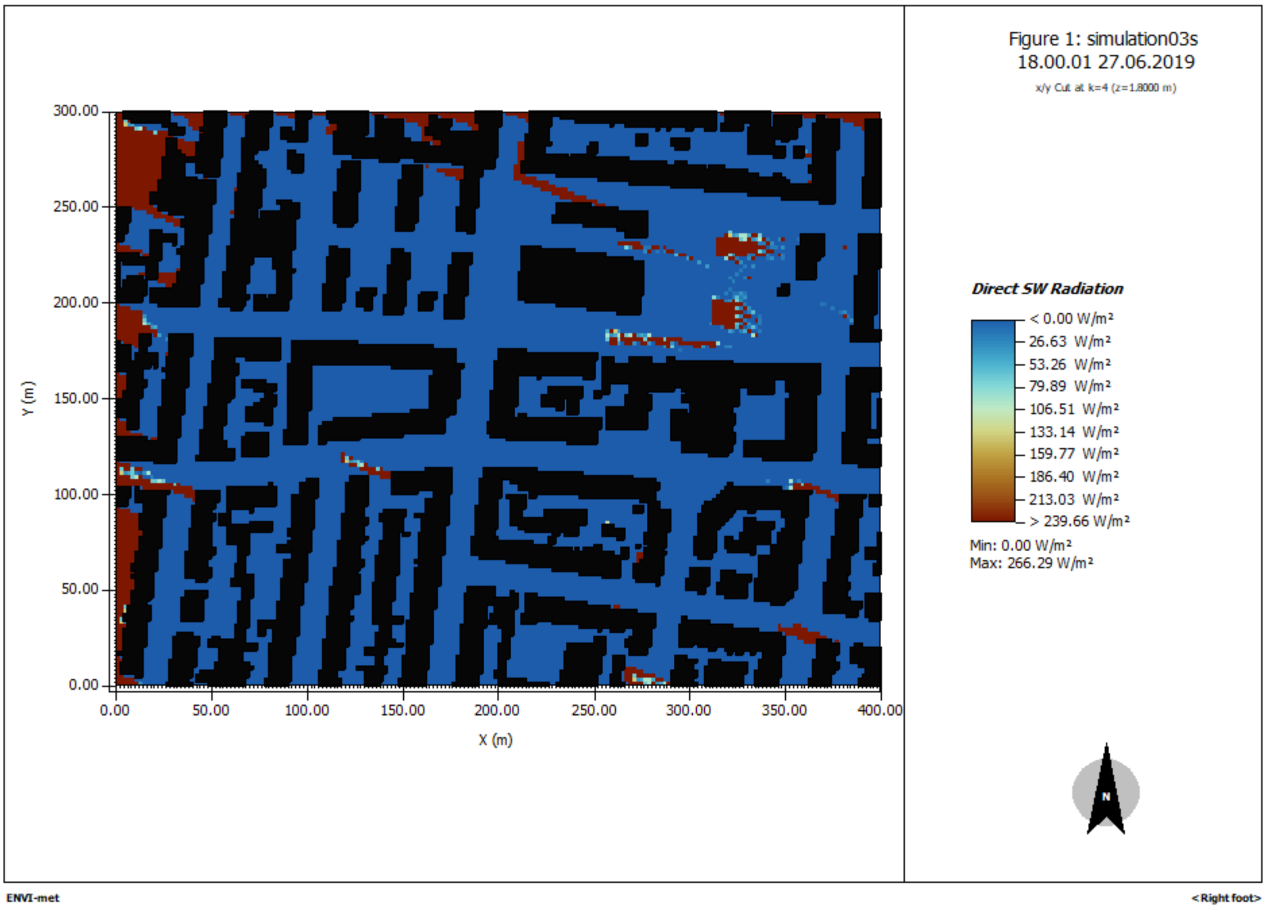


Figure 118. Direct radiation, scenario PH, 18:00

Figure 119. Surface temperature, scenario PH, 18:00

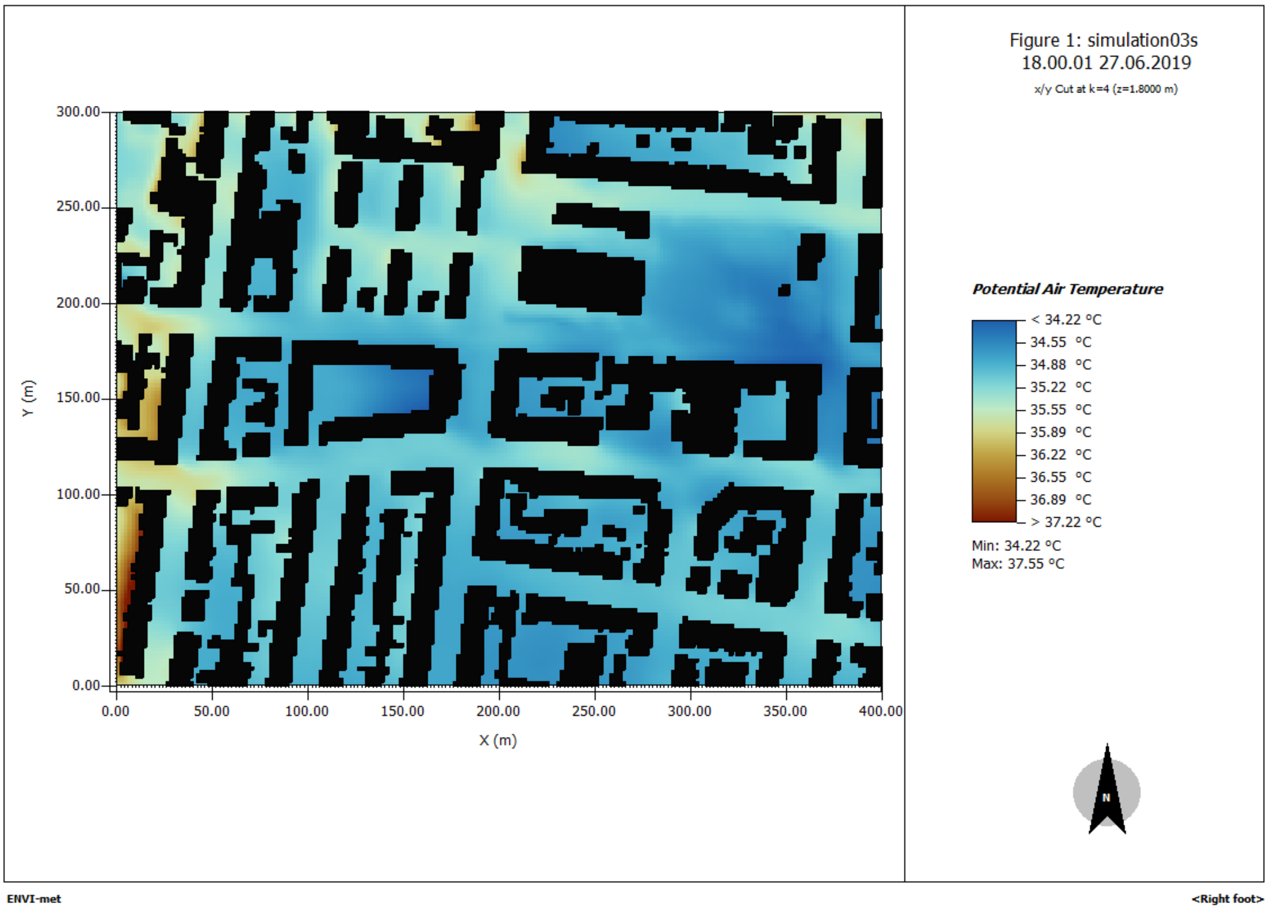


Figure 120. Potential air temperature, scenario PH, 18:00

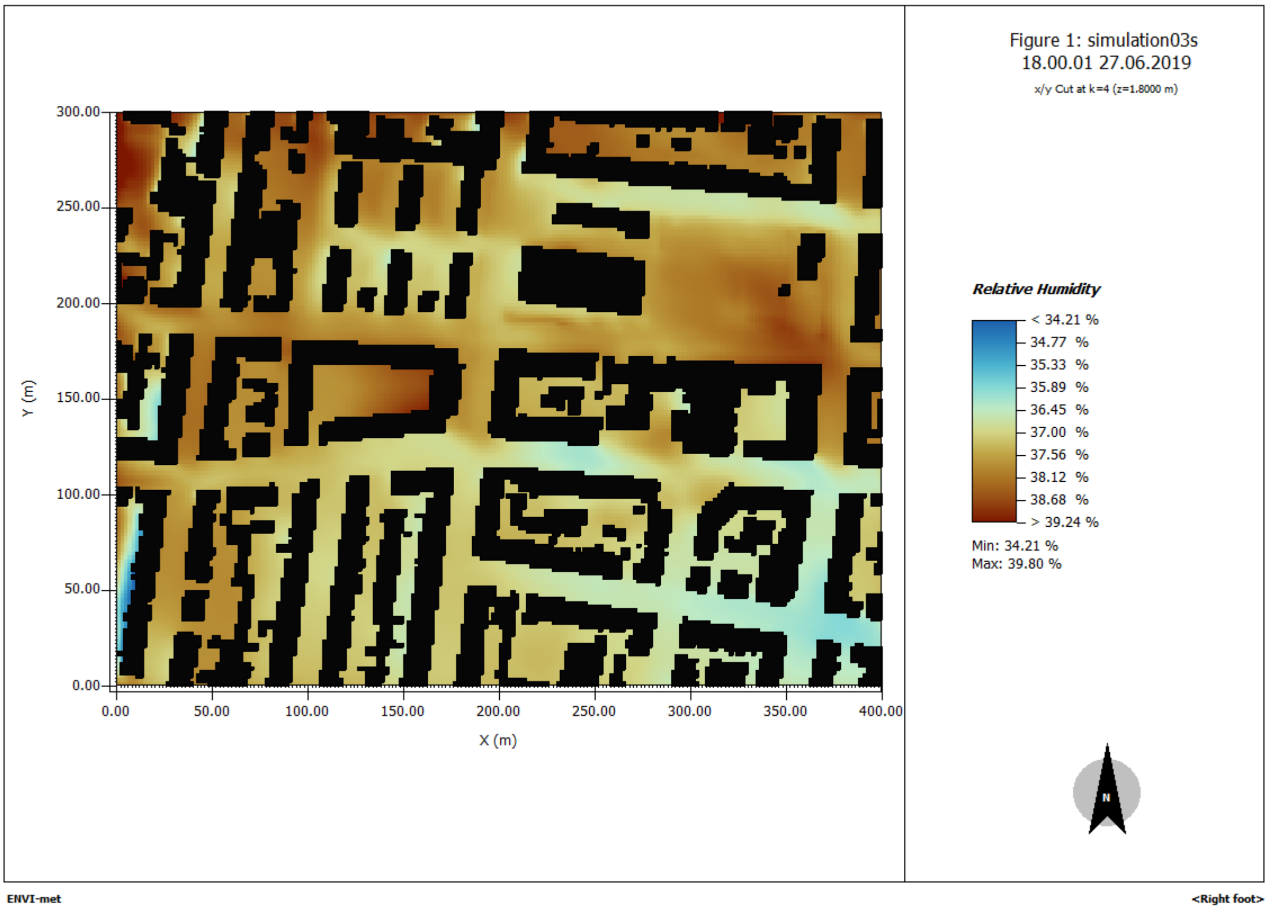


Figure 121. Relative humidity, scenario PH, 18:00

Figure 122. Wind speed and direction, scenario PH, 18:00

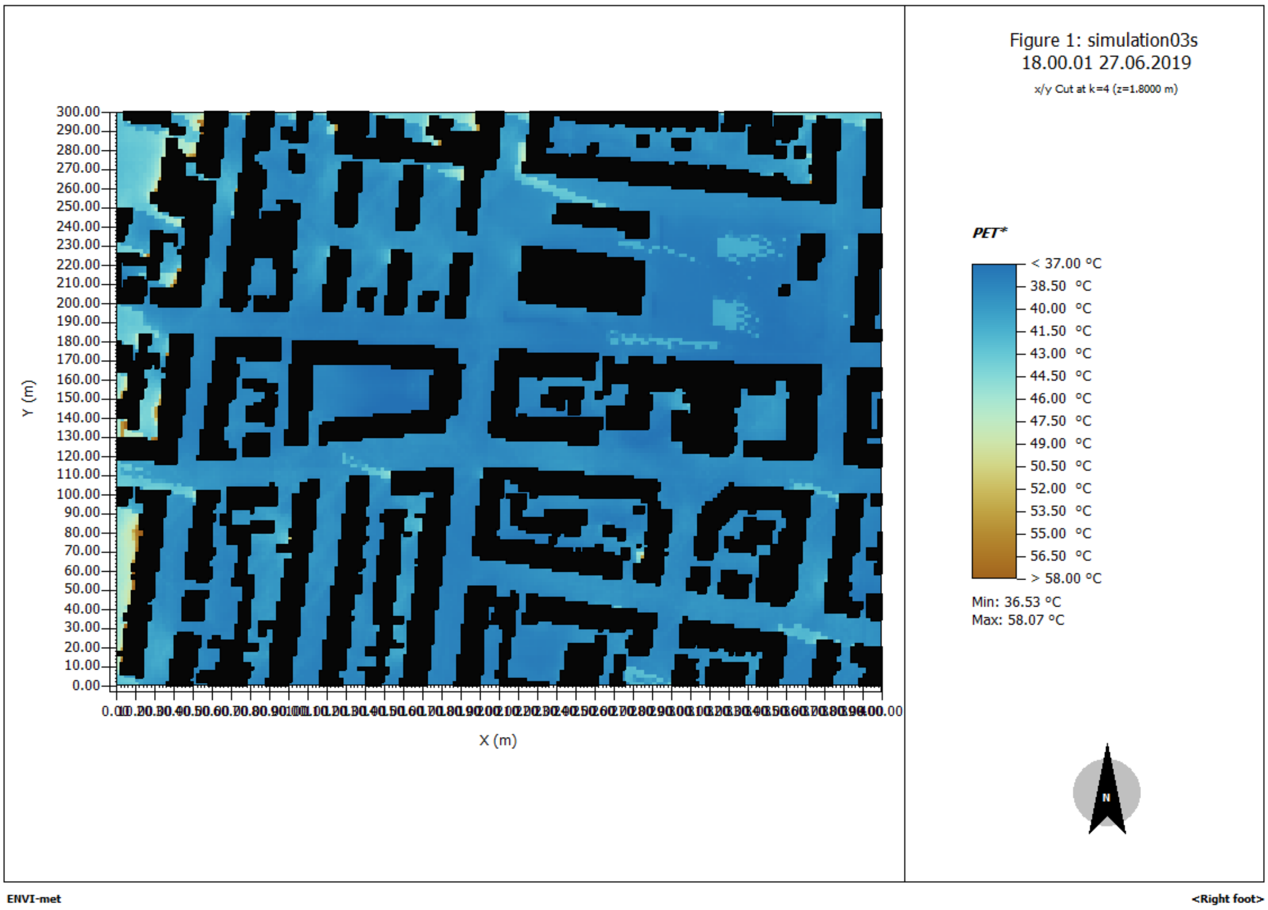


Figure 123. PET, scenario PH, 18:00

7.2. Evaluation of the effects of the proposal in terms of improvement of pedestrian comfort

The comparison of the results of the simulation allowed to observe the effect of the measures introduced with the project, by focusing on two different scenarios, the first one prioritising green spaces in order to allow the planting of trees belonging to the second category (10 m to 15 m high), the second one prioritising parking stalls, by maintaining measures for thermal comfort, and trees belonging to the third category (5 m to 10 m high).

As introduced by the literature framework, the main tool for the improvement of thermal comfort is shading. In all cases, it was evident how direct solar radiation has a strong impact on the PET, as well as highly influencing surface temperatures, and to a lower extent air temperature. The shadow produced by the buildings resulted to be the most effective, while the one provided by trees is less homogeneous and less impacting on temperature reduction, although relevant on thermal comfort conditions. The actions of the project focused on modifying the conditions on the northern side of the streets, since the southern side is shaded by the buildings during the central hours of the day, at least partially. However, further measures could be studied in order to provide continuity in the shading of the southern sidewalks, due to the interruptions in the facades in correspondence with the intersections and with the accesses to the courtyards. The shading on the northern sidewalks is provided by lines of trees, in most cases alternated with parking stalls. This measure resulted to be effective especially during the central hours of the day, rather than in the early morning, since the shadows orientation allows to cover the sidewalks. Most importantly, the size of the trees has an influence on the different parameters, and especially the PET and the surface temperature, due to its impact on shading. It must be noted that, in the context of this work, the shape and size of the trees chosen are selected from the database of the software, while more detailed simulations could be conducted with more information regarding the species and the conditions of planting on the site, with a different output in the simulation. Because of this element, it would appear that the scenarios T, prioritising the presence of larger trees, are more effective, due to their better conditions of shading. Despite its lower effectiveness in shading compared the buildings, vegetation resulted to contribute to the reduction of air temperature, probably due to the combined effect with evapotranspiration, as it is shown by the higher values of humidity. Additional measures for shading could be considered, in order to allow continuity where planting is not possible, for example shading devices in correspondence with intersections. Although it was not implemented in the simulation, it could be considered that shelters would be introduced at the bus stops, contributing to shading.

It was observed that grass areas have lower values of surface temperature and contribute to the reduction of PET, even though their effect is limited. Their effect on air temperature is not directly noticeable. In the area of study, it is difficult to state whether the simple measure of introducing high albedo surfaces contributes or is detrimental to thermal comfort. The effect on surface temperature is evident, as it can be observed for both scenarios during the whole day. As it was mentioned, the literature showed that the impact of this measure on thermal comfort is different according to the study. In the area of study, it is difficult to analyse this phenomenon. This is because in most cases the shading of the trees prevails on the reduction of the temperatures, by making it difficult to observe the effect of the materials. The map referred to the PET at 12:00 for the scenario PH, where along via Asinari di Bernezzo the trees are lower, shows a slight increase in the index in correspondence with the intersections, where the extension of pedestrian surfaces and the raised intersections increase the surfaces composed by high albedo materials. This could be an indication of an influence of these materials on thermal comfort, although it must be underlined that the PET index is the result of multiple variables, which could contribute differently to the results. In order to have a clear indication of the influence of high albedo materials in the selected area, it could be useful to perform a simulation without modifying the shading conditions and the presence of green areas, by isolating therefore the simple effect of the materials.

8. Conclusion

The present thesis applies on a case study in the city of Turin an approach for street design based on concepts from two main theoretical areas: traffic calming strategies and thermal comfort solutions. It was explained how urban streets have a crucial role in the life of a city, and how they are characterised by a multiplicity of functions, often conflicting due to the common necessity for space. Street design, therefore, is an essential tool in order to manage the conflicts and to provide the adequate conditions so that the different uses can take place on the surface of the street. The literature review showed that the principles for the design varied over time according to the priority of the context. Current cities are facing the increasing effects of climate change, and high temperatures affect the conditions of use of public spaces, making thermal comfort a key component to take into account in the design, with the objective of creating liveable spaces. Based on a recognition of tools belonging to the category of traffic calming and of strategies aimed at improving adaptation to rising temperatures, an approach is proposed by the thesis on a case study, proposing a redesign of a portion of the neighbourhood Parella in Turin, with a redistribution of space increasing the surface destined to pedestrians, introducing dedicated bicycle infrastructure, and applying strategies to improve street safety and thermal comfort.

Each of the components of the street design is characterised by specific quantitative and qualitative requirements, often deriving from regulations, which have to be taken into account and related with each other. This is especially valid for the dimensioning, which demands minimum distances and surfaces in order to allow the use or the effectiveness of the measure. In order to combine these needs, different scenarios have been produced, by adapting the measures according to the prioritisation of specific purposes. The resulting design allowed to understand the necessity of compromises, given the limited space available, while additional functions are added to the street. The compromises are linked in some cases to the regulatory constraints, which impose specific distances and minimum areas to be respected. In this context, it was particularly evident how the distances imposed for tree plantings largely affect the overall design, imposing changes or the elimination of other uses, such as car parking. In other cases, rather than with the compliance with a regulation, the choices are due to the prioritisation of one element, such as the increase of green areas in spite of parking spaces, in order to allow the placing of higher trees.

Through the analysis of the results of the simulations, the effectiveness of the project on thermal comfort was evaluated. It was shown that the selected tools contribute to the improvement of comfort conditions on pedestrian areas. The introduction of the trees constitutes the most valuable tool. First, the line of tree planting constitutes an almost continuous shading effect along the northern sidewalks, especially during the central hours of the day: it was seen how the interruption of direct radiation is the main factor in the improvement of thermal comfort. Moreover, the shadows reduce surface temperatures, and the vegetation contributes to the reduction of air temperature through evapotranspiration processes. The location of the trees is an important element to take into account, especially considering the distance from the sidewalks and the orientation of the shadows during the warmest hours of the day. Moreover, the dimensions of the trees are fundamental in order to provide sufficient shading to pedestrians: it was observed how the scenario maximising the space destined to higher trees provides an almost continuous shaded path, while the one prioritising parking only allows smaller trees, which have a limited effect in shading. The vegetation, in all cases, allows to reduce potential air temperature and the PET, especially contributing to the mitigation of the heat on the most critical areas. The project also introduced different high albedo materials in the design. A clear difference from the current state is highlighted by comparing surface temperatures, however, it is difficult to evaluate the impact of this measure on potential air temperature and on the PET. It can be concluded, therefore, that the thermal comfort conditions resulting from the project scenarios are improved: while the reduction of potential air temperature is limited to 1° in the cases where the difference is the highest, a reduction of the PET index, varying around 10°, is registered along the pedestrian spaces of the streets. Between the two scenarios compared, the most suitable resulted to be the GLT, prioritising the size of the trees, especially because of the scarce effectiveness of the PH scenario, due to the reduced size of the trees. Although more detailed information could be added to the simulation, the results show the importance of maximising shading: because of this, due to the necessity to comply to the regulations in force, sufficient space should be reserved to the vegetation, meaning that a reduction of the space destined to other functions should be taken into account, highlighting the importance of the decisions made in the prioritisation of the different elements during the process of street design, by taking into consideration multiple needs.

In the context of the present work, sectorial regulations were the main tool in order to define the spaces and the components of the design. The minimum dimensioning standards were applied for the spaces destined to vehicular traffic and parking, with the objective of a more equal and effective use of space, while larger dimensions, where possible, were attributed to the infrastructure dedicated to bicycle and pedestrians. A critical step in the design was the application of the norms regarding the chicanes and the intersections. In the first case, given the absence of a specific regulation in Italy, standards from another country were applied. In the second case, a verification of the application of the existing norms, provided by CNR, highlighted the difficulty, and in some cases the impossibility to strictly apply the parameters defined. The resulting method, therefore, is the result of a functional approach, aimed at allowing the circulation of emergency vehicles as a priority, as well respecting the category of vehicles allowed according to the Highway Code. A further improvement of the work could focus on the compatibility between the norms in force, the availability of space for an application in the urban context, and the measures of traffic calming. Regarding greenery, the main tool considered is the urban regulations on public and private green, integrated with considerations from the literature, with the objective of obtaining the necessary dimensioning requirements and distances for street plantings. A more detailed study would require additional consideration to the selection of species, especially by analysing their adaptation to climate change effects and their effectiveness in improving thermal comfort. Similarly, indications are provided in the thesis regarding the characteristics of the materials which should be selected, by associating to the use of each portion of the street a typology of material, with the objective of evaluating the effect through the simulation. Further elements could be brought by a project detailing the characteristics of the public spaces, integrating the materials to other elements such as urban furniture.

In the context of climate change effects, the thesis focused on the adaptation to the increase of temperatures, by integrating in the design measures to improve thermal comfort. As it was mentioned, however, multiple challenges regarding climate change effects and cities exist: on top of heatwaves, the urban area of Turin must also face the issues of extreme events related with water, such as cloudbursts and drought. These elements should therefore be integrated in the design, by adapting the materials and the characteristics of space in order to increase water drainage and storage. This would increase the complexity of the issues, the tools, and the outcomes of the project. Moreover, a further study could detail the development and management of the design process, since, as it was mentioned, the tools applied vary in their characteristics and scale, and they involve different sets of actors.

References

Ajuntament de Barcelona (2022a). *Superilla Barcelona - PRESENTACIÓ PROJECTES EXECUTIUS.* https://ajuntament.barcelona.cat/superilles/sites/default/files/20220210_presentacio_projectesexecutius.pdf.

Ajuntament de Barcelona (2022b). *IMPLANTACIÓ DE LA NOVA MOBILITAT ALS EIXOS VERDS I PLACES DE L'EIXAMPLE.* https://www.barcelona.cat/pla-superilla-barcelona/sites/default/files/2022-11/fulleto_novamobilitat_novembre2022_web.pdf.

Ambros, J., Tomešová, L., Jurewicz, C., & Valentová, V. (2023). A review of the best practice in traffic calming evaluation. *Accident Analysis & Prevention, 189,* 107073.

Armson, D., Stringer, P. W., & Ennos, A. R. (2012). The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry & Urban Greening, 11*(3), 245–255.

Atmaca, İ., Kaynaklı, Ö., & Yiğit, A. (2007). Effects of radiant temperature on thermal comfort. *Building and Environment, 42*(9), 3210–3220.

Bertolini, L. (2020). From "streets for traffic" to "streets for people": can street experiments transform urban mobility? *Transport Reviews, 40*(6), 734–753.

Biddulph, M. J. (2003). Towards successful home zones in the UK. *Journal of Urban Design, 8*(3), 217–241.

Bovo, G., Miglietta, P., Peano, O., Vanzo, A., Torino Assessorato per l'ambiente e lo sviluppo sostenibile. (1997). *Manuale per tecnici del verde urbano.* Comune di Torino.

Brindle, B. (1991). Traffic calming in Australia. a definition and commentary. *Australian Road Research, 21*(2), 37–55.

Broadbent, A. M., Coutts, A., Tapper, N., Demuzere, M., & Beringer, J. (2017). The microscale cooling effects of water sensitive urban design and irrigation in a suburban environment. *Theoretical and Applied Climatology, 134*(1–2), 1–23.

Bruse, M., & Fleer, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software, 13*(3–4), 373–384.

Buchanan, C. (1963), *Traffic in towns: the specially shortened edition of the Buchanan report.* Middlesex, Penguin Books London HM Stationery Office.

Bunte, L., (2000). *Traffic Calming Programs & Emergency Response*, National Association of City Transportation Officials. United States of America.

Butera, F. (1998). Chapter 3—Principles of thermal comfort. *Renewable & Sustainable Energy Reviews, 2*(1–2), 39–66.

Canale, S. (2009). *Progettare la sicurezza stradale : criteri e verifiche di sicurezza per la progettazione e l'adeguamento degli elementi delle infrastrutture viarie : intersezioni, tronchi, sovrastrutture, gallerie, opere idrauliche, barriere di sicurezza, illuminazione, segnaletica ed interventi di traffic calming.* EPC Libri.

Canale, S., (2011). *Progettare le intersezioni :*

tecniche per la progettazione e la verifica delle intersezioni stradali in ambito urbano ed extraurbano secondo il D.M. 19/4/2006 (2. ed). EPC.

Chen, L., & Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities, 29*(2), 118–125.

Chimba, D. & Mbuya, C. (2019). *Simulating the Impact of Traffic Calming Strategies*.

Circolare Ministero dell'Interno - 22/10/2020 - Prot. n. 7923 - Circolazione stradale (2020)

Circolare Ministero dei Lavori Pubblici – 11/8/1966 – Prot. n. 8321.

Città Metropolitana di Torino (2022). *Piano Urbano della Mobilità Sostenibile*.

Città di Torino (2010). *Piano Urbano della Mobilità Sostenibile*.

Città di Torino (2023). *Corso Umbria, al via la riqualificazione del viale con fondi europei React Eu Pon Metro.* http://www.comune.torino.it/verdepubblico/alberi/corso-umbria-al-via-la-riqualificazione-del-viale-con-fondi-europei-react-eu-pon-metro/

Citta' di Torino - Regolamenti - n. 317 - Verde pubblico e privato

C.N.R. n. 90/83 "Norme sulle caratteristiche geometriche e di traffico delle intersezioni stradali urbane"

Codice della Strada – d.lgs. 30/04/1992 s.m.i.

Comune di La Loggia (2021). *Progetto esecutivo nuova rotatoria tra via Vinovo e Strada Nizza.* https://www.comune.laloggia.to.it/cgi-bin/agc/1222202193833_COMUNE_DI_LA_LOGGIA.pdf

Coutts, A., White, E. C., Tapper, N., Beringer, J., & Livesley, S. J. (2016). Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments (vol 124, pg 55, 2016). *Theoretical and Applied Climatology,* 126.

Davico, P., Devoti, C., Lupo, G. M., Viglino, M., (2014). *La storia della città per capire, il rilievo urbano per conoscere : borghi e borgate di Torino.* Politecnico di Torino.

Debbage, N., & Shepherd, J. M. (2015). The urban heat island effect and city contiguity. *Computers, Environment and Urban Systems, 54*, 181–194.

Departmet of Transport (2007). *Manual for streets*.

Dessì, V., Farnè, E. Ravanello, L., Salomoni, M.T. (2017). *Rigenerare la città con la natura - Strumenti per la progettazione degli spazi pubblici tra mitigazione e adattamento ai cambiamenti climatici. 2° edizione*. Maggioli.

Djekić, J., Djukić, A., Vukmirović, M., Djekic, P. J., & Dinic-Brankovic, M. (2018). Thermal comfort of pedestrian spaces and the influence of pavement materials on warming up during summer. *Energy and Buildings, 159*, 474–485.

Dobos, E. (2005). Albedo. In *CRC Press eBooks.*

Doulos, L. T., Santamouris, M., & Livada, I. (2004b). Passive cooling of outdoor urban spaces. The role of materials. *Solar Energy, 77*(2), 231–249.

Ebi, K. L., Capon, A., Berry, P., Broderick, C., De Dear, R., Havenith, G., Honda, Y., Kovats, S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Jay, O. (2021). Hot weather and heat extremes: health risks. *The Lancet, 398*(10301), 698–708.

Eggimann, S. (2022). Expanding urban green space with superblocks. *Land Use Policy, 117*, 106111.

Emilsson, T., & Sang, Å. O. (2017). Impacts of climate change on urban areas and Nature-Based Solutions for adaptation. In *Theory and practice of urban sustainability transitions* (pp. 15–27).

ENVI-met (n.d.). *PET and PET* (PET Reviewed) [A holistic microclimate model]*. https://ENVI-met.info/doku.php?id=apps:biomet_pet

ENVI-met GmbH (2024). *ENVI-met Quick Tip #5 | Simple Forcing vs. Full Forcing*. https://www.youtube.com/watch?v=EXUjUbz4ysA

Erell, E., Pearlmutter, D., & Williamson, T. (2011). *Urban Microclimate: designing the spaces between buildings*.

Falasca, S., Ciancio, V., Salata, F., Golasi, I., Rosso, F., & Curci, G. (2019). High albedo materials to counteract heat waves in cities: An assessment of meteorology, buildings energy needs and pedestrian thermal comfort. *Building and Environment, 163*, 106242.

Gachkar, D., Taghvaei, S. H., & Norouzian-Maleki, S. (2021). Outdoor thermal comfort enhancement using various vegetation species and materials (case study: Delgosha Garden, Iran). *Sustainable Cities and Society, 75*, 103309.

Garcia, M. (2021, July 6). *Un panot renovat i porós rellevarà l'asfalt a la superilla verda de l'Eixample*. Betevé. https://beteve.cat/politica/panot-renovat-rellevara-asfalt-superilla-verda-eixample/

Gehl, J. (2011). *Life Between Buildings: Using Public Space*. Washington, USA: Island Press. ISBN-13: 978-1-59726-827-1

Hamilton-Baillie, B. (2008). Towards shared space. *Urban Design International, 13*(2), 130–138.

Han, X., Hu, Z., Li, C., Wu, J., Li, C., & Sun, B. (2023). Prediction of human thermal comfort preference based on supervised learning. *Journal of Thermal Biology, 112*, 103484.

Harvey, T.A. (1992). *A REVIEW OF TRAFFIC CALMING TECHNIQUES*.

He, B., Wang, J., Liu, H., & Ulpiani, G. (2021). Localized synergies between heat waves and urban heat islands: Implications on human thermal comfort and urban heat management. *Environmental Research, 193*, 110584.

Höppe, P. (1999). The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology, 43*(2), 71–75.

Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., & Jamei, Y. (2016). Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. *Renewable & Sustainable Energy Reviews, 54*, 1002–1017.

Jay, O., Capon, A., Berry, P., Broderick, C., De Dear, R., Havenith, G., Honda, Y., Kovats, S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Ebi, K. L. (2021). Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. *The Lancet, 398*(10301), 709–724.

Jayakody, R. R. J. C., Keraminiyage, K., Alston, M., & Dias, N. (2018). DESIGN FACTORS FOR a SUCCESSFUL SHARED SPACE STREET (SSS) DESIGN. *International Journal of Strategic Property Management, 22*(4), 278–289.

Johansson, E., Thorsson, S., Emmanuel, R., & Krüger, E. L. (2014). Instruments and methods in outdoor thermal comfort studies – The need for standardization. *Urban Climate, 10*, 346–366.

Jones, P. M., Marshall, S., & Boujenko, N. (2008). CREATING MORE PEOPLE-FRIENDLY URBAN STREETS THROUGH 'LINK AND PLACE' STREET PLANNING AND DESIGN. *IATSS Research, 32*(1), 14–25.

Juhász, M., & Koren, C. (2016). Getting an Insight into the Effects of Traffic Calming Measures on Road Safety. *Transportation Research Procedia, 14*, 3811–3820.

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). Nature-Based Solutions to Climate Change Adaptation in Urban Areas—Linkages between science, policy and practice. In *Theory and practice of urban sustainability transitions* (pp. 1–11).

Karndacharuk, A., Wilson, D. W., & Dunn, R. (2013). Analysis of Pedestrian Performance in Shared-Space Environments. *Transportation Research Record, 2393*(1), 1–11.

Karndacharuk, A., Wilson, D. W., & Dunn, R. (2014). A review of the evolution of shared (Street) space concepts in urban environments. *Transport Reviews, 34*(2), 190–220.

Kempa, J. (2019). Respecting a speed limit and its effectiveness in a traffic calming zone. *IOP Conference Series, 603*(4), 042068.

Kjemtrup, K., & Herrstedt, L. (1992). Speed management and traffic calming in Urban areas in Europe: a historical view. *Accident Analysis & Prevention, 24*(1), 57–65.

Klemm, W., Heusinkveld, B., Lenzholzer, S., & Van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. *Landscape and Urban Planning, 138*, 87–98.

Koppe, C., Kovats, S., Jendritzky, G., Menne, B., Baumüller, J., Bitan, A., Díaz, J., Ebi, K., López-Santiago, C., Michelozzi, P., Nicol, F., Matzarakis, A. (2004). *Heat-Waves: Risks and Responses*.

Lam, C. K. C., Weng, J., Liu, K., & Hang, J. (2023). The effects of shading devices on outdoor thermal and visual comfort in Southern China during summer. *Building and Environment, 228*, 109743.

Li, X., Ratti, C., & Seiferling, I. (2018). Quantifying the shade provision of street trees in urban landscape: A case study in Boston, USA, using Google Street View. *Landscape and Urban Planning, 169*, 81–91.

Lontorfos, V., Efthymiou, C., & Santamouris, M. (2018). On the time varying mitigation performance of reflective geoengineering technologies in cities. *Renewable Energy, 115*, 926–930.

Maggiulli, D., Manzon, L., Massa, M.T., Orsini, F., (2006). *L'abbattimento delle barriere architettoniche nello spazio pubblico*. Città di Torino – Divisione infrastrutture e mobilità.

Magrinyá, F., Aloy, J. M., & Ruiz-Apilánez, B. (2023). Merging Green and Active Transportation Infrastructure towards an Equitable Accessibility to Green Areas: Barcelona Green Axes. *Land, 12*(4), 919.

Massetti, L., Petralli, M., Napoli, M., Brandani, G., Orlandini, S., & Pearlmutter, D. (2019). Effects of deciduous shade trees on surface temperature and pedestrian thermal stress during summer and autumn. International *Journal of Biometeorology, 63*(4), 467–479.

Mazhar, N., Brown, R. D., Kenny, N., & Lenzholzer, S. (2015). Thermal comfort of outdoor spaces in Lahore, Pakistan: Lessons for bioclimatic urban design in the context of global climate change. *Landscape and Urban Planning, 138*, 110–117.

McMichael, A. J., Woodruff, R., & Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet, 367*(9513), 859–869.

Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science, 305*(5686), 994–997.

Middel, A., Selover, N., Hagen, B., & Chhetri, N. (2016). Impact of shade on outdoor thermal comfort—a seasonal field study in Tempe, Arizona. *International Journal of Biometeorology, 60*(12), 1849–1861.

Mohammad, P., Aghlmand, S., Fadaei, A., Gachkar, S., Gachkar, D., & Karimi, A. (2021). Evaluating the role of the albedo of material and vegetation scenarios along the urban street canyon for improving pedestrian thermal comfort outdoors. *Urban Climate, 40*, 100993.

Morakinyo, T. E., Kong, L., Lau, K. K., Yuan, C., & Ng, E. (2017). A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. *Building and Environment, 115*, 1–17.

Nasir, R. A., Ahmad, S. S., Zain-Ahmed, A., & Ibrahim, N. (2015). Adapting human comfort in an urban area: The role of Tree shades towards Urban Regeneration. *Procedia - Social and Behavioral Sciences, 170*, 369–380.

Nasrollahi, N., Ghosouri, A., Khodakarami, J., & Taleghani, M. (2020). Heat-Mitigation Strategies to Improve pedestrian thermal comfort in Urban Environments: A review. *Sustainability, 12*(23), 10000.

Nello-Deakin, S. (2019). Is there such a thing as a 'fair' distribution of road space? *Journal of Urban Design, 24*(5), 698–714.

Nello-Deakin, S. (2022). Exploring traffic evaporation: Findings from tactical urbanism interventions in Barcelona. *Case Studies on Transport Policy, 10*(4), 2430–2442.

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy, 70*(3), 227–235.

Norma sulla segnaletica per il traffico lento (SN 640 829)

Oke, T. R. (2002). *Boundary layer climates*.

Routledge.

Olgyay, V. (2015). *Design with climate: bioclimatic approach to architectural regionalism, new and expanded edition (REV-Revised)*. Princeton University Press.

Øvstedal, L. R., & Olaussen, E. O. (2002). UNDERSTANDING PEDESTRIAN COMFORT IN EUROPEAN CITIES: HOW TO IMPROVE WALKING CONDITIONS? *European Transport Conference 2002MVA, Limited; Association for European Transport*.

Palenzuela, S. R. (2021). Superblocks base of a new model of mobility and public space. Barcelona as an example. In *Elsevier eBooks* (pp. 249–257).

Pejović, A. (2022). *Microclimate mitigation, analysis and design tools: Case study of controviali in Turin*. Politecnico di Torino.

Pennsylvania Department of Transportation (2012). *Pennsylvania's Traffic Calming Handbook*.

Perkins, S. E., Alexander, L. V., & Nairn, J. (2012). Increasing frequency, intensity and duration of observed global heatwaves and warm spells. *Geophysical Research Letters, 39*(20).

Pharoah, T. (1993). Traffic calming in West Europe. *Planning Practice and Research, 8*(1), 20–28.

Pharoah, T., & Russell, J. R. (1991). Traffic calming policy and performance: The Netherlands, Denmark and Germany. *Town Planning Review, 62*(1), 79.

Pilsēta cilvēkiem. (2019). *Paņem labāko no ziemas!.* https://www.pilsetacilvekiem.lv/sneckdowns/

Pollo, R., & Trane, M. (2021). Adaptation, Mitigation, and Smart Urban Metabolism towards the Ecological Transition. In *Adaptation, Mitigation, and Smart Urban Metabolism towards the Ecological Transition.* Palermo University Press.

Rahman, M. A., Armson, D., & Ennos, A. R. (2014). A comparison of the growth and cooling effectiveness of five commonly planted urban tree species. *Urban Ecosystems, 18*(2), 371–389.

Reza, F., Kojima, S., & Andō, W. (2021). Analyzing the effect of water body on the thermal environment and comfort at indoor and outdoor spaces in Tropical University Campus. *International Journal of Environmental Science and Development, 12*(10), 282–288.

Regione Piemonte (n.d.). *Le specie vegetali esotiche invasive.* https://www.regione.piemonte.it/web/temi/ambiente-territorio/biodiversita-aree-naturali/conservazione-salvaguardia/specie-vegetali-esotiche-invasive

Regolamento di esecuzione del Codice della Strada, D.P.R., 16/12/1992 n° 495

Richez Associés, Franck Boutté consultants, Léonard (2022). *La rue commune - Guide méthodologique pour la transformation des rues ordinaires.* Ademe.

Rijal, H. B. (2011). Thermal adaptation outdoors and the effect of wind on thermal comfort. In *Springer eBooks* (pp. 33–58).

Rizwan, A. M., Leung, D. Y., & Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of*

Environmental Sciences, 20(1), 120–128.

Rizwan, A. M., Leung, D. Y., & Liu, C. (2008b). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences, 20*(1), 120–128.

Robinson, P. (2001). On the Definition of a Heat Wave. *Journal of Applied Meteorology, 40*(4), 762–775.

Roshan, G., Moghbel, M., & Attia, S. (2020). Evaluating the wind cooling potential on outdoor thermal comfort in selected Iranian climate types. *Journal of Thermal Biology, 92*, 102660.

Rosso, F., Pisello, A. L., Cotana, F., & Ferrero, M. (2016). On the thermal and visual pedestrians' perception about cool natural stones for urban paving: A field survey in summer conditions. *Building and Environment, 107*, 198–214.

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. *Renewable & Sustainable Energy Reviews, 26*, 224–240.

Santamouris, M., & Yun, G. Y. (2020). Recent development and research priorities on cool and super cool materials to mitigate urban heat island. *Renewable Energy, 161*, 792–807.

Santamouris, M., Ban-Weiss, G., Osmond, P., Paolini, R., Synnefa, A., Cartalis, C., Muscio, A., Zinzi, M., Morakinyo, T. E., Ng, E., Tan, Z., Takebayashi, H., Sailor, D. J., Crank, P. J., Taha, H., Pisello, A. L., Rossi, F., Zhang, J., & Κολοκότσα, Δ. (2018). PROGRESS IN URBAN GREENERY MITIGATION SCIENCE – ASSESSMENT METHODOLOGIES ADVANCED TECHNOLOGIES AND IMPACT ON CITIES. *Journal of Civil Engineering and Management, 24*(8), 638–671.

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy, 85*(12), 3085–3102.

Sharifi, A. (2020). Trade-offs and conflicts between urban climate change mitigation and adaptation measures: A literature review. *Journal of Cleaner Production, 276*, 122813.

Sharmin, T., Steemers, K., & Matzarakis, A. (2017). Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. *Sustainable Cities and Society, 34*, 293–308.

Shashua-Bar, L., Tsiros, I. X., & Hoffman, M. E. (2012). Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions. *Building and Environment, 57*, 110–119.

Socco, C. (2009). *Linee guida per la sicurezza stradale. Linee guida 2. Sezione B*. Regione Piemonte.

South Central Regional Council of Governments (2008). *Traffic calming resource guide*.

Sun, S., Xu, X., Lao, Z., Liu, W., Li, Z., García, E. H., He, L., & Zhu, J. (2017). Evaluating the impact of urban green space and landscape design parameters on thermal comfort in hot summer by numerical simulation. *Building and Environment, 123*, 277–288.

Syafii, N. I., Ichinose, M., Kumakura, E., Chigusa, K., Jusuf, S. K., & Wong, N. H. (2017). Enhancing the Potential Cooling Benefits of Urban Water Bodies. Nakhara : *Journal of Environmental Design and Planning, 13*, 29–40.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings, 25*(2), 99–103.

Taleghani, M., & Berardi, U. (2018). The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. *Urban Climate, 24*, 449–459.

Tan, C. L., Wong, N. H., & Jusuf, S. K. (2013). Outdoor mean radiant temperature estimation in the tropical urban environment. *Building and Environment, 64*, 118–129.

Tan, J., Belcher, R. N., Tan, H., Menz, S., & Schroepfer, T. (2021). The urban heat island mitigation potential of vegetation depends on local surface type and shade. *Urban Forestry & Urban Greening, 62*, 127128.

Teskey, R. O., Wertin, T. M., Bauweraerts, I., Ameye, M., McGuire, M. A., & Steppe, K. (2014). Responses of tree species to heat waves and extreme heat events. *Plant, Cell & Environment, 38*(9), 1699–1712.

Torino Metropoli. (n.d.). *Il Piano della mobilità ciclistica - Biciplan della Città metropolitana - Città Metropolitana di Torino*. http://www.torinometropoli.it/cms/trasporti-mobilita-sostenibile/pums/pums-piano-approvato-2022/biciplan/biciplan

Tous À Pied (2021). *Sneckdown*. https://www.tousapied.be/articles/sneckdown/

Vanderschuren, M. & Jobanputra, R. (2009). *TRAFFIC CALMING MEASURES - REVIEW AND ANALYSIS*.

Von Schönfeld, K. C., & Bertolini, L. (2017). Urban streets: Epitomes of planning challenges and opportunities at the interface of public space and mobility. *Cities, 68*, 48–55.

Wai, K. M., Liu, X., & Tan, Z. (2021). Improvement of the Outdoor Thermal Comfort by Water Spraying in a High-Density Urban Environment under the Influence of a Future (2050) *Climate. Sustainability, 13*(14), 7811.

Walther, É., & Goestchel, Q. (2018). The P.E.T. comfort index: Questioning the model. *Building and Environment, 137*, 1–10.

Xu, Z., FitzGerald, G., Lee, H., Jalaludin, B., & Tong, S. (2016). Impact of heatwave on mortality under different heatwave definitions: A systematic review and meta-analysis. *Environment International, 89–90*, 193–203.

Zalewski, A., Chmielewski, J., Kempa, J., Santos, B., & Gonçalves, J. (2021). Traffic calming in historic city centres - a case study. *IOP Conference Series, 1203*(2), 022106.

Zou, M., & Zhang, H. (2021). Cooling strategies for thermal comfort in cities: a review of key methods in landscape design. *Environmental Science and Pollution Research, 28*(44), 62640–62650.

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