

# **Thermodynamics of Public Space**

Designing Comfortable and Social Public Space Adaptive to Seasonal Temperature Extremes in Vilnius, Lithuania

## COLOFON

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*Author: Kristupas Kadys | 6056849*  
Graduation Studio: Metropolitan Ecologies of Place

*First mentor: Dr. Daniela Maiullari*  
Assistant Professor Environmental Technology & Design  
Faculty of Architecture and the Built Environment  
Department of Urbanism

*Second mentor: Birgit Hausleitner*  
Dipl.ing., Architect, Urbanist and Lecturer of Urban Design  
Faculty of Architecture and the Built Environment  
Department of Urbanism

*Delegate of the Board of Examiners: Antonio Cantero Vinuesa*  
PhD, Assistant Professor Public Building and Housing Design  
Faculty of Architecture and the Built Environment

*Delft, The Netherlands*

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Figure 01. Adapting to Summer (Blažys, 2022)



## Abstract

Urban public spaces face the growing dual challenge of responding to extreme temperature conditions, intensifying summer heat and persistent cold in winters, exacerbated by climate change. These issues, often separate in urban planning and climate adaptation discourses, have to be addressed through a holistic approach that integrates urban design, microclimate analysis, and public space usability. In Vilnius, Lithuania and other cities in continental climates, where both heat and cold stress are significant, urban form plays a critical role in shaping microclimate conditions and thermal comfort, which influences social well-being and activity patterns in public spaces. Therefore, the following research question emerges: "How could public spaces in Vilnius, Lithuania be adapted to seasonal temperature extremes, while simultaneously fostering social well-being throughout the year?"

The study conceptualises vulnerability through the aspects of exposure, sensitivity, and adaptive capacity, linking them to thermal comfort, well-being, and public space usability. Using a multi-scalar methodological framework, it evaluates Vilnius's diverse public spaces, from enclosed compact spaces to sprawling suburban peripheries, under temperature extremes. The findings are used to create a design framework, comprising of a temperature vulnerability map, adaptable design strategies, and prototypes for year-round temperature-proof public spaces.

By integrating heat and cold adaptation, this research advances the discourse on urban climate resilience, offering evidence-based solutions for creating inclusive, functional, and sustainable public spaces in continental climate zones. The developed adaptation patterns provide insights, that inform spatial implications for policymakers, urban planners and designers required to mitigate temperature extremes, while enhancing urban livability and community well-being.

### Key words:

**Climate Change, Temperature Extremes, Vulnerability, Adaptation, Public Space, Local Climate Zones.**

Figure 02. Adapting to Winter (taken by Author)



## Motivation

### Personal

Growing up in a dense urban environment, I have always been interested in the way public space shapes how people interact with their surroundings and each other. I think cities can be considered as dynamic systems that are shaped by rapid changes in infrastructure, demographics, and climate. However, I have also observed how these spaces often fail to adapt to environmental challenges, such as rising summer temperatures or freezing winter conditions. I have often myself experienced how extreme heat and cold can limit the usability and enjoyment of urban public spaces. This personal awareness has sparked my interest in exploring how cities can be designed to provide more comfortable, inclusive, and resilient spaces for everyone.

The importance of equitable and accessible public spaces became especially clear to me during recent travels and studies. I noticed how well-designed urban environments in some cities provide relief from extreme heat through shading, water features, and strategic greenery, while others lack these features, creating unwelcoming or even hazardous conditions. On the other hand, there has been very little adaptation to winter conditions, leaving a majority of spaces unusable during this time period. This contrast highlights the urgent need for cities to prioritize climate-adaptive solutions, especially as climate change continues to intensify temperature extremes. My personal experiences have shown me that urban public spaces must be more than functional — they must actively support human well-being and comfort, regardless of the season.

Another driving force for my research is addressing social and environmental inequalities. I believe that urban public spaces play a critical role in fostering inclusivity, community engagement, and social cohesion. However, these benefits are often unevenly distributed, leaving vulnerable populations without access to safe, climate-resilient spaces. I am particularly motivated to address these challenges in a way that prioritizes environmental justice, ensuring that public spaces are accessible and beneficial to all residents, regardless of their age or socio-economic background. By combining my personal passion for equitable design and my growing knowledge of climate adaptation strategies, I aim to contribute to creating healthier, more sustainable, and livable urban spaces.

### Professional | Academic

Academically, I am driven by the increasing urgency of adapting urban environments to the challenges of climate change. Urbanization is putting immense pressure on cities, resulting in shrinking green spaces, rising urban heat stress in densifying city centres, and neglecting cold stress challenges in rapidly spreading sparsely built urban peripheries, creating a need for year-round climate adaptation. As cities continue to grow, it is essential to develop design strategies that balance these extremes, ensuring public spaces remain functional, accessible, and comfortable throughout the year.

From an academic perspective, I see public spaces as a vital tool for climate adaptation throughout the scales — ranging from small pocket parks to large-scale urban green networks, from sheltered courtyards to poly-centric community spaces. My interest lies in integrating nature-based solutions with innovative urban design principles to address seasonal temperature extremes by cooling through shading and evapotranspiration in summer and wind protection in winter. By exploring the interplay between public space design, climate adaptation, and human well-being, I aim to contribute to the growing body of research that bridges the gap between theory and practice.

In addition to addressing climate adaptation, this research is an opportunity to investigate the role of public spaces in improving social cohesion, mental health, and quality of life. Studies have shown that access to restorative environments can reduce urban stress, enhance mental well-being, and improve public health outcomes. By considering the multiple benefits of public spaces — ecological, social, and climatic — my research seeks to create integrated solutions that address the interconnected challenges of urbanization, climate change, and social equity.

By focusing on the adaptation of public spaces to temperature extremes, I aim to contribute to the sustainable urban development strategies that not only mitigate environmental-climatic challenges, but also enable cities to adapt and remain livable while enhancing the daily lives of urban residents, particularly for vulnerable inhabitants.

Figure 03. Photo of Ognios Miestas Public Space and Urban Transformation (Tukaj, 2017)



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This thesis is dedicated to the cities we create.

*June, 2025*

Kristupas Kadys

**Figure 04.** Photo of Ogmios Miestas Public Space and Urban Transformation (Ogmios miestās, 2022)



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**Figure 05.** Lakes of Vilnius - Heatwave Adaptation Spaces  
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## Glossary of Terms

### *Adaptation*

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2018).

### *Adaptive Capacity*

The ability of a system or population to adjust its characteristics and behaviour to better manage current and future stresses. It includes strategies such as leveraging social networks, taking up protective behaviours, and accessing cooling or heating resources, shaped by household socio-economic conditions and larger systemic factors (Wilhelmi & Hayden, 2010).

### *Climate Change*

A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period (IPCC, 2018). In this thesis, all mentions of climate change is attributed directly or indirectly to human activity.

### *Cold wave*

A period of abnormally cold weather, in Lithuania associated with some dangerous, natural and catastrophic meteorological phenomena. Dangerous phenomena include: "Šaltos dienos" [Cold Spell], when the lowest daily temperature drops below -15°C (Lietuvos Respublikos aplinkos ministerija [Ministry of Environment of the Republic of Lithuania], 2024), "Stiprus šaltis" [Severe Cold], when the lowest daily temperature is below -25°C, and "Speigas" [Severe Frost] is classified, when the minimum air temperature drops to -30°C and below. When such temperature persists for 4 days or longer – severe frost is classified as a catastrophic meteorological phenomenon. The minimum temperature may be higher (-10°C, -20°C) if the cold wave reaches Lithuania in late autumn or early spring (Bukantis, 2024).

### *Exposure*

The uneven distribution of heat across urban areas, that is amplified or suppressed by the reflective, heat-storing, and conductive properties of urban materials and vegetation (Wilhelmi & Hayden, 2010).

### *Hazard*

The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC, 2018).

### *Heatwave*

A period of abnormally hot weather. In the Netherlands, a heat wave is defined as a period of 5 consecutive days when the maximum air temperature is above 25 °C and during this period at least 3 days are above 30 °C. In Lithuania, there is no fixed definition of a heat wave, although in the list of Natural catastrophic meteorological and hydrological phenomena "Stichinė kaitra" [Intense Heat] is defined when the maximum air temperature is equal to or higher than 30 °C for 3 consecutive days or more. Such indicators basically meet the criteria of a heat wave in Lithuania (Bukantis, 2024).

### *Placemaking*

"A collaborative process by which we can shape our public realm in order to maximize shared value [...] placemaking facilitates creative patterns of use, paying particular attention to the physical, cultural, and social identities that define a place and support its ongoing evolution" (Project for Public Spaces, 2024).

### *Public Space (broadly defined)*

"All those parts of the built and natural environment, public and private, internal and external, urban and rural, where the public have free, although not necessarily unrestricted, access. It encompasses: all the streets, squares and other rights of way, whether predominantly in residential, commercial or community/civic uses; the open spaces and parks; the open countryside; the 'public/private' spaces both internal and external where public access is welcomed – if controlled – such as private shopping centres or rail and bus stations; and the interiors of key public and civic buildings such as libraries, churches, or town halls." (Carmona et al., 2021, p.5).

### *Public Space (narrowly defined)*

All those parts of the built and natural environment, internal and external, where the public has free, although not necessarily unrestricted, access (Adapted from Carmona et al., 2021).

### *Sensitivity*

The degree to which a system or population can endure impacts without experiencing lasting harm. It varies depending on socio-economic and health factors, with vulnerable groups, such as the elderly, young children, low-income individuals, and the socially isolated, being disproportionately impacted. (Wilhelmi & Hayden, 2010).

### *Temperature Extremes*

Hazard events, considered under the meteorological family, when temperature variations are above (extreme heat) or below (extreme cold) normal conditions (Smith, 2014). The exact temperature criteria vary by location, but an extreme event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function assessed from observations.

### *Thermal comfort*

Satisfactory and desirable condition, that a person experiences in relation to how warm or cold their surroundings are (Nikolopoulou & Lykoudis, 2006).

### *Urban Heat Island effect (UHI)*

A phenomenon when, in most of the large cities, the centre of the city experiences higher temperatures than its surrounding suburban areas (Nuruzzaman, 2015).

### *Vulnerability*

The degree to which a system (in this research considered public spaces) is susceptible to harmful effects of climate change, including climate variability and extremes (Gabbe et al., 2021).

### *Well-being*

"A multidimensional concept that encompasses various aspects of an individual's life in an urban setting. It involves the physical, psychological, social and environmental dimensions of well-being, all of which are interrelated and influenced by the urban context" (Setiawan & Ningtyas, 2023, p. 56).

# 01

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## INTRODUCTION

Urban Space Adaptation  
Urban Climate & Public Space

### Problem Domain

*Inadequate in Winter*  
*Exposed in Summer*  
*Climate Change Impact*  
*Public Space System*

## Urban Space Adaptation

The climate crisis presents an urgent challenge for urban environments, demanding a dual approach to address its impacts: *mitigation* and *adaptation*. Mitigation strategies aim to lower the potential impacts of a risk caused by climate change by reducing greenhouse gas emissions (GHG) to slow the pace of global warming (European Environment Agency, 2024). These include initiatives like promoting renewable energy, improving energy efficiency, and expanding urban forests. On the other hand, adaptation aims to adjust urban systems, spaces, and communities to cope with the already unavoidable impacts of climate change, ensuring that urban environments remain functional and resilient under new climatic conditions (European Environment Agency, 2024). Examples include building flood-resistant infrastructure, designing temperature-proof public spaces, and planning for sustainable water management.

Both strategies are crucial for fostering sustainable, livable cities, but adaptation in the past has received less attention and found difficulties in implementation compared to mitigation strategies, leaving cities unprepared for extreme weather events such as heatwaves, flooding, and cold spells (Fankhauser, 2017). While mitigation tackles clear long-term climate goals, adaptation remains less identified, as it addresses localised, current and developing future challenges. However, as the effects of climate change are becoming more pronounced, cities worldwide are recognizing the pressing need to adapt their public spaces to changing environmental conditions.

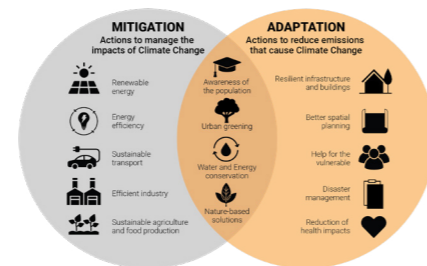
### Why Cities Must Prioritize Adaptation?

Urban areas are most impacted by climate change, with large populations and dense infrastructures that amplify vulnerability. Public spaces offer a unique opportunity to implement climate-responsive design that supports both environmental and social well-being.

Despite the growing awareness, adaptation strategies often remain reactive rather than proactive, implemented only after climate disasters occur. However, cities like Paris, New York, Quebec and Seville are demonstrating how forward-thinking design can prepare urban spaces for future challenges. By incorporating nature-based solutions, technological innovations, and sensible urban design, these projects create adaptable and inclusive public spaces that enhance resilience while fostering livability.

As cities continue to face unprecedented climate pressures, urban design and planning can play a crucial role in driving adaptation, reducing the impacts of climate hazards, while also ensuring that communities can cope with these challenges.

One of the important climate change hazards is the duality of heat and cold extremes. These extreme temperature events pose significant challenges to cities and their populations, affecting public space usability and amplifying health risks (Seltenrich, 2015). The IPCC projections warn that while extreme cold events may remain relatively similar, extreme heat events are projected to increase in frequency and intensity (Sarto & Flandoli, 2024). These changes require a holistic adaptation approach. While urban adaptation to heat has become a more prominent discourse in the past few decades (Gabbe et al., 2021) and adaptation to winter has been debated in some parts of the world establishing winter city movements, such as the World Winter Cities Association for Mayors (Government, 2018) and the Livable Winter Cities Association (Stout et al., 2018), these two debates are still siloed and not studied as being in one spectrum. This division has to change to ensure that careful planning and adaptation is considered for both problems, as some urban characteristics can mitigate one problem but exacerbate another. One example of this can be seen by examining the phenomenon of the Urban Heat Island effect, which illustrates higher temperatures in dense urban environments compared to sparse rural ones. This effect can moderate cold stress in dense neighbourhoods during cold spells but hinder them during heatwaves by capturing and storing heat (Yang & Bou-Zeid, 2018). To bridge the discourse, this thesis explores how urban public spaces can adapt to both temperature extremes.



**Figure 06.** Mitigation & Adaptation Actions (adapted from Ministry of Environment of the Republic of Lithuania, 2024)

**Figure 07.** [Heat] Paris Oasis Schoolyard Programme, Permentier 10th school, Paris France (Ville de Paris, 2023)



**Figure 09.** [Cold] Technical guide of adapting urban form to the climate, Quebec Canada (Ville de Québec, 2024)



**Figure 08.** [Heat] Using Overhangs to block sunlight, Seville Spain. (Centro Historico, 2022)



**Figure 10.** [Cold] Cristo's "The Gates", an outdoor on-site sculpture exhibit, New York USA (Walljasper, 2009)

## Urban Climate & Public Space

### Urban Climate

Climate is influenced by various spaces and urban environments, creating localised areas of distinct climatic conditions that differ from the surrounding regional climate. These variations can include differences in temperature, humidity, wind patterns, and solar radiation. They are influenced by natural features, such as topography, water bodies and vegetation, but the largest effect is seen in the built environment, where natural elements interface with buildings, infrastructure and human activity to create a patchwork of microclimates that impact people, energy usage and the environment itself (van Esch, 2015).

Climate is a multi-scale phenomenon ranging from a macro scale, which refers to the regional climate, to meso, local and micro scales that accordingly refer to climate of the city, its neighbourhoods and open public spaces (Oke, 1987). The city itself modifies the climate in two vertical ranges – the Urban Boundary Layer (UBL) above the city and the Urban Canopy Layer (UCL) between the buildings. In the UBL, the settlement significantly, but evenly modifies the climate, while the UCL is characterised by a high variance of climate settings within very short distances (Oke, 1987; van Esch, 2015).

As this study is examining urban adaptation to temperature, the influential scales are meso, local and especially the micro scale, within the Urban Canopy layer, as these form the surroundings of people in the urban context and directly impact their thermal comfort and physical well-being.

To understand temperature, the characteristics and the

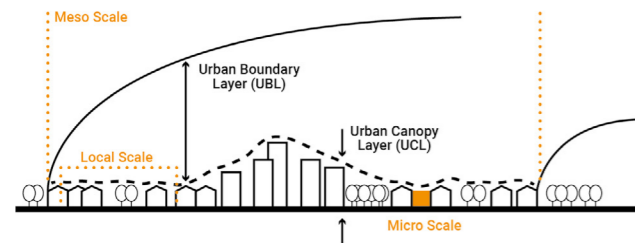


Figure 11. Microclimate scales (adapted from Oke, 1987)

relationship between heat and cold must be examined. In modern scholarship, heat is understood as a form of energy, while cold is the absence of heat (Borrelli, n.d.). With this interpretation of temperature, the scale between hot and cold can be reinterpreted as a gradation from low heat to high heat. Heat generation, distribution, collection and dispersion determines the temperature ranges within the city's microclimates. This method of interpretation utilises the concept of the Urban Heat Island effect to not only measure areas in danger of overheating but also to perceive areas susceptible to cold.

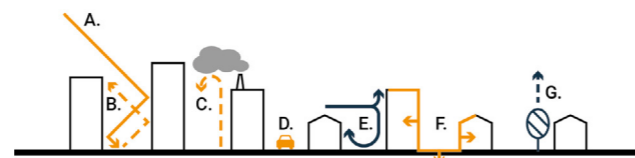


Figure 12. Causes of Urban Heat Islands (adapted from van Esch, 2015)

The built environment influences the urban climate in several ways. Buildings, with their height, orientation, and materials, can create shadowed, sheltered, or sunlit zones, altering the local thermal and airflow conditions. Deep street canyons absorb (A) and trap (B) short-wave radiation in low albedo materials. Air pollution prohibits low-wave radiation from escaping into the atmosphere (C). Human activities, such as traffic, space heating and industries, produce anthropogenic heat (D). Wind patterns are also significantly modified by the built environment. Tall buildings can create wind tunnels or block airflow, resulting in areas with stagnant air (E) or excessive gusts, both of which impact comfort and air quality. Paved surfaces, such as roads and parking lots, together with building materials with large thermal admittance absorb, store and radiate heat (F). Vegetation and water features, when incorporated into urban design, can mitigate these effects by cooling the air through shade and evapotranspiration (G) (van Esch, 2015).

All of these urban design elements influence the urban climate and human thermal comfort in indoor and outdoor spaces.

### Public Space

Among outdoor urban spaces, public spaces play a crucial role in urban systems and their thermal characteristics can greatly impact their livability. These spaces are shared areas in the urban environment that are open and accessible to all individuals. They include parks, plazas, streets, squares, and other communal areas designed to foster interaction, recreation, and civic engagement (Carmona, 2010). They serve as vital hubs for social connection, cultural expression, and economic activity, providing an inclusive setting for people to gather, relax, and participate in community life. Gehl (2001) highlights that the quality of outdoor environments directly influences the types of activities they can sustain, from necessary tasks, such as commuting, to optional activities, like recreation, or social activities, such as conversing with strangers or participating in community events.

Theories on public life and space emphasise the importance of designing environments that foster and support human activity. Organisation "Project for Public Spaces" has defined the four main qualities that make a successful public space: sociability, which establishes opportunities that allow social contact, uses and activities, which provide inclusive and engaging programming, access and linkages, that connect spaces accessible to surrounding neighbourhoods, and lastly, comfort and image, that define attractiveness and simple use of space (Project for Public Spaces, 2024). While these are the main pillars of public spaces, designers and academics are beginning to give more emphasis on comfort, by examining it from an individual lens, separating it from "image", as seen in figure 10 (Santos Nouri & Costa, 2017).

One crucial characteristic that describes comfortable public spaces is thermal comfort. It depends on several microclimate parameters, such as air temperature, solar radiation, wind, and humidity, as well as behavioural and cultural factors, such as clothing and the physical intensity of acted out activity (Gehl, 2010; Nikolopoulou & Lykoudis, 2006). The quality of a place can be defined by its ability to provide physical protection from negative climatic conditions while enhancing exposure to positive environmental aspects. For example, a shaded plaza with adequate seating, vegetation, and water features can provide cooling relief during summer

heat, while a sheltered square designed to minimise wind exposure and maximise solar gain can create a more comfortable environment in winter. Without these design considerations, public spaces risk becoming underutilised, as they fail to meet the required thermal needs of their users.

Public spaces can be seen as opportunities to combine physical and social aspects to adapt to various climatic settings. By interlinking paradigms of physical and social resilience, cities can ensure that public spaces both remain highly sociable places that improve urban life and help residents to better adapt to seasonal climates through their physical features (Peinhardt, 2021).

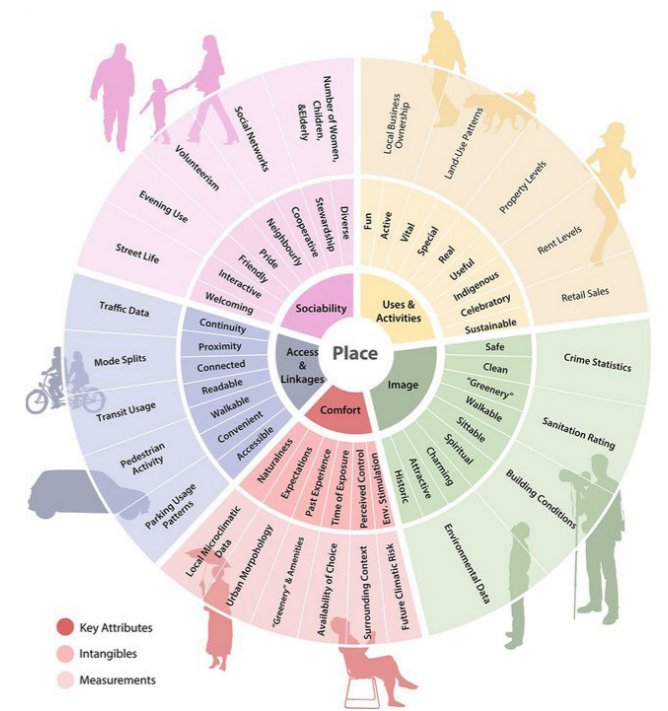


Figure 13. Place Diagram (Santos Nouri & Costa, 2017)

## Inadequate in Winter

Public spaces are often designed without considering colder time periods. While urban spaces are typically designed to encourage activity and social interaction, their lack of adaptability to colder conditions renders many of them underutilised or even useless during the winter months. This results in significant reductions in physical activity, increased isolation, and a notable decline in mental well-being.

Cold temperatures, icy conditions, and inadequate shelter or heating in public spaces discourage people from engaging in outdoor activities that are essential for maintaining a healthy and active lifestyle. As a result, opportunities for exercise, such as walking, running, or cycling, are significantly reduced. Prolonged inactivity during winter contributes to various health problems and an increased risk of chronic diseases such as diabetes and hypertension. Additionally, cold spells pose direct health risks, including hypothermia and increased susceptibility to respiratory illnesses (Seltenrich, 2015; Tucker & Gilliland, 2007).

The lack of winter-adaptive design also impacts social interactions. Public spaces usually become inaccessible or uncomfortable in winter, isolating individuals and reducing

opportunities for community engagement. This isolation, combined with seasonal affective disorder (SAD) and the stress associated with prolonged confinement indoors, can exacerbate mental health issues such as depression and anxiety (National Institute of Mental Health, 2023; Pressman, 1991)

By failing to address these challenges, many urban public spaces remain underused during winter, limiting their potential to support active, healthy lifestyles and social connections year-round. This challenge underlines the urgent need for climate-responsive design strategies that make public spaces functional, comfortable, and inclusive during colder months.

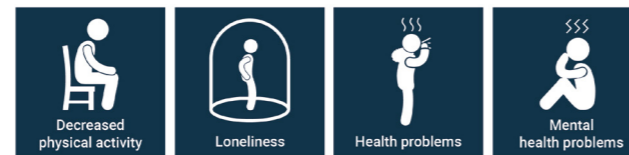


Figure 15. Problems resulting from cold stress



Figure 14. Photo of a bus stop affected by winter (Žiūra, 2021a)

## Exposed in Summer

During summer hot days and heatwaves, urban public spaces often become uncomfortable, unsafe, and even dangerous, limiting their usability and significantly impacting the health and well-being of people in these spaces (Meerow & Keith, 2022). Extended exposure to high temperatures can lead to a range of physical and mental health issues, particularly for vulnerable populations such as children, elderly and people with pre-existing health conditions.

The Urban Heat Island effect further exacerbates these challenges, as densely built environments absorb and retain heat, driving local temperatures significantly higher than surrounding rural areas. Materials like asphalt and concrete, common in urban public spaces, intensify heat buildup and radiate long waves long after sundown, offering little relief during nighttime, resulting in tropical nights (Nuruzzaman, 2015). Prolonged heat exposure increases the risk of dehydration, heat exhaustion and heatstroke, which can lead to life-threatening consequences. Additionally, chronic conditions such as cardiovascular and respiratory diseases can be exacerbated by extreme heat, leading to higher rates of hospitalization and mortality during heatwaves (Seltenrich,

2015). Mental health also suffers under extreme heat conditions, with studies linking heat exposure to increased exhaustion, anxiety, and reduced cognitive performance (Lee et al., 2023). These impacts are amplified by the lack of shaded, cool, or ventilated areas in urban public spaces, making them unusable during peak summer months, discouraging any physical activity or social interaction (Sharifi & Boland, 2017).

The lack of heat mitigating features, such as shaded pathways, reflective materials, water features, and vegetation, worsens the situation. Public spaces designed primarily for mild weather fail to account for the rising frequency and intensity of heat events, leaving them abandoned during summer.



Figure 17. Problems resulting from heat stress



Figure 16. Photo of an overheating public square (Tribouillard, 2021)

## Impact of Climate Change

### Shifting Climate

Climate change is reshaping how public spaces are used and perceived. While global warming is steadily raising average temperatures, it also amplifies the occurrence of extreme weather events. Both extreme heat and cold events pose significant risks to urban populations, requiring a comprehensive strategy to adapt public spaces to these challenges.

The Intergovernmental Panel on Climate Change (IPCC) conceptualised three primary ways temperature extremes may shift due to climate change: increasing mean temperature, greater variability, and asymmetric impact distribution. To explore which conceptual distribution will be the most likely, systematic research has been undertaken to simulate future climatic scenarios. Studies have shown that both rising mean temperature and increased variance will occur, illustrated in the third diagram (Kodra & Ganguly, 2014; Sarto & Flandoli, 2024). This shift in climate explains that extreme cold events will stay constant or similar to the

current distribution while extreme heat events will increase in occurrence. Additionally to the frequency distribution, studies have emphasised that these extreme events, both heatwaves and cold spells, are expected to intensify as the century progresses.

By understanding how climate change is impacting the whole temperature range, and especially the distribution extremities, it becomes clear that adaptation to climate hazards requires a holistic approach, that focuses on the worst-case climate scenarios, but also considers the more moderate problems as well – designing from the extremes towards the mean. The setup illustrates a dual challenge: designing urban spaces that mitigate heat during summer while remaining accessible and safe during winter. Such strategies are increasingly necessary in cities that already experience extreme weather variability, such as those in northern temperate and continental climates.

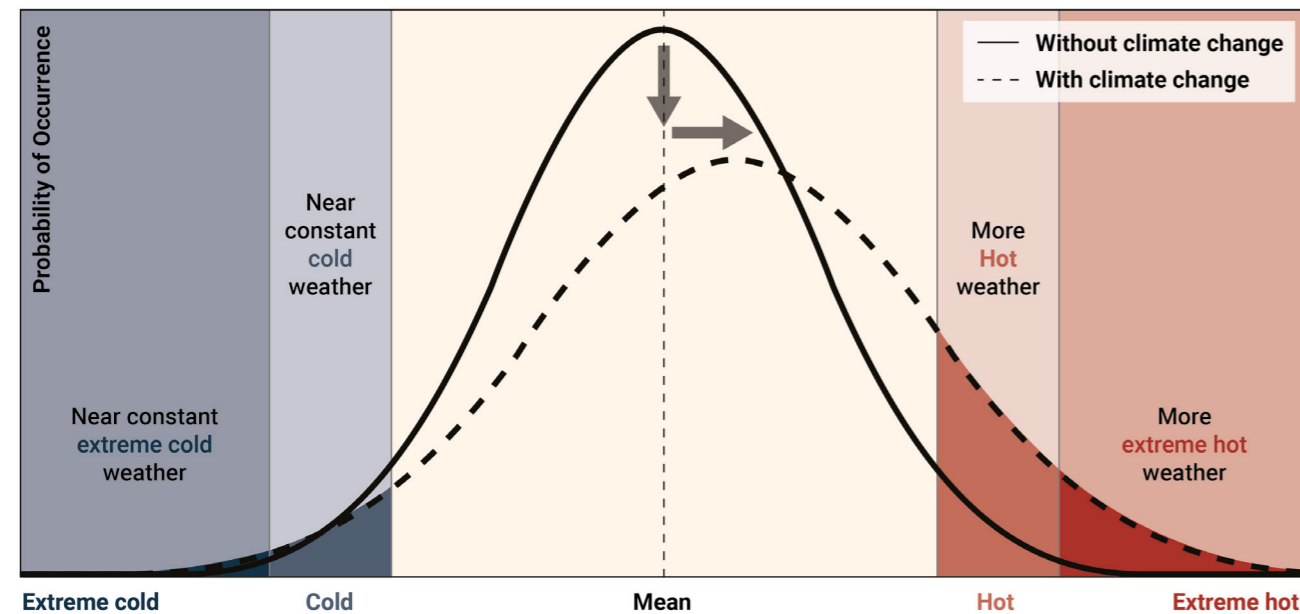


Figure 18. Conceptual changes in the extremes of the temperature distribution (adapted from Sarto & Flandoli, 2024)

### Health Hazards

As climate shifts, extreme heat and cold have different impacts on health and cause temperature-related mortalities, highlighting how important it is to implement targeted adaptation strategies. Globally, cold temperatures currently cause significantly more deaths than heat, with cold-related mortality accounting for about ten times more fatalities in Europe. Currently, around 6.51% of observed deaths are attributed to cold, compared to just 0.65% for heat (Gasparrini et al., 2017; Martínez-Solanas et al., 2021). These impacts are relatively homogeneous across Europe, although less economically resilient regions, like Eastern Europe, are disproportionately affected.

Certain population groups are also overly affected by temperature extremes, making them particularly vulnerable to the impacts of climate change. Children, elderly and people with pre-existing health conditions are at higher risk of heat and cold related stress and cannot quickly and effectively adjust to environmental changes (Masselot et al., 2023). This means that these groups are more likely to experience temperature-related health problems, as they lack the ability to adapt temperature extremes.

Heat-related mortality rates are increasing across all regions, even in those characterised by cold climate. Projections show, that by the end of the 21st century, heat-related deaths everywhere will reach the level of cold-related mortality rates (Gasparrini et al., 2017). This shift highlights the urgency for cities and regions to prioritise acclimatisation to new climate patterns. Across all emission scenarios, from RCP1.9 to RCP8.5, regions in continental climate zones will still encounter challenges with cold (Masselot et al., 2023). While up till now focus has been placed on mitigating rising universal heat-related threats, northern cities will require a dual strategy for climate adaptation.

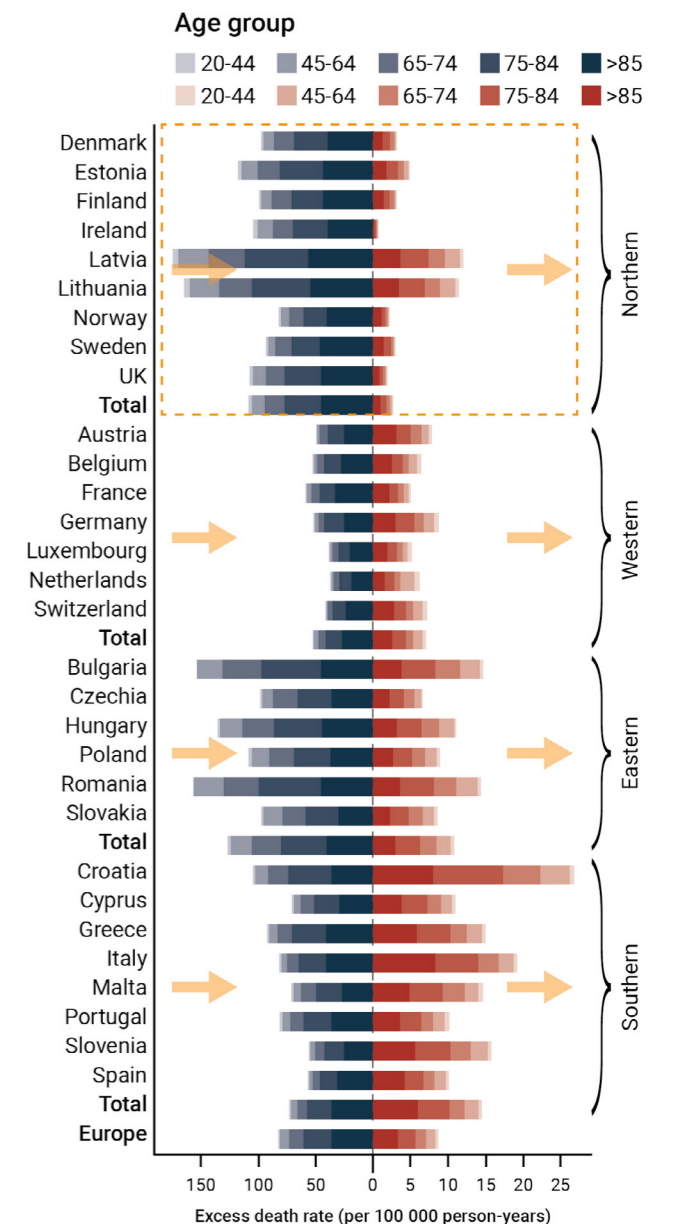


Figure 19. Country level cold (in blue) and heat (in red) annual raw death rates broken down by age group (adapted from Masselot et al., 2023)

## Adapting the Public Space System

Public spaces are essential urban communal spaces, which are severely affected by climate, creating numerous distinct microclimates characterised by the urban form. People are drawn to spaces that feel welcoming, safe, and comfortable, and microclimate plays a key role in achieving these qualities (Gehl, 2010). Urban design adaptation that emphasises comfort can not only increase social and participatory functions of public spaces, but also safeguard vulnerable population during temperature hazards.

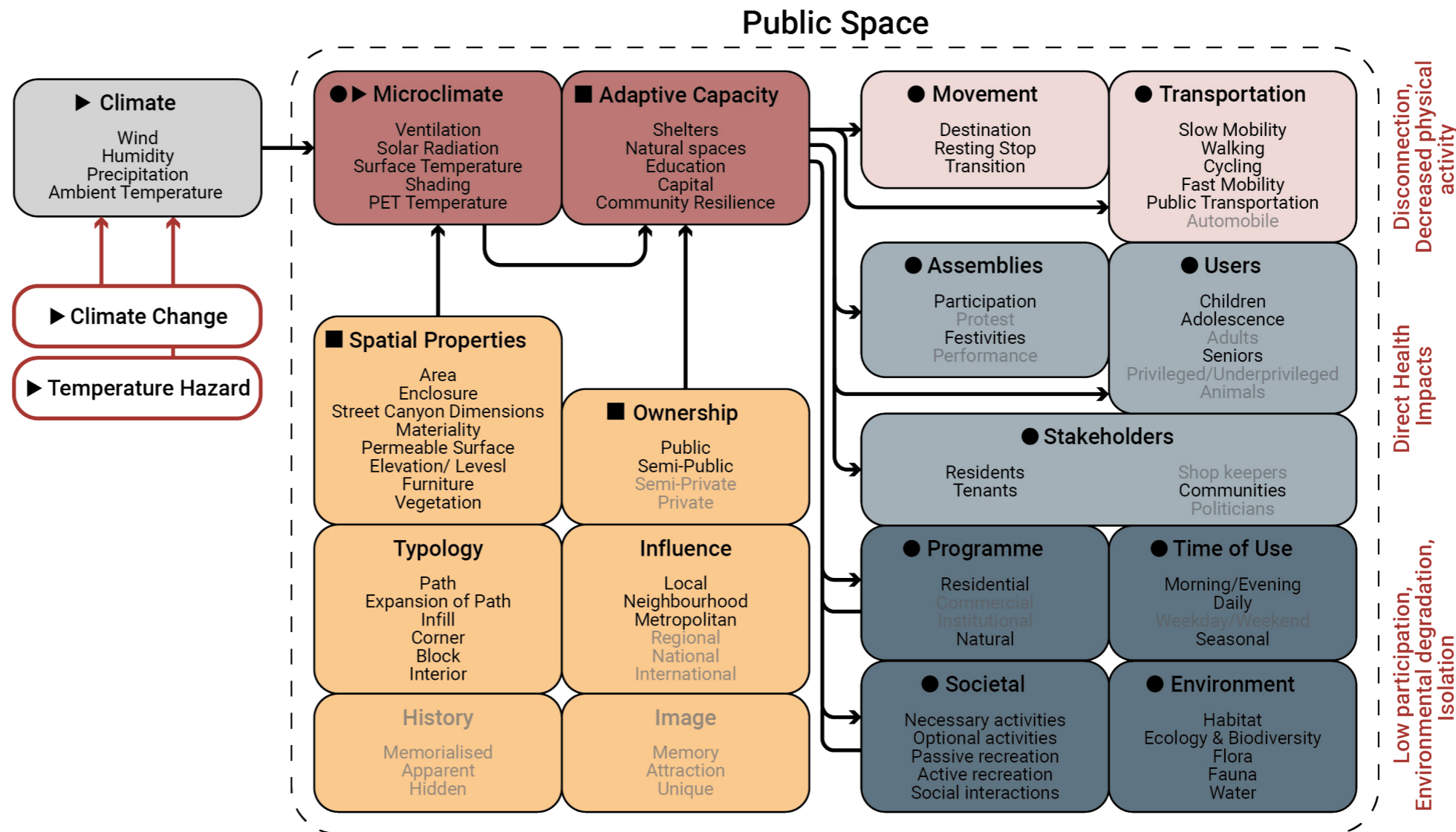
As climate change accelerates, the need for effective public space adaptation increases. Shifting temperature distributions indicate that extreme heat events will become more frequent and intense, while extreme cold events are likely to persist. Urban planners must develop evidence-based design strategies that can transform their public spaces into climate-resilient assets, capable of supporting active, connected, and healthy urban communities under the future climatic conditions and anticipated temperature hazards. Beyond physical interventions, these strategies must include community action to ensure public spaces meet the diverse needs of urban populations. Failure to adapt public spaces will increase health risks, such as heat-related illnesses and cold stress, and will limit opportunities for physical activity and social interactions.

This thesis addresses these challenges through urban adaptation strategies to both temperature extremes.

**Figure 20.** Problem Flow Chart

The system flow illustrates how climate variable, understood as an Input, can impact the whole public space system, defined by the main 5 qualities.

- Comfort
- Function
- Access
- Sociability
- Identity
- ▶ Input
- System
- Outcome
- Impact



# 02

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## Case Study Area

Climate Scope

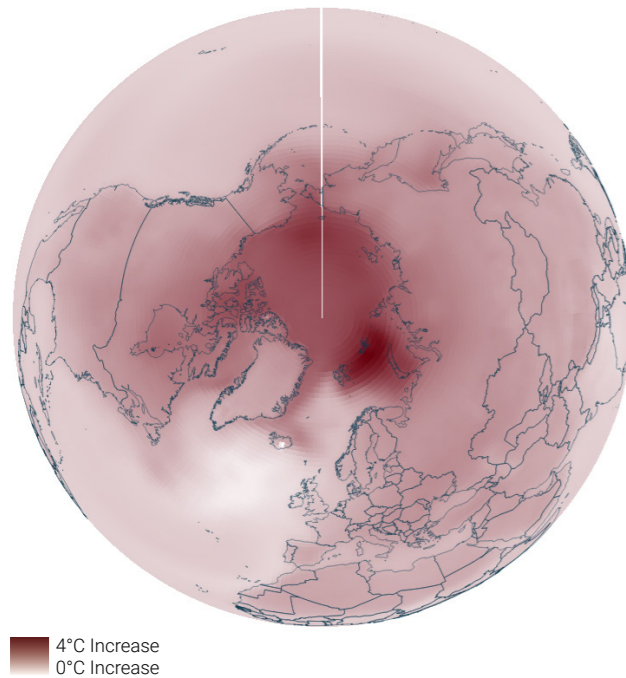
**Vilnius, Lithuania**

*Public Space  
Temperature Hazards*

## Climate Scope

To explore the challenges posed by temperature extremes and their implications for the design of public spaces, this thesis will focus on a specific climate region and city. By narrowing the scope, the research aims to provide a detailed examination of how local climatic conditions influence urban design strategies and the usability of public spaces.

The study contextualises world's climates using the Köppen–Geiger climate classification, developed by a German climatologist Wladimir Köppen, which bases the climate regions on vegetation, temperature, and precipitation patterns (Arnfield, 2024). It divides the world into five major climate types: Tropical (A), Arid (B), Temperate (C), Continental (D), and Polar (E), with further subdivisions within these groups. Each of these types, except for B, is defined by temperature criteria.



**Figure 21.** Mean temperature change, limited to global warming of 1.5°C (adapted from Gutiérrez et al., 2021)

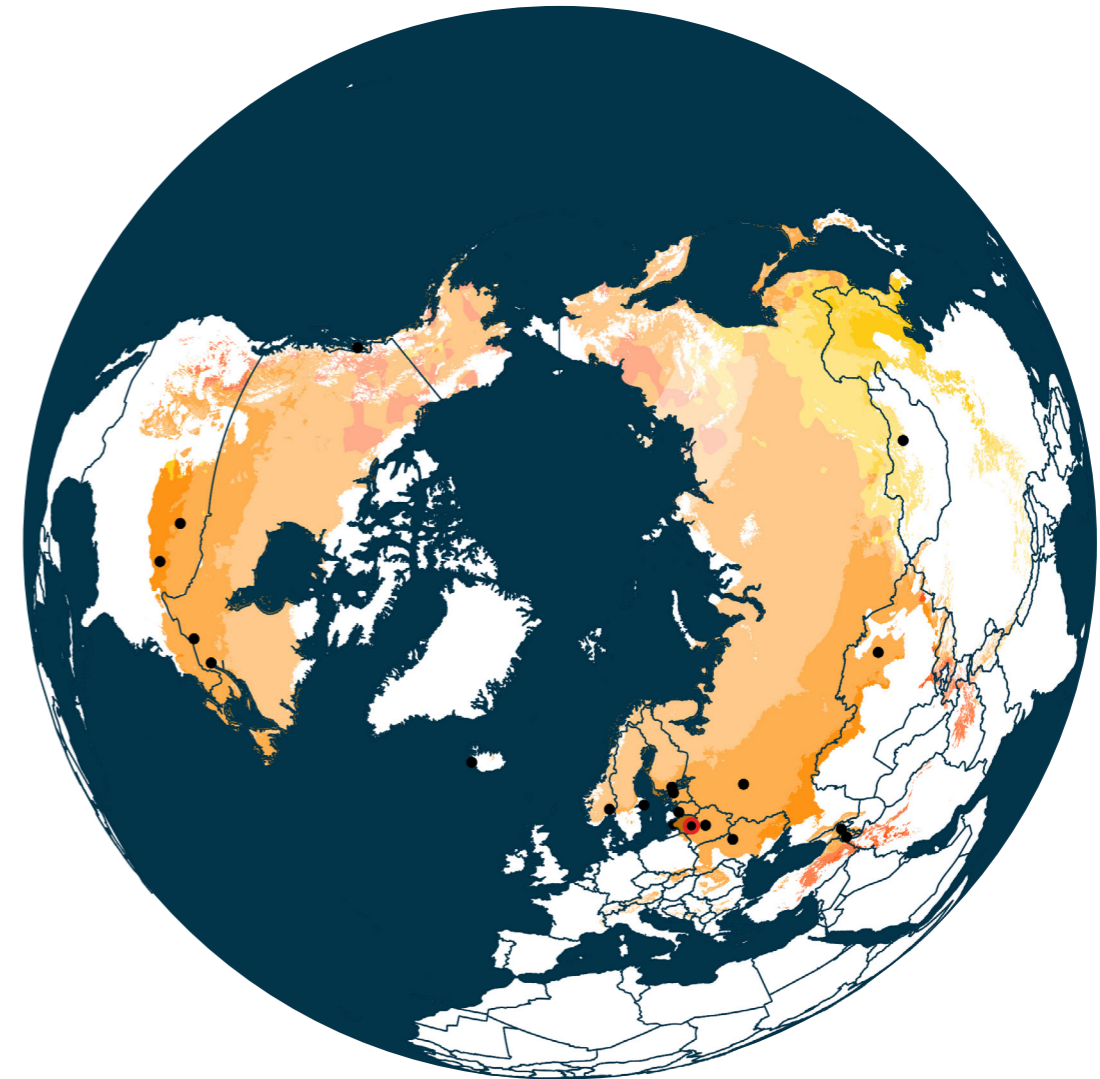
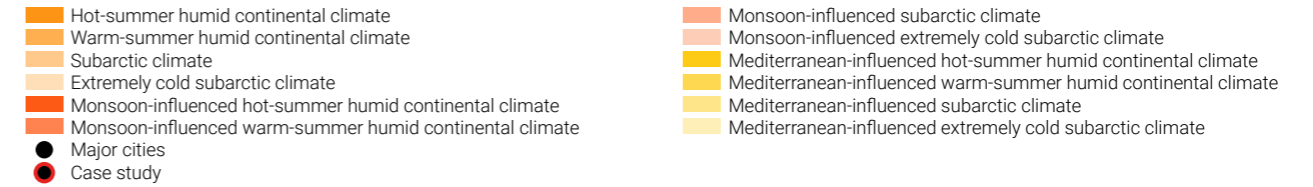
### Continental Climate

Regions that experience the widest temperature range are classified as continental climate, shown in figure 20. These regions have significant temperature variations between seasons – warm to hot summers and cold winters, as well as substantial diurnal temperature variations. This seasonal contrast makes settlements in continental climate zones particularly vulnerable to both heatwaves and cold spells, with climate change expected to exacerbate these temperature fluctuations. These northern regions are also projected to experience the most significant increases in mean annual temperature, even in the best-case scenario of limiting the global temperature rise to 1.5°C, which underscores a challenge of acclimatisation to new climatic conditions (Gutiérrez et al., 2021). Populations accustomed to cold climates are particularly sensitive to rapid warming, as their cultural practices and physical and psychological adaptations are tailored to historically cooler temperatures (Martinez et al., 2018).

Due to the reduction of annual cold, these regions will also encounter additional social and economic transformational challenges, as the current approach frames winter as a period to “wait out”, keeping the cold out, by prioritising insulation and energy efficiency (Pressman, 1991). The present infrastructure and energy systems designed to prioritise heating during cold seasons may struggle to meet increased demands for cooling during warmer months. On the other hand, this transformation also provides a better opportunity to shift the planning approach to “winter urbanism”, which embraces cold periods, by designing cities and public spaces to be enjoyable and functioning in cold and marginal seasons (Leng et al., 2020; Pressman, 1988).

Limiting the scope and analysing these settlements is crucial for developing effective temperature adaptation strategies that address the full spectrum of climatic extremes.

**Figure 22.** Continental climate distribution by Köppen–Geiger climate classifications (data from Rubel et al., 2017)

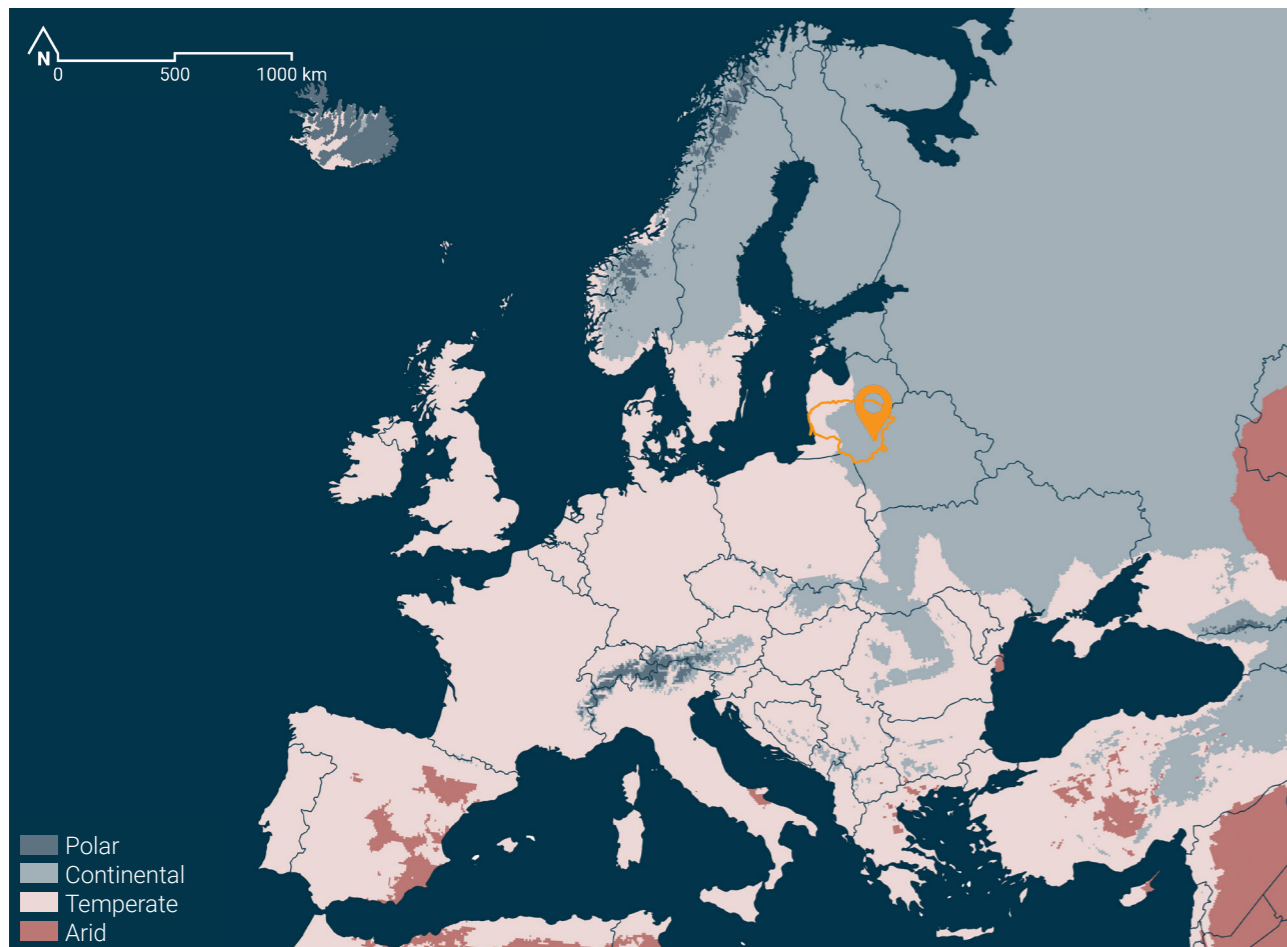


## Vilnius, Lithuania

Vilnius, the capital of Lithuania, is positioned in the southeastern part of the Baltic region, as it lies at the crossroads of Eastern and Northern Europe. This location makes the city a significant case study for understanding urban adaptation to climate variability, characterised by cold winters, warm summers, and increasing seasonal extremes.

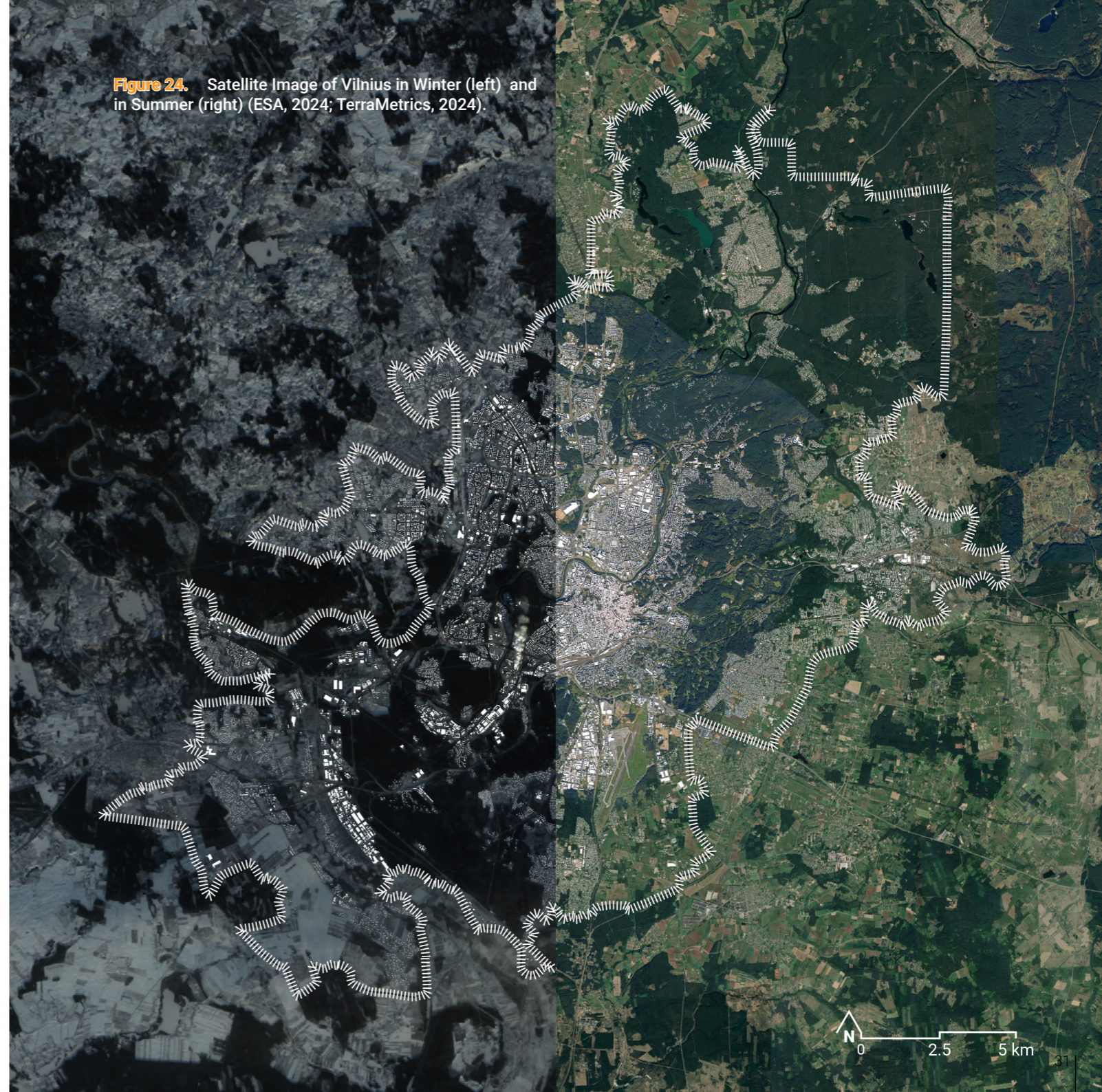
Today, Vilnius is a dynamic, rapidly modernising city with a population of nearly 600,000 (Official statistics portal, 2021). Urban development has been shaped by its post-Soviet

transition, leading to diverse architectural styles and mixed urban form patterns. The city's ongoing initiatives, such as expanding green infrastructure, enhancing pedestrian-friendly areas, and promoting renewable energy, provide opportunities for innovative adaptation strategies. Vilnius has the potential to serve as a model for other cities in continental climate zones seeking to balance modernisation with resilience.



**Figure 23.** Vilnius in Context within the European Climate Zones (data from Rubel et al., 2017)

**Figure 24.** Satellite Image of Vilnius in Winter (left) and in Summer (right) (ESA, 2024; TerraMetrics, 2024).



## Vilnius, Lithuania | Public Space

Vilnius is characterised by its rich historical heritage, large green spaces, and distinctive urban form that merges compact grid-based historical oldtown, open soviet free-planning "mikrorajonai" [micro districts], and sprawled-out village type suburbs (Vasiulytė, 2018). These three characteristics have generated very distinct and uneven public spaces, that face separate core problems and a common challenge in adapting to effects of climate change, particularly in managing different temperature extremes (Bokmota & Šabanovas, 2019).

### Compact Public Space

The most vibrant public spaces are situated in the city's Old Town, extending from the central station to the river Neris. Clusters of street life can be observed in areas with mixed-use developments and successful revitalisation projects, providing diverse functions for different users throughout the day (Kalinauskas, 2014). People-centred streets, which have restricted or reduced car mobility, extend the network of lively places, by connecting the active public clusters. The dense and narrow street network offers numerous opportunities to meet and activities to stay. The vitality of these spaces is also linked to the compact urban fabric and enclosed block structure, as public and private spaces have a clear separation (Moroni & Chiodelli, 2014). This allows residents to participate in cultural and civic activities, while also providing privacy and a retreat from the public realm, creating protected spaces for the local community.

However, the compact structure, that creates a lively social environment by maximising the use of spaces, is also excluding natural elements from the built environment. This leaves these spaces at risk to temperature extremes as the moderating effects of vegetation and water bodies are not part of the structure. Here heat is a particular problem, as these public spaces are situated in the core of the city, amplifying the warmth due to the Urban Heat Island effect (LRT, 2024a).

### Open Public Space

During the Soviet occupation, from the 1940's to the 1990's, Vilnius underwent extensive urban and industrial development. The city was expanded by seven new microdistricts, following modernist urban planning principles. These areas feature large, high-density apartment blocks set within green spaces, designed to meet the housing needs

of a growing population. Most Vilnius residents still live in these neighbourhoods today (Žemaitis, 2024). The city's industrialisation also led to the formation of numerous factories around the city. Public transport networks were developed to ensure that people can move between these mono-functional zones.

This urban structure disregarded quality public spaces and excluded private spaces, creating large open spaces, that are not well-maintained to sustain community activities, nor can be considered quality green spaces. Additionally, these spaces are susceptible to temperature variation, as large unsheltered areas are exposed to wind, while large concrete structures with high thermal admittance can store and radiate heat, further decreasing the usability of these spaces. When given the chance, young residents move away from these neighbourhoods, leaving the elderly and underprivileged to stay, further decreasing community engagement and resilience (Pakalnis, 2016).

### Periphery Public Space

Prevalent suburbanisation around Vilnius has been shaped by economic trends, spatial development policies and emerging living patterns (Stanilov, 2007). Following Lithuania's independence in 1990, the country shifted towards a free-market economy with the restoration of private property rights. This shift encouraged many residents to leave the socialist housing estates and move to the outskirts of Vilnius and build single-family homes. The beginning developments were often chaotic, as they lacked competent territorial planning (Stanilov, 2007).

This urban sprawl and low population density of 10 to 40 residents per hectare complicate the creation of vibrant public spaces. It has led to car-dominant neighbourhoods, that are reliant on private vehicles to reach the city's services, such as employment, education and other daily services. Despite poor infrastructure and lacking public spaces, the trend of young families moving here persists (Official statistics portal, 2021).

As these spaces are on the periphery, they act as separate public islands, which are the main community spaces of the neighbourhood. Ensuring these spaces withstand temperature hazards can lead to a sustainable development of local centres.



Figure 27. Vilnius Compact Centre Public Space (Google Earth, 2025)

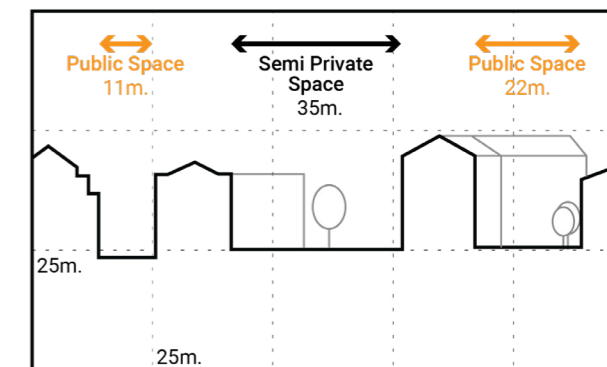


Figure 25. Vilnius Micro-district Public Space (Google Earth, 2025)

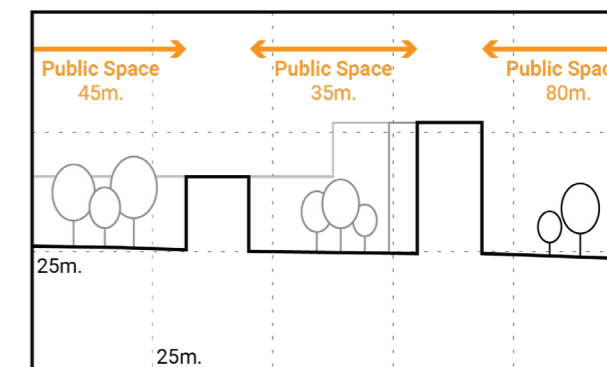
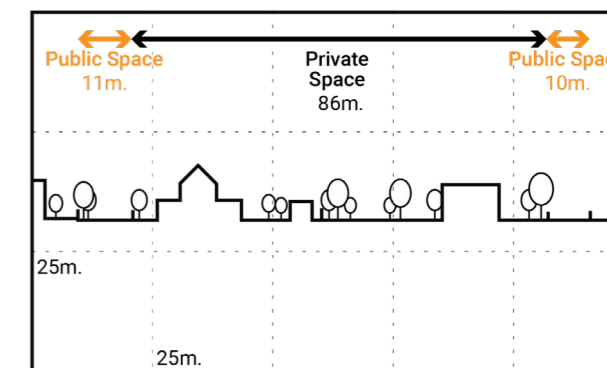


Figure 26. Vilnius Periphery Suburban Public Space (Google Earth, 2025)



## Vilnius, Lithuania | Temperature Hazards

From a climate perspective, Vilnius experiences the widest temperature range in Lithuania, as it is the furthest major city from the moderating influence of the sea. The average temperatures of the coldest month (January) are between -6°C and -2°C, while the warmest month's (July) average high is 23°C and average low 13°C. During winter, snowfalls are common, and occasional intense cold spells can originate from the East. In summer, brief heatwaves can occur, with temperature reaching and exceeding 30°C. Precipitation is evenly distributed throughout the year, but winter months see frequent snowfall, while the summer months are prone to occasional storms. The predominant wind direction in Vilnius is from the Southwest, with colder months being windier, reaching an average hourly speed of 4.2m/s, while summer is the calmest only reaching an average 2.8m/s (Weather Spark, 2025).

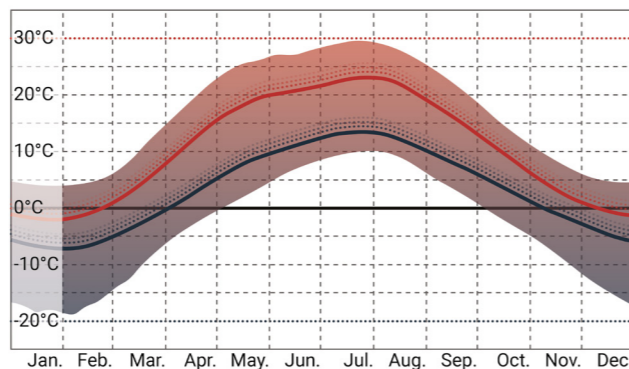


Figure 28. Average Temperature in Vilnius (adapted from Weather Spark, 2025).

When examining the temperature extremes, Vilnius faces significant temperature-related climate hazards that will increasingly affect its urban population by 2100. The city is experiencing rising heat risks, with summer heatwaves (defined in figure 29) becoming more intense and 3.5 times more frequent in the worse-case scenario. This rising heat risk demands urgent attention, as it contributes to heat-related illnesses and mortality, especially affecting sensitive populations, such as people with pre-existing health conditions, elderly and young children (Martinez et al., 2018). However, despite the warming trend, cold spells (defined in figure 30) remain a critical hazard in Vilnius as well. Although the frequency of extreme cold events is decreasing, it is projected to decrease at a much slower rate compared to the rise in heat extremes (Lietuvos Respublikos aplinkos ministerija [Ministry of Environment of the Republic of Lithuania], 2024). Additionally, the city must not overlook cold stress, as currently cold accounts for the largest share of climate-related mortality in Vilnius (Martinez et al., 2018).

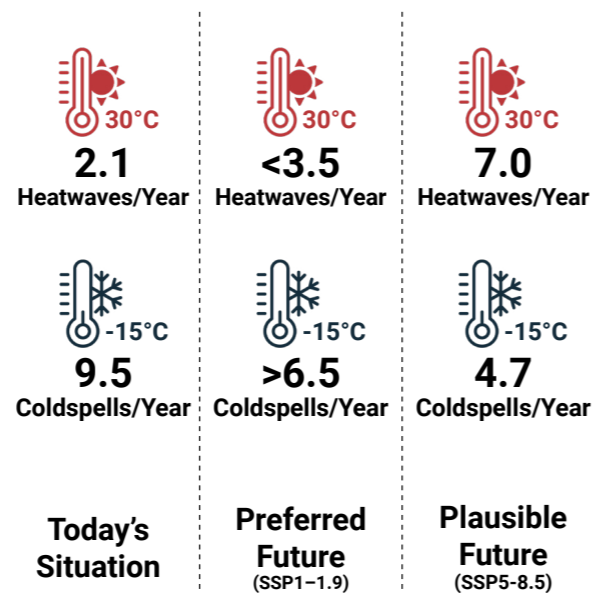


Figure 29. Shifting Temperature Extremes (adapted from Lietuvos Respublikos aplinkos ministerija [Ministry of Environment of the Republic of Lithuania], 2024).

In summary, Vilnius presents a compelling case for studying the challenges of extreme heat and cold, as its significant temperature variability, ranging from harsh winter cold spells to increasingly frequent and intense summer heatwaves, highlights the city's vulnerability to temperature-related hazards. By addressing these challenges in Vilnius, it not only serves as a relevant case for the city's adaptation planning, but also provides valuable insights into designing public spaces situated in similar climate contexts.

Figure 30. Heatwave hazard properties (Heatwave recording 23/08/2022 - 25/08/2022) (Lithuanian Hydrometeorological Service, 2025)

### Heatwaves in Lithuania

Heatwaves generally can be understood as a period of abnormally hot weather. While there is no fixed definition of a heatwave, the most similar meteorological phenomena in the list of Natural catastrophic meteorological and hydrological phenomena would be "Stichinė kaitra" [Intense Heat], which is used when the maximum air temperature is equal to or higher than 30 °C for 3 consecutive days or more. Such indicators basically meet the criteria of a heat wave in Lithuania (Bukantis, 2024).

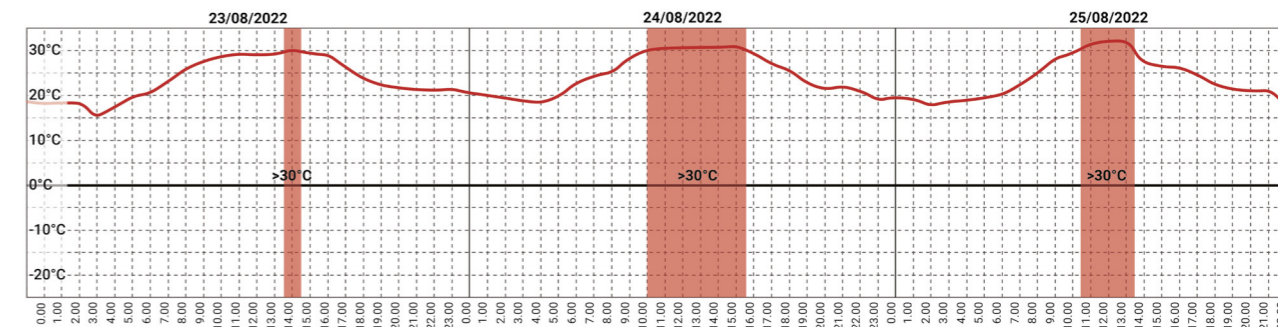
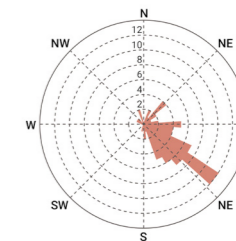
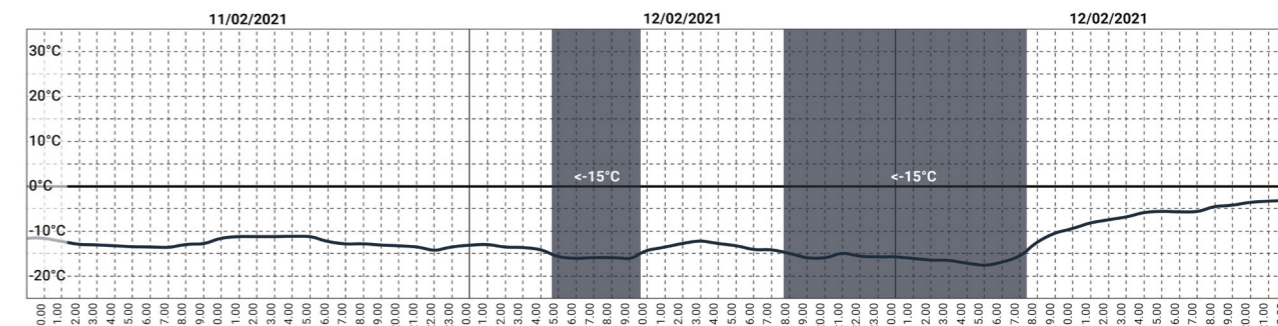
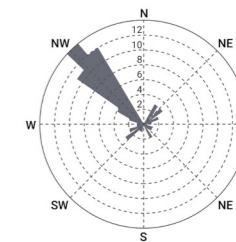


Figure 31. Cold spell hazard properties (Cold spell recording 11/02/2021 - 13/02/2021) (Lithuanian Hydrometeorological Service, 2025)

### Cold spells in Lithuania

Cold waves can be understood as periods of unusually low temperatures. While there is no fixed definition of a cold spell, the most similar meteorological phenomena in the list of Natural catastrophic meteorological and hydrological phenomena, would be "Šaltos dienos" [Cold Spell], when the lowest daily temperature drops below -15°C (Lietuvos Respublikos aplinkos ministerija [Ministry of Environment of the Republic of Lithuania], 2024).



# 03

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## RESEARCH UNDERPINNING

Problem Statement

Research Aim

Literature Review

*Built Density*

*Public Space*

*Vulnerability*

*Exposure*

*Sensitivity*

*Adaptive Capacity*

*Thermal Comfort*

*Well-being*

Research Questions

Conceptual Framework

Concept Operationalisation

Methodological Framework

Thesis Relevance

## Problem Statement

Cities in continental climate zones face significant seasonal temperature extremes, including intense heatwaves in summer and severe cold spells in winter. According to the European Environment Agency (2021), cities in northern and eastern Europe are experiencing increasingly frequent and intense temperature fluctuations, leading to unexpected and unprepared for extremes. These trends are projected to worsen in the coming decades. While cold-related mortality currently surpasses heat-related mortality, global warming is increasing casualties from heat, particularly among vulnerable populations, raising public health concerns for both temperature extremes (Martinez et al., 2018).

In urban areas, public spaces are particularly vulnerable to these extremes. During summer heatwaves, users of public spaces face health risks such as heat exhaustion, heatstroke, and negative impacts on mental health. In contrast, winter cold spells reduce accessibility and engagement in public spaces, adversely affecting community well-being and social cohesion (Huaroc, 2024). Public spaces are essential urban areas where people gather, interact, and participate in social and civic activities, but these spaces are not uniformly adapted to handle the range of seasonal temperature extremes (Jeon et al., 2023).

Urban public spaces are further impacted by the microclimates they create, with variations in temperature, humidity, and wind patterns shaped by built and natural elements (van Esch, 2015). Vilnius's diverse urban forms illustrate distinct challenges in adapting public spaces to climate extremes. The compact core suffers from limited vegetation and intensified heat due to the Urban Heat Island effects. Soviet built micro-districts, with vast open public spaces, face heat absorption from concrete surfaces in summer and heightened wind exposure in winter, highlighted by sensitive communities residing in the areas. Suburban peripheries struggle with poor infrastructure and fragmented public spaces, leaving residents exposed to climatic extremes (Bokmota & Šabanovas, 2019).

From a design perspective, urban temperature adaptation efforts tend to prioritize either heat mitigation or winter resilience, rarely integrating strategies for year-round adaptation. This siloed approach limits the effectiveness of urban climate adaptation planning. For example, the Urban Heat Island effect is primarily viewed as a factor that amplifies heat stress, whereas in a winter context, it could play a beneficial role in mitigating extreme cold (Yang & Bou-Zeid, 2018)

In the case of Vilnius, however, public spaces often lack proactive adaptation measures, with designs typically catering to moderate temperatures rather than extremes. Limited shading and heat-storing materials together with inadequate winter shelters reduce their usability and comfort during marginal seasons, limiting public engagement and community interaction across the city (Gehl, 2010; Kalinauskas, 2014).

This thesis seeks to bridge this gap by developing a holistic, adaptive design framework that addresses both summer heat and winter cold, as well as creating concrete design solutions for extreme temperature adaptation. The thesis integrates both analytical tools and spatial interventions to guide transformations of public spaces in Vilnius and similar climates. By focusing on thermal comfort, seasonal functionality and space inclusivity, the combined design framework and adaptation solutions support the development of adaptive public spaces.

**Figure 32.** Temperature Effectuated Public Space (taken by author)



## Research Aim

This thesis aims to advance the understanding of public space climate-adaptive design by addressing the dual challenges of intensified heat stress and persistent cold stress, which are often treated as disconnected issues in urban planning and design. By addressing these two extremes, the research seeks to develop a holistic approach to managing urban extreme temperature hazards, ensuring that public spaces remain functional, vibrant, and inclusive throughout the year.

The research examines the relationship between urban physical components, such as urban form, vegetation, materiality, and spatial configuration, together with social processes, including mobility, public activities, and patterns of space usage. Through this analysis, the thesis will demonstrate how these factors influence microclimatic conditions and shape the usability of public spaces under temperature extremes.

By combining insights from climate science, urban morphology, and behaviour dynamics, the thesis aims to provide urban planners and designers with a practical framework for decision-making. This framework will include strategies for integrating temperature adaptation into the planning, design, and improvement of public spaces, in the form of pattern language cards, promoting resilience to climate change while enhancing social benefits.

The second aim of this thesis is to explore the application of temperature-adaptive measures through the case study of Vilnius. By focusing on selected public spaces within the city, the research will illustrate how targeted interventions in a few key components can transform these spaces into more accessible, comfortable, and engaging environments, even under extreme temperature conditions.

The case study will provide an environment to test and refine adaptive strategies, demonstrating how interventions can complement each other to significantly improve thermal comfort, usability, and overall well-being in public spaces. This exploration functions as a model for other cities in continental climate zones, highlighting the potential for scalable, context-sensitive solutions.

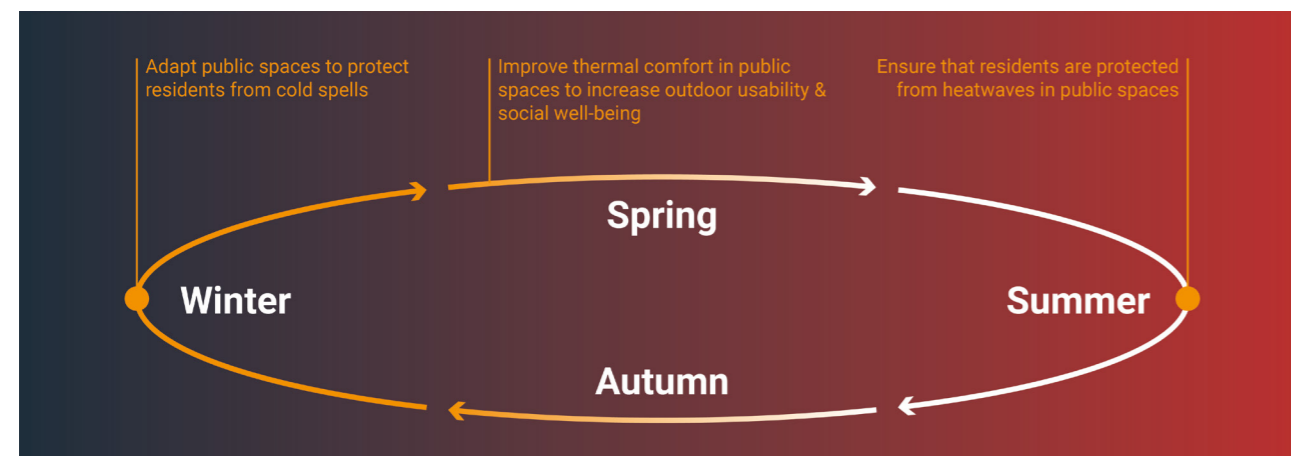


Figure 33. Project objectives related to the Problem

## Research Questions

### Main Research Question:

The thesis is guided by a main research question and the following 6 sub-research questions:

**How could public spaces in Vilnius, Lithuania be adapted to seasonal temperature extremes, while simultaneously fostering social well-being throughout the year?**

### Sub-Research Question No.1 |

What is the current vulnerability of public spaces in Vilnius, concerning seasonal temperature extremes?

*Aim:* To map the city's temperature exposure, sensitivity to temperature and its adaptive capacity, outlining the city's risk map.

*Methods:* Data based analysis, Spatial analysis, Mapping

### Sub-Research Question No.2 |

How to classify urban climate zones in the context of Vilnius based on morphological characteristics?

*Aim:* To develop a city framework, which divides the city into climate contexts, describing similar thermal conditions.

*Methods:* Mapping, Morphology definition.

### Sub-Research Question No.3 |

Which design strategies and technologies have been proven effective to manage urban temperature extremes?

*Aim:* To collect and categorise the various temperature adaptation strategies into an atlas from the carried-out literature reviews and precedents. To contextualise the knowledge and observe implementation challenges and opportunities.

*Methods:* Literature review, Pattern Language.

### Sub-Research Question No.4 |

What are the potential spaces for heat/cold adaptation that improve social well-being in Vilnius urban fabric?

*Aim:* To analyse the area's social communal spaces, that the local communities use or are missing. To evaluate their thermal qualities?

*Methods:* Fieldwork, Spatial analysis, Pattern Language.

### Sub-Research Question No.5 |

What design solutions can be implemented to public spaces in Vilnius to enhance their functionality and social well-being throughout the year?

*Aim:* To develop possible design solutions for each of the chosen problematic public spaces.

*Methods:* Research by design, Pattern Language.

### Sub-Research Question No.6 |

How effective are the integrated adaptive design solutions during seasonal temperature extremes?

*Aim:* To methodically evaluate the design's effectiveness to temperature extremes.

*Methods:* ENVI-MET Simulations, Pattern Assessment.

## Literature Review

In order to address the challenges set in the introduction, research was conducted in the domains of heat adaptation planning, built density, public space design and winter city movements. Each of these domains have advanced their research through the development of concepts to better understand the components of climate-related risks, space and form's influence on livability and people's approach to climate. This review examines climate, or more specifically, temperature, and the city through three main lenses, which are climate as a threat, climate as an effect and climate as an opportunity.

### Heat adaptation planning

The first domain focuses on planning and designing spaces that emphasise resilience to dangerous hazards, such as extreme heat. The papers examining this topic highlight the importance of integrating adaptive or mitigating measures for urban spaces as well as increasing social capital for community preparedness. The relevant concepts extracted from these readings include vulnerability, exposure, sensitivity and adaptive capacity.

### Built density and form & Public space design

These two domains focus on examining how the built environment shapes the urban microclimates, which then influence how people use public spaces. Here theory emphasises that public spaces provide essential opportunities for thermal protection whilst promoting space sociability for diverse user groups. The applicable concepts from these readings include density matrix, proximity and space usability.

### Winter city movements

And lastly, winter city movements, while limited in scope to cities situated in the northern latitudes, address urban problems relating to cold climates. They advocate for rethinking urban design to include the marginal seasons, increasing the significance of public spaces while also providing social and health benefits. These readings were the driving force to expand the temperature adaptation to both extremes, not limiting the problem to heat. Important concepts found here, such as thermal comfort and well-being, are also applicable to public space theories.

By gathering insights and putting these research domains in collaboration with each other, this literature review aims to establish foundational concepts to be implemented by this thesis. Each of the relevant concepts are explained further on to inform the research questions and develop the conceptual framework.

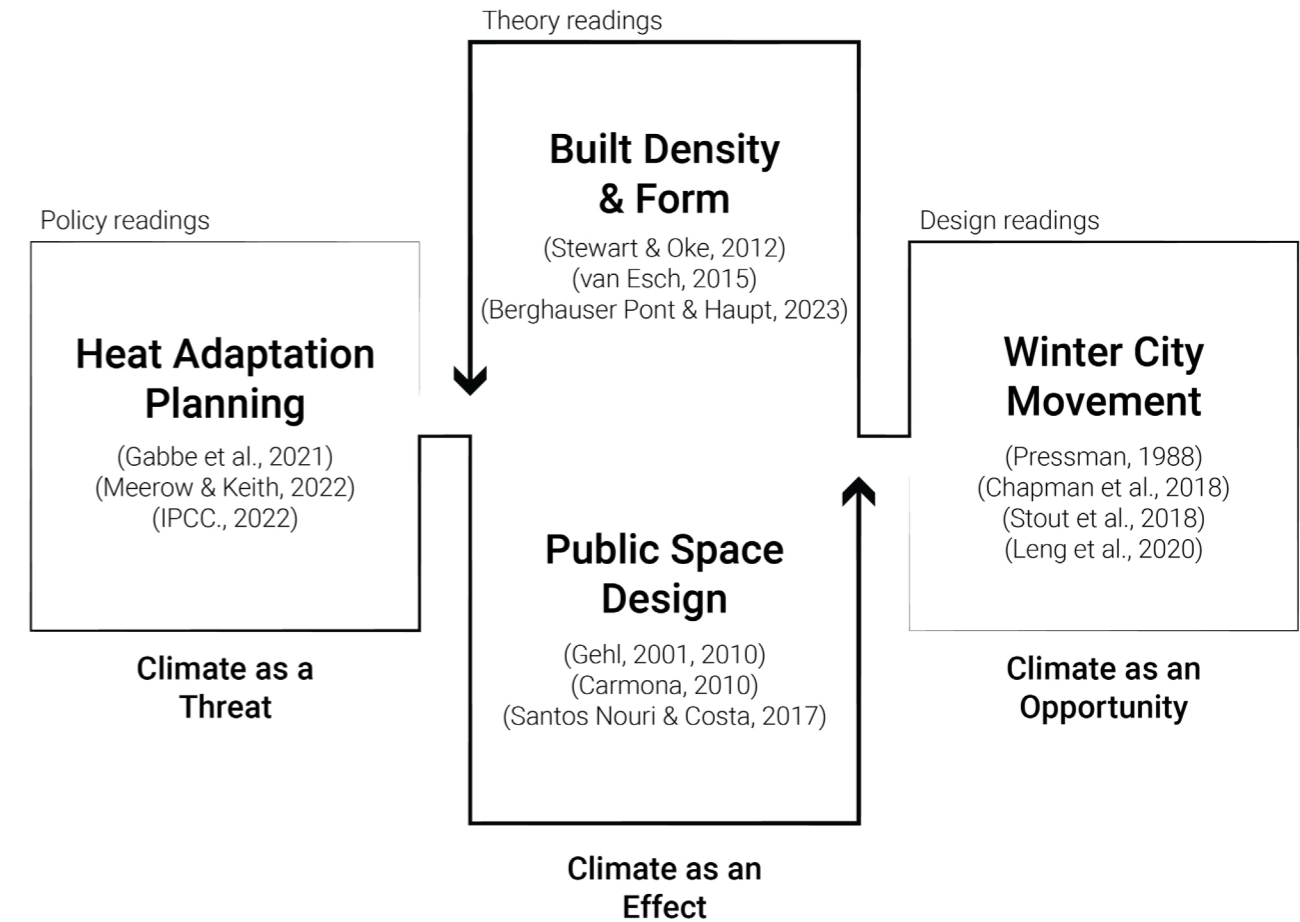


Figure 34. Examined Fields of Policy and Theory

## Vulnerability

To understand climate-related risks, defining vulnerability is critical, as this term integrates all the other concepts within this domain. Vulnerability is a multi-faceted concept that refers to the susceptibility of a system, community, or individual to harm from external stressors, such as climate change and extreme weather events (IPCC, 2018).

Concepts relating to climate hazard's vulnerability, risk and adaptability have received increasing attention in the past few decades and have been redefined and redeveloped due to climate change's worsening impacts (Li et al., 2024). The past few publications by the Intergovernmental Panel on Climate Change (IPCC) have been focused on vulnerability and adaptability. In the 4th, 5th and 6th assessment reports, vulnerability was integrated into the concept of climate risk and changed the relationship between its foundational concepts (IPCC, 2022). This shift has redefined the framework to a broader approach, providing a baseline understanding of risk modelling. Vulnerability assessment following this approach, identifies hotspots where urban planning interventions are needed to mitigate risks and improve resilience, however, it does not specify implementation possibilities, as it remains an overview tool. It generalises the concept to integrate various climate hazards. The general formula is stated below:

$$\text{Risk} = \text{Exposure} \times \text{Vulnerability} \times \text{Hazard}$$

$$\text{Vulnerability} = (\text{Sensitivity} - \text{Adaptive Capacity})$$

(IPCC, 2022)

While the IPCC report's definition is the most recent one, there are alternative vulnerability definitions that describe the framework in more detail and relation to temperature hazards, originating from the discourse of heat related risks (Gabbe et al., 2021).

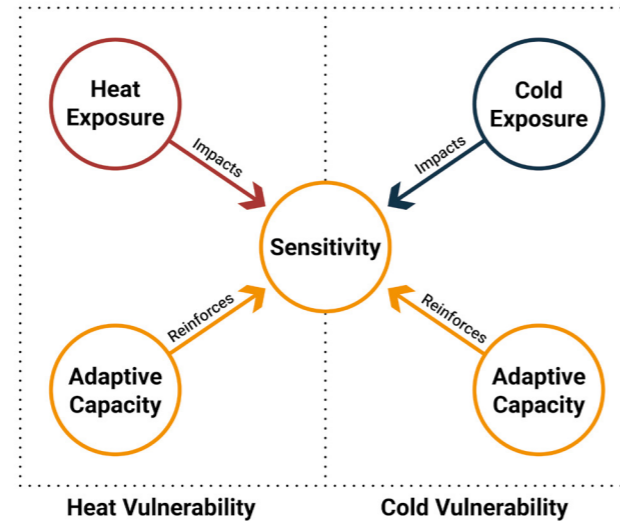
By retaining the concept of "exposure" within vulnerability, it allows a more actionable response, as the sub-concepts interrelate to one another, as shown below:

$$\text{Vulnerability} = \text{Exposure} + \text{Sensitivity} - \text{Adaptive Capacity}$$

(Gabbe et al., 2021)

The second vulnerability definition is more relevant to this thesis as it better illustrates the susceptibility of public spaces and their users to heat and cold impacts. This

framework describes that reducing public space vulnerability to heat or cold requires reducing exposure and sensitivity and increasing adaptive capacity.



**Figure 35.** Temperature Vulnerability Framework

## Exposure

In risk related literature, exposure refers to the presence of people, infrastructure, and ecosystems in areas susceptible to climate-related hazards (IPCC, 2022). In heat adaptation planning, heat exposure relates to heat wave occurrence and the distribution of heat within the urban environment due to the causes creating the Urban Heat Island effect. The distribution is intensified by spatial factors, such as proximity to heat generating land-use or heat retaining urban structures, as well as areas with insufficient vegetation (Wilhelmi & Hayden, 2010). Cold exposure can be comparably defined as an inverse coloration to the uneven distribution of heat within the urban fabric (López-Bueno et al., 2022).

Exposure is typically evaluated using environmental measures. To identify temperature exposure and its heat distribution across urban landscapes, studies and municipality assessments are beginning to calculate precise temperature measurements across different spaces and timeframes (Vankevičė, 2024). The most direct approach in measuring exposure would be to calculate ambient air temperature. However, this approach is heavy on time and resource consumption, only advantageous in interior spaces or small environments.

An alternative, widely used method to calculate proxy for exposure, would be to measure Land Surface Temperature (LST). It shows high radiance variance between various surface conditions, directly influencing the surrounding temperature (Kumar et al., 2023).

## Sensitivity

The concept of sensitivity measures the degree to which a system or population is affected, as well as the extent to which a system or population can endure its effects without experiencing lasting harm (Gabbe et al., 2021). It can encompass physical, social and economic dimensions, depending on the chosen targeted subject. Sensitivity can be calculated for individuals, examining their health status, or physical structures, such as housing or electricity infrastructure, by assessing their tipping (breaking) points.

Sensitivity to temperature concerns vulnerable populations. It is dependant on socio-economic and health factors, as proven by demographic and health condition data, elderly, young children, low-income individuals, and socially isolated people are the most disproportionately impacted (Wilhelmi & Hayden, 2010).

From an urbanist point of view, when examining sensitivity, the concept is descriptive, assessing the situation in order to recognise, which vulnerable group requires the most attention, instead of transforming the group itself to minimise sensitivity. To minimise the vulnerability of a particular sensitive group, attention is required to mitigate exposure and increase adaptive capacity.

## Adaptive Capacity

In general terms, adaptive capacity is the ability of a system or community to adjust to, cope with, or recover from the impacts of climate hazards (IPCC, 2022). This definition is too broad, as seen in literature, where the concept application is widely contested, with certain research papers relating it to mitigation of exposure, while others use it as an extension of sensitivity. However, there is a consensus that individual adaptive capacity is a socio-economic aspect, defining capacity measures, such as income, education, health, material assets and participation in organisations to be universally beneficial when responding to threats (Guardaro et al., 2022).

A more precise definition relating to temperature adaptation comes from Wilhelmi & Hayden (2010), who states that adaptive capacity is the ability of a system or population to actively adjust its characteristics and behaviour to better manage current stresses. This emphasises active (partaking) strategies, such as leveraging social networks, taking up protective behaviour and accessing cooling or heating resources before and during a climate hazard.

When considering the adaptive capacity of public spaces, it can be understood as twofold. Within a defined space it is the active transformation or influence that mitigates exposure, by changing the microclimate through technological means, rearranging furniture and amenities to create a more pleasant space or changing one's current activity. The alternative adaptation would be to relocate to a less exposed area. This requires guaranteeing access and knowledge about available shelters.

While these concepts have advanced the understanding and response to climate vulnerability, research has also put increased emphasis on urban environment's role in affecting climate and the usability of public spaces due to its' spatial characteristics.

### Built Density and Form

Concepts, such as built density and built form strongly influence urban temperature differences. Dense areas result in higher thermal heat storage, while urban form, such as building geometry and orientation, can trap heat and hinder natural ventilation (van Esch, 2015). While density can be defined in many different ways, ranging from population density to dwelling density, Berghauser Pont and Haupt (2023) suggest treating density as a multivariable phenomenon, that incorporates Floor Space Index (FSI), that calculates the ratio of total built floor area to the plot area, and Ground Space Index (GSI), that calculates the ratio of the buildings footprint to the plot area. This approach allows a more nuanced understanding of urban areas and a closer relation to urban form.

One correlated concept of built density is proximity. Proximity describes spatial closeness of amenities, services or urban elements, within proximity based-planning, such as 15-min cities or transit-oriented planning (Allam et al., 2020). However, proximity can also ensure adaptive capacity, as accessible and nearby built environments or services, such as shelters, can provide refuge for people during temperature hazards. An additional influential aspect of urban climate are surface properties, which correlate with built density, as dense environments are limited with in-between spaces, requiring higher percentage of paved surfaces, resulting in reduced vegetation and increased heat absorption (Berghauser Pont & Haupt, 2023).

Other studies, such as by Stewart and Oke (2012), have created morpho-typologies that use urban density and form to create distinct contexts that differ in temperature storage and radiation. This Local Climate Zone classification uses indicators of compactness and openness (GSI), from low-rise to high-rise (FSI) and surface properties. The different environments are not only distinct in their climatic properties but also differ in their space distribution, as various built densities require or are limited to specific functions, creating uneven public spaces.

### Public Spaces

Public spaces have long been central to urban life, serving as the stage for social interaction, cultural exchange, and individual activity. These spaces are defined broadly as areas accessible to everyone, regardless of their social or economic

status (Gehl, 2010). This inclusivity allows public spaces to be considered as commons, assets that are collectively used and maintained by a community or the whole society (Bezboroa, 2020). The uses and values of these spaces are shared by everyone, making them essential safeguards for people during climate hazards. However, these spaces provide different purposes and theories and classifications of public spaces have evolved to reflect their diverse roles. Among the different classifications of public space, Carmona (2010) distinguishes public spaces by their function, control and ownership. Additionally, the classification system incorporates interior public spaces, which are crucial when considering shelters during temperature extremes.

As the thesis is examining spaces shared by all, the definition of public spaces is limited by excluding privately owned spaces, with the exception of public “private” spaces, as these spaces are meant for communities. The narrowed definition of public spaces is:

All those parts of the built and natural environment, internal and external, where the public has free, although not necessarily unrestricted, access (Adapted from Carmona et al., 2021).

### Space Usability

Usability is one of the key concepts in studies focusing on public spaces. It refers to the extent to which a physical environment supports the needs, activities, and comfort of its users. Different spaces are used for various purposes, from relaxation and recreation to commuting and commerce. Usability is shaped by factors such as accessibility, environmental conditions, and design elements like seating or shading. For instance, Jan Gehl's (2001) categorization of activities, as necessary, optional, and social, which provides a framework to evaluate usability. Necessary activities, such as commuting, are less influenced by spatial quality, whereas optional and social activities depend heavily on the comfort of the space.

The usability of outdoor public spaces fluctuates, depending on environmental conditions, creating daily, weekly and seasonal usage patterns (Shooshtarian & Rajagopalan, 2017). Outdoor areas usually see high activity during mild weather but become underutilized during extreme temperatures. It is a critical consideration in urban planning and design, as usability directly influences how and why people engage with a space, reflecting the spaces realisation.

Space type	Distinguishing characteristics	Examples
1. Natural/semi-natural urban spaces	Natural and semi-natural features within urban areas, typically under state ownership	Rivers, natural features, seafronts, and canals
2. Civic space	The traditional forms of urban space, open and available to all and catering to a wide variety of functions	Streets, squares, and promenades
3. Public open space	Managed open space, typically green and available and open to all, even if temporally controlled	Parks, gardens, commons, urban forrests, and cemeteries.
4. Movement space	Space dominated by movement needs, mainly for motorised transport	Main roads, motorways, railways, and underpasses
5. Service space	Space dominated by modern servicing requirement needs	Car parks and service yards
6. Leftover space	Space left over after development, often designed without function	“SLOAP” (space left over after planning), modernist open space
7. Undefined space	Undeveloped space, either abandoned or awaiting redevelopment	Redevelopment space, abandoned space, and transient space
8. Interchange space	Transport stops and interchanges, whether internal or external	Subway, bus interchanges, railway stations, and bus/tram stops
9. Public “private” space	Seemingly public external space, in fact, privately owned and controlled	Privately owned “civic” space, business parks, and church grounds
10. Conspicuous space	Public spaces designed to make strangers feel conspicuous and potentially unwelcome	Cul-de-sacs and dummy-gated enclaves
11. Internalised “public” space	Formally public and external, but internalised and often privatised	Shopping/leisure malls and introspective megastructures
12. Retail space	Privately owned but publicly accessible exchange space	Shops, covered markets, and gas stations
13. Third place space	Semi-public meeting and social places, public, and private	Cafes, restaurants, libraries, town halls, and religious buildings
14. Private “public” space	Publicly owned, but visually public space	Institutional grounds, housing estates, and university campuses
15. Visible private space	Physically private, but visually public space	Front gardens, allotments, and gated square
16. Interface space	Physically demarked but publicly accessible interfaces between public and private space	Street cafes and private pavement space
17. User selecting space	Spaces for selected groups, determined, and sometimes controlled by age or activity	Skateparks, playgrounds, and sports fields/ground/courses
18. Private open space	Physically private open space	Urban agricultural remnants and private woodlands
19. Extrenal-private space	Physically private spaces, grounds, and gardens	Gated streets/enclaves, private gardens, private sports clubs, and parking courts
20. Internal-private space	Private or business space	Offices, houses, etc.

Figure 36. Different types of public spaces, categorised by M. Carmona (Carmona, 2010)

### Thermal Comfort

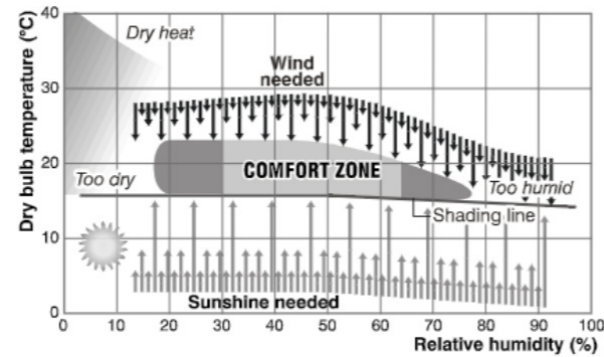
Another fundamental concept associated with temperature is thermal comfort. It is defined as a condition in which a person expresses satisfaction with the thermal environment (Shoostarian et al., 2020). It is influenced by environmental factors, such as air temperature, humidity, wind speed and solar radiation, physiological acclimatisation, correlating with quick changes in the surrounding conditions and long-lasting embedded biological adjustment to their living environment, and lastly cultural adaptations, such as physical activity or clothing (Nikolopoulou & Lykoudis, 2006). Every climatic region has its own characteristics and meanings of a thermal comfort index.

Thermal comfort is especially considered in indoor spaces, as with passive design and active HVAC technology, these spaces are fully controlled to create the best environment. However, achieving thermal comfort in outdoor spaces is problematic due to the complexity of outdoor microclimates (Latini et al., 2010). Microclimatic conditions in urban open spaces are shaped by urban morphology, surface materials, and vegetation. These factors directly affect the thermal environment through processes such as heat absorption, reflection, evapotranspiration, and shading.

While the study by Nikolopoulou and Lykoudis (2006) identified air temperature and solar radiation as the most significant aspects of realising outdoor thermal comfort, all meteorological parameters influence thermal comfort. Long exposure to high temperatures creates heat stress, while low temperatures prompt cold stress. Humidity amplifies the perception of heat, limiting the body's ability to cool itself. Wind speed results in heat dissipation in warm conditions but increases the sensation of cold in low temperatures.

Various indexes have been developed to quantify thermal comfort. By combing two or more climatic parameters, more accurately perceived experiences can be calculated, such as wind-chill index, heat index or physiological equivalent temperature (PET), which reflects the thermal balance of the human body.

Research highlights the need for integrating environmental, physiological, and psychological factors into urban planning and design when targeting thermal comfort.



**Figure 37.** Bioclimatic chart (Reiter & Herde, 2003), illustrating that comfort is dependent on each climatic factor

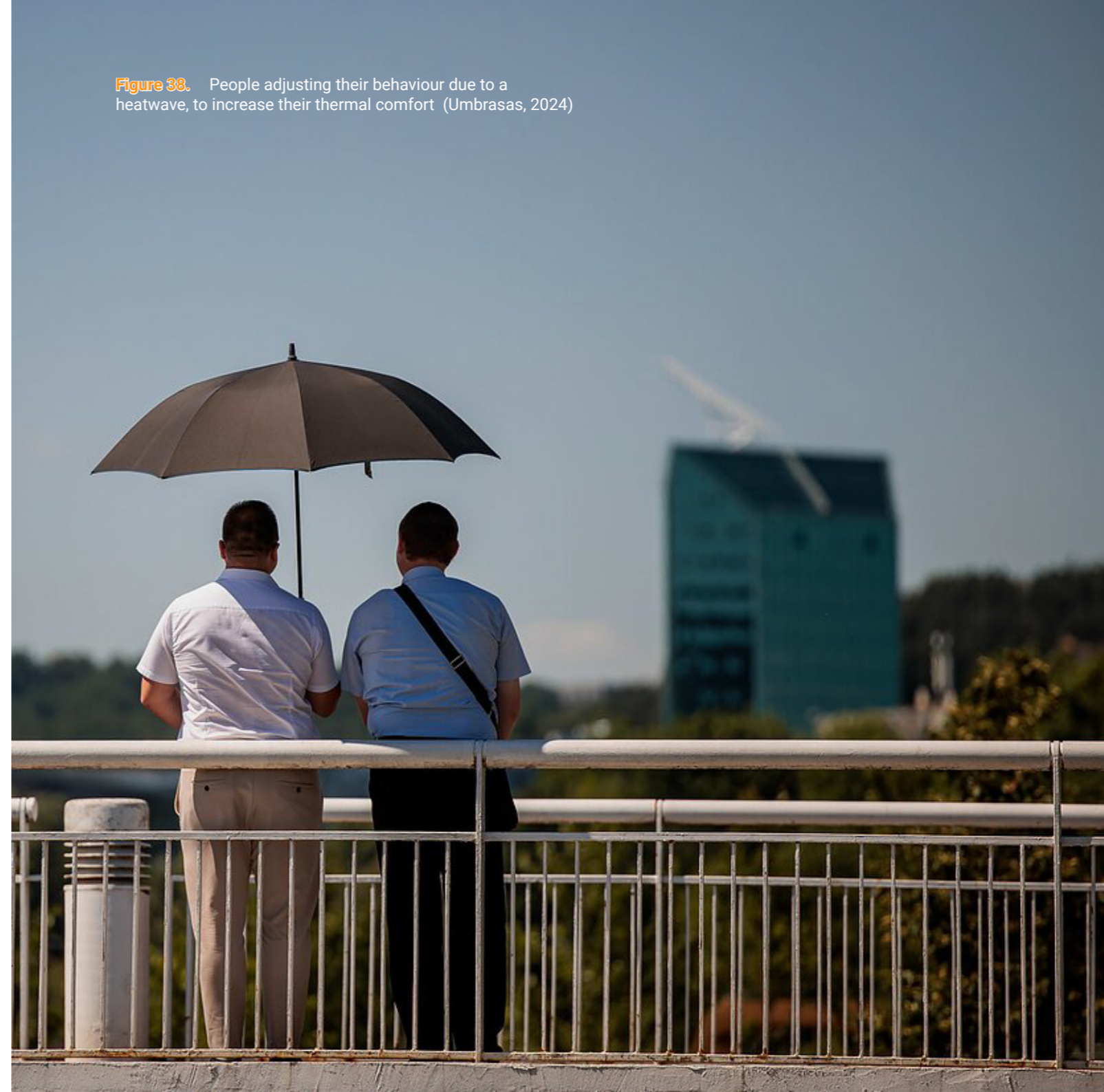
### Well-being

Lastly, when designing spaces for people, understanding well-being is required. In literature, urban well-being is a concept that incorporates many aspects of a person's life, that are shaped by infrastructure, social networks, and community development (Setiawan & Ningtyas, 2023). The four main dimensions of well-being are physical, psychological, social, and environmental.

Physical well-being highlights physical health and urban systems that support it, such as access to green spaces and adequate housing. Psychological well-being ensures high mental health by a sense of safety and freedom from stressors. Social well-being defines strong social networks, community engagement, and a sense of belonging within the neighbourhood. And lastly, environmental well-being identifies living in a sustainable and healthy environment that supports long-term human and ecological health.

While all four sections are critical for creating livable and inclusive environments, this thesis puts emphasis on physical and social well-being. This focused definition examines urban health, relating to sensitivity, together with sociability and community development, linking to adaptive capacity. Effective adaptation to temperature extremes directly supports urban social well-being by reducing physical risks, enhancing comfort, and fostering inclusive community engagement.

**Figure 38.** People adjusting their behaviour due to a heatwave, to increase their thermal comfort (Umbrasas, 2024)



## Conceptual Framework

In order to answer these questions, the thesis is grounded in a multi-disciplinary conceptual framework that integrates climate adaptation concepts with urban design and public space theories. By employing the key concept of vulnerability through Exposure, Sensitivity and Adaptive Capacity, as well as thermal comfort and well-being, the framework establishes a comprehensive approach to designing temperature-adaptive public spaces in Vilnius. These concepts are interconnected and collectively form a layered ringed structure.

The exterior arrows communicate the problem examined in the thesis, which are two temperature extreme hazards, positioned on opposite sides. The circular structure of the diagram illustrates reoccurring cycle of seasons and these challenges, as adaptation is a continuous task, that requires ongoing modifications.

The outer layer, consisting of Exposure, Sensitivity and Adaptive Capacity collectively inform the public space general vulnerability to hazards of temperature extremes. Each of the concepts additionally inform the project with the required Focus for which extreme, the Urgency related to a specific sensitive group, and the possible Adaptive Approach, accordingly, as seen in figure 38. These concepts operationalise the analysis from a climate meso-scale, building on the understanding and relationship between the urban structure and the urban climate.

The inner layer, consisting of thermal comfort and well-being is linked with the outer layer by defining tangible evaluation criteria for public space usability and possible adaptation grading. Each of these concepts are linked with the larger vulnerability scheme, as thermal comfort can examine exposure reduction for nearby shelters and specific paths connecting to alternative options increasing adaptive capacity, while well-being can inform the sociability of a particular resident group. Thermal comfort are examined by measurements and observations of the current spaces between buildings to evaluate the physical design, while well-being determines the strength and sociability of the community, portraying its resilience, as seen in figure 39. These criteria are relevant within a district, block or parcel scale, local and micro climate scales, creating design briefs for public space adaptation, regeneration or creation.

The core demonstrates the main topic of exploration, which is public space. By utilising the concepts within the circle, the exterior challenges can be better understood and prepared for, to ensure that the core is least affected.

The main concepts are operationalised or measured through the indicators, which are attached to each of the concepts. These indicators are explained in the next chapter "Concept Operationalisation".

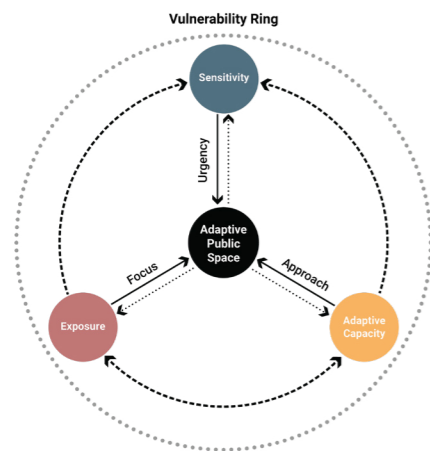


Figure 39. Vulnerability Concepts

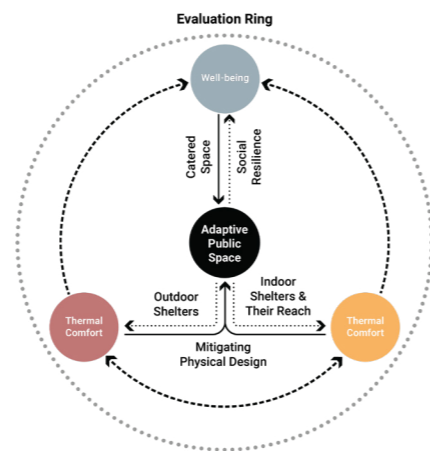


Figure 40. Evaluation Concepts

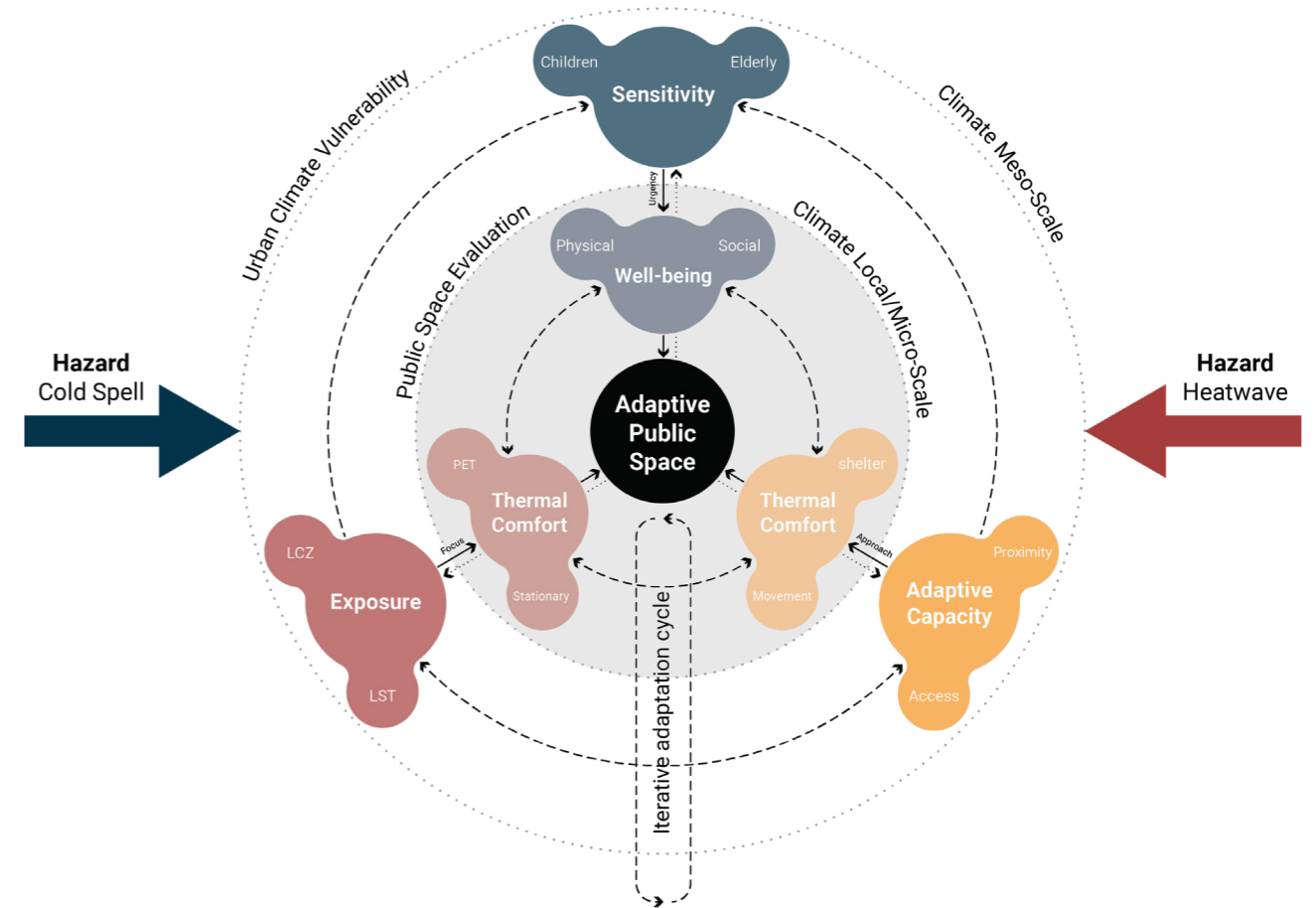


Figure 41. Conceptual Framework

## Concept Operationalisation

### Vulnerability concept operationalisation

To understand how vulnerability can be measured, a literature review was conducted to collect, which indicators were determined to operationalise the three sub-concepts of the framework. A research paper search was conducted with Google Scholar using these specific key words:

*'Heat' / 'Cold' / 'Vulnerability' / 'stress' / 'Exposure' / 'Sensitivity' / 'Adaptive Capacity' / 'urban' / 'public space' / 'indicators' / 'variables'*

From each article, which had a relevant or similar topic to this thesis, a column, table or list containing indicators or variables was extracted. The indicators that were irrelevant or not applicable to a continental context, Lithuania's demographic and urban context were removed. From the remaining list, indicators which could be spatialised were chosen, as the study focuses on public spaces.

Exposure and Adaptive Capacity, for this study focuses on the built environment: Exposure indicates which areas are prone to overheating while others are quickly dissipating it, Adaptive Capacity indicates the available and accessible resources to protect oneself from temperature hazards. While Adaptive Capacity, in other studies, examines the income and education, for public space analysis these indicators were non-operationable. With income and knowledge, people are capable of actively adjusting (adapting) to their environment or their position. Therefore, the study takes accessibility and proximity as indicators that describe Adaptive Capacity. They have embedded requirements of knowledge of these spaces and resources to reach them. Exposure and Adaptive Capacity are used to not only describe the vulnerable spaces but also to inform their design.

Sensitivity acts as an informing concept, indicating the areas with populations most susceptible to temperature extremes. The study recognises that relocating certain age groups has ethical considerations, so there is no intent to transform the area's demographic composition. Although personal health problems are outside the scope of this thesis, it is important to adapt the spaces these demographics use as they need the most attention.

The final indicator list, with their measurement, aggregation units, explanations and methods of analysis can be seen in [figure 41](#).

### Public Space Evaluation concept operationalisation

The meso-scale analysis is followed by a more detailed evaluation of public spaces in particular microclimates utilising the concepts of thermal comfort and social well-being.

Thermal comfort is used to examine the spaces with climate measurements of specific zones in the public space. The main indicators used to evaluate this concept include the Wet-Bulb Globe temperature (WBGT), wind chill index, and Physiological Equivalent Temperature (PET).

Social well-being informs how the spaces are intended to be used and if their design is successful. These concepts are acquired from readings on public space theory and design together with winter city movement ideas, where public spaces are reconsidered for seasons that are not optimal in their thermal comfort. Both usability and well-being are related to space sociability, requiring indicators that measure people and space. Jan Gehl's (2001) classification of human activities from his observation studies implies space usability and well-being. Optional and social activities, which describe joining the collective space or interacting with others, tracks the community's sociability, informing the concept of social well-being. On the other hand, necessary activities and spaces designed for specific functions, illustrate if the surrounding space provide required and adequate amenities for resident usability.

The comparison between indicators across nearby spaces helps to evaluate the most socially successful and temperature robust areas. These evaluations can also be done on large scale public spaces by dividing the space into a grid or limiting the observations and measurements to one space and examining it through a set period of time.

Public space evaluation indicators are listed in [figure 42](#).

Concept	Indicator	Unit	Aggregation Unit	Explanation	Method of Measurement/ Analysis
Exposure to Heat	Land Surface Temperature (LST) <i>(during a heatwave)</i>	°C	Grid <i>(ha x ha)</i>	Measuring temperature of the ground surface as an indicator for heat distribution and concentration within urban spaces.	Remote sensing using satellite imagery (Landsat-8).
Exposure to Cold	Land Surface Temperature (LST) <i>(during a cold spell)</i>	°C	Grid <i>(ha x ha)</i>	Measuring temperature of the ground surface as an indicator for heat distribution and concentration within urban spaces.	Remote sensing using satellite imagery (Landsat-8).
Sensitivity	Children Population Density Elderly Population Density Children Distribution in the Area Elderly Distribution in the Area	People/ha %	Grid <i>(ha x ha)</i> / Block	Observing the concentration of sensitive age groups in urban areas, influencing higher susceptibility to heat and cold stresses.	Census data and spatial analysis in GIS.
Adaptive Capacity to Heat	Dense Vegetation Proximity	Service radius distance (m)	Grid <i>(ha x ha)</i> / Block	Examining natural cooling space service areas (within a 300/800/800+ metre radius) on population residence maps to identify lack of accessibility.	GIS-based spatial analysis combining green spaces, service radius buffers, and population data.
Adaptive Capacity to Cold	Indoor Public Space Proximity	Service radius distance (m)	Grid <i>(ha x ha)</i> / Block	Examining temperature shelter service areas (within a 300/800/800+ metre radius) on population residence maps to identify lack of accessibility.	GIS-based spatial analysis combining shelter locations, service radius buffers, and population data.
Adaptive Capacity	Street Network Connectivity (Angular Integration)	Integration Value	Street (line) Segment	Analysing integration values of varying radius threshold to determine between regional (high integration for 300m. threshold) and local (high integration for 5000m. threshold) streets. High integration routes indicate better movement potential and higher chance of public life.	GIS-based spatial analysis using Space Syntax (DepthmapX) to calculate integration values across the street network.

**Figure 42.** Selected Indicators for Vulnerability Assessment

Thermal Comfort	Physiological equivalent temperature (PET) Wet-bulb globe temperature (WBGT) Wind Chill Index	°C	Grid (5x5m) / Specific zones in space	Calculate perceived temperature based on human thermal comfort, including effects of solar radiation, wind, and humidity.	Measured with Heat stress tracker (Kestrel) or simulated using tools like ENVI-Met
Social Well-being	Necessary Public Activity Optional Public Activity Social Public Activity Functional Space Distribution	Activity / Dedicated Space Count	Mapping Specific zones in space	Frequency of necessary, optional activities or social interactions occurring in the space, indicating its role in fostering community engagement. Measure areas within the public space allocated to specific uses, such as resting places, play areas, sports zones, etc...	Observational studies and Photography. Spatial analysis to classify each functional space type.

**Figure 43.** Selected Indicators for Public Space Evaluation

## Methodological framework

The methodological framework is built upon the six sub-questions stemming from the main research question. To structure the narrative of this thesis, they are addressed in the given order. Each research question is linked to specific aims, methods and their outputs. The methodology is divided into five phases.

In the first phase, literature review of temperature extremes and urban climate is explored, from which the problem statement is formulated, and the conceptual framework is constructed. This framework is utilised throughout the thesis to analyse and evaluate public spaces and their adaptation. In the analytical phase, vulnerability level of public spaces is studied in Vilnius based on temperature data, population demographics and proximity to shelters (SQ1) and urban climate zones are categorised in Vilnius based on the Local Climate Zone classification system (SQ2). Alongside this, effective design strategies to manage temperature extremes are collected through a literature review (SQ3) in the form of a pattern language atlas. Further on, potential spaces for adaptation are examined through detailed site analyses based on developed patterns addressing thermal comfort and well-being (SQ4). Through research by design and synergies found between adaptation patterns, design solutions are developed for the vulnerable public spaces in Vilnius (SQ5) and evaluated by testing ENVI-met simulations and the use of the developed patterns (SQ6). Lastly, the thesis reflects on the achieved conclusions and discusses possible applications and limitations of the discoveries and the overall research.

The thesis applies a novel method of approaching spatial temperature adaptation, which generates outputs:

- A temperature vulnerability map for Vilnius's public spaces.
- An atlas of design solutions (patterns).
- Prototypes of site-specific interventions.

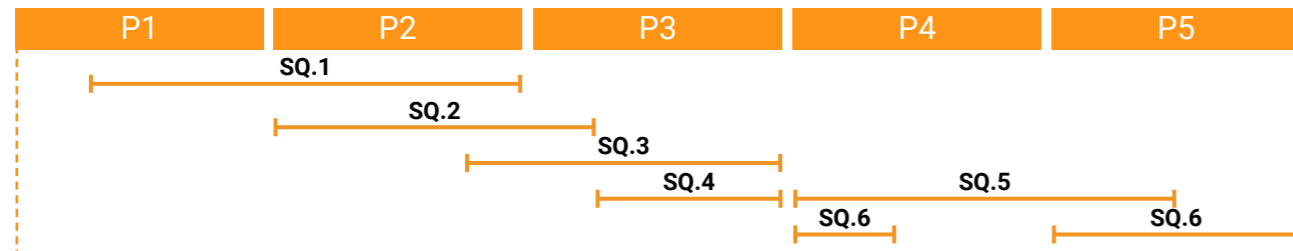


Figure 44. Research timeline divided into academic presentation periods

### Geo-spatial analysis

Geo-spatial analysis involves the systematic collection, processing, and interpretation of quantitative data using maps to understand patterns and relationships. This method achieves objective insights for evaluating spatial, social, or environmental data. This approach is crucial in the beginning of the thesis, approaching from a large scale, to transform basic information into actionable knowledge, evaluating the current situation and informing, which interventions are required, represented through a pattern language.

### Pattern Language

The pattern language, introduced by Christopher Alexander, is a systematic approach to managing complexity in design in the form of a collection of interconnected design principles, each offering multiple possible solutions (Alexander et al., 1977). It is a dynamic tool, open to modifications by both designers and people not familiar with design-based thinking, allowing to create a first draft toolset, as well as adapting on existing ones. In this thesis, the pattern language will be employed to implement Focus, Urgency and Approach Adaptation Goals, through Exposure Reduction, Social Well-being and Coping Networks patterns, respectively.

### Research by design

This methodology uses design as a tool for exploration. It bridges theory and practice, allowing researchers to experiment with spatial and urban interventions in real-world settings. It is iterative and generative, producing insights through the process of conceptualising and visualising. For the thesis, this approach will be cooperating with the pattern language, using the patterns as an available toolkit, to create prototypes of a particular space to illustrate possible perspectives.

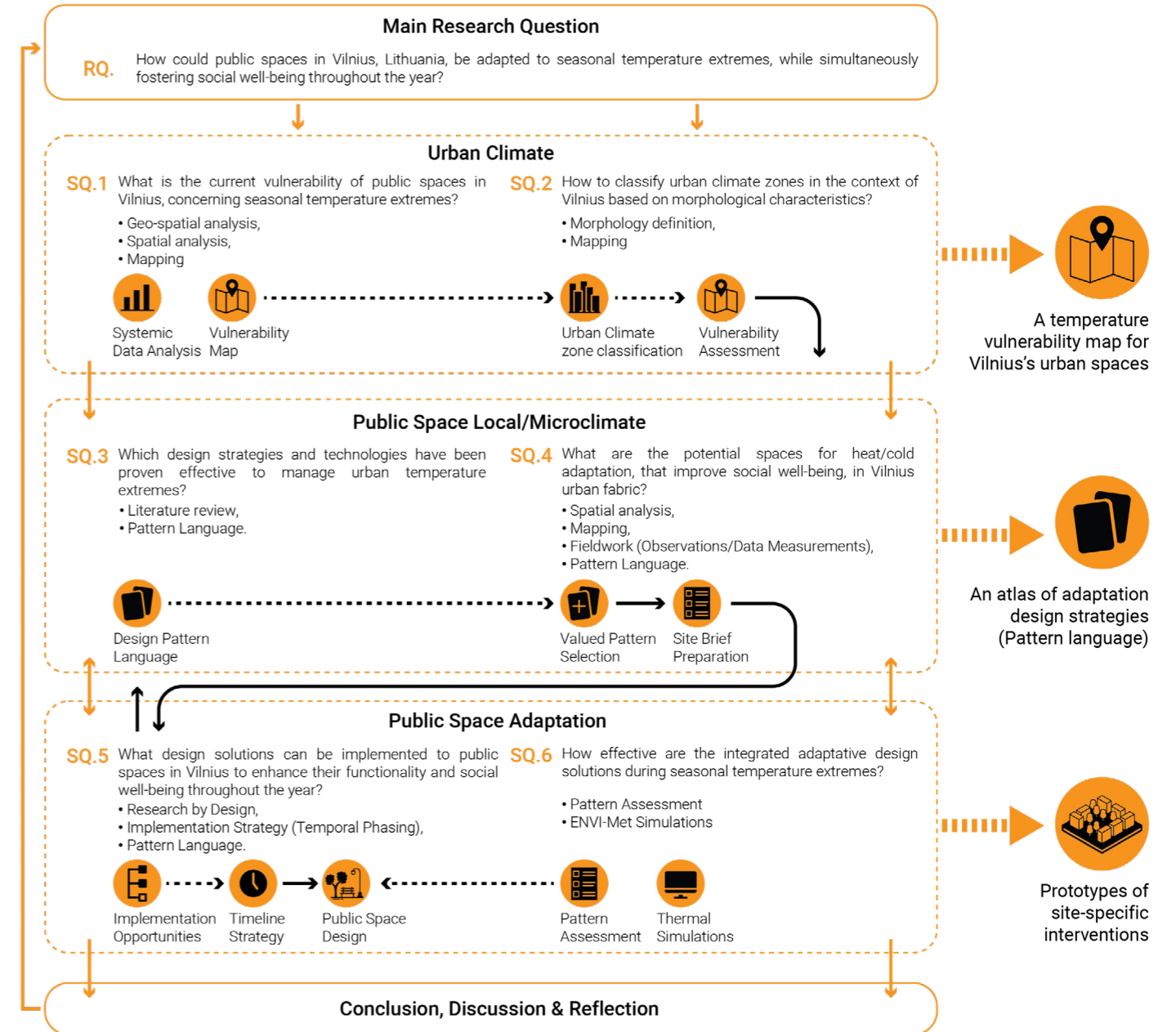


Figure 45. Methodological scheme

## Thesis Relevance

### Societal Relevance

This study is particularly important for settlements in continental climate zones, where seasonal extremes are more pronounced. These regions usually have decreased physical activity and limited outdoor opportunities during winter and, due to increasing global temperatures across the world, open spaces that are active during summer cannot cope with more intense heatwaves, pushing public spaces into crisis.

This thesis addresses the pressing challenge of adapting public spaces to the impacts of extreme temperatures, which affect the health, comfort, and overall well-being of urban populations. The biggest impact is felt by vulnerable groups such as elderly, children, and low-income residents, who's voices have to be included in the study to ensure that appropriate considerations, ambitions and implementations are set.

This research contributes to a broader understanding of temperature adaptation through design solution integration to create resilient urban environments that should remain functional and welcoming throughout the year. By focusing on temperature-adaptive public spaces, which are shared by everyone, this project becomes relevant to all residents, while also being transferable to many other neighbourhoods, cities or regions, that share a similar climate context.

1.  **"Climate crisis to blame for dozens of 'impossible' heatwaves, studies reveal"**  
18/11/2024
2.  **"Heatwave deaths increased across almost all Europe in 2023, says UN weather agency"**  
22/04/2024
3.  **"30-degree heat is the new normal in Lithuania – experts"**  
01/07/2024
- .....
4.  **"How extreme cold events fit into the global warming model"**  
19/04/2024
5.  **"Europe hit by extreme cold, flooding and power cuts"**  
04/01/2024
6.  **"Weather forecasters predict extreme cold: in some places it can be as cold as -17 degrees"**  
05/12/2023

Figure 46. Newspaper Headlines about Both Climate Extremes

- |  |  |
|--|--|
| 1. <a href="https://www.theguardian.com/environment/2024/nov/18/climate-crisis-to-blame-for-dozens-of-impossible-heatwaves-studies-reveal">https://www.theguardian.com/environment/2024/nov/18/climate-crisis-to-blame-for-dozens-of-impossible-heatwaves-studies-reveal</a> | 5. <a href="https://www.euronews.com/2024/01/04/europe-hit-by-extreme-cold-storms-and-flooding">https://www.euronews.com/2024/01/04/europe-hit-by-extreme-cold-storms-and-flooding</a>   |
| 2. <a href="https://news.un.org/en/story/2024/04/11487960">https://news.un.org/en/story/2024/04/11487960</a>   | 6. <a href="https://www.madeinvilnius.lt/en/news/Lithuanian-news/forecasters-predict-high-temperatures%2C-in-some-places-it-can-be-up-to-17-degrees/">https://www.madeinvilnius.lt/en/news/Lithuanian-news/forecasters-predict-high-temperatures%2C-in-some-places-it-can-be-up-to-17-degrees/</a> |
| 3. <a href="https://www.lrt.lt/en/news-in-english/19/2307650/30-degree-heat-is-the-new-normal-in-lithuania-experts">https://www.lrt.lt/en/news-in-english/19/2307650/30-degree-heat-is-the-new-normal-in-lithuania-experts</a>   |  |
| 4. <a href="https://www.earth.com/news/how-extreme-cold-events-fit-climate-change-model-global-warming/">https://www.earth.com/news/how-extreme-cold-events-fit-climate-change-model-global-warming/</a>   |  |

### Scientific Relevance

At present, there is insufficient knowledge concerning temperature adaptation of public spaces for both heat and cold extremes. While heat resilience is well-studied and a growing field of research and there have been studies focusing on cold resilience, especially in colder regions, literature on bridging these study fields is still lacking (Stout et al., 2018). This thesis aims to integrate the research from both problems, to develop a holistic design approach to ensure public spaces can adapt to urban temperature extremes without undermining one or the other extreme. The thesis would expand on the framework concepts regarding heat adaptation and propose an integrated temperature adaptation framework that accounts for both summer heat and winter cold.

Currently, studies focusing on developing temperature risk frameworks are lacking operationalisation, as there is no clear link between the measured risks and problems concerning urban environmental problems, such as temperature extremes, and their direct solutions (Gabbe et al., 2021). By collecting and developing a tool set, consisting of functional design and planning solutions, that can be synthesised and implemented jointly in problematic areas described by their temperature vulnerability assessment, this question of theory implementation into practise is addressed. By doing so, this thesis contributes to the climate adaptation discourse and provide an approach to develop resilient urban public spaces that work year-round, enhancing the sustainability and livability not only in Vilnius, but also other cities in temperate and continental climate zones.

The thesis provides valuable insights for policymakers, municipalities and urban planners looking to mitigate health and environmental impacts of harsh temperatures in cities, while also helping urban designers to advance their research on designing climate-adaptive public spaces by introducing design solutions that are tailored to specific seasonal challenges. It also bridges the gap between climate science, urban design, and social well-being, to illustrate the importance of multi-disciplinary approach when addressing urban climate adaptation.



Figure 47. This output contributes to the following UN Sustainable Development Goals (SDGs)

# 04

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## URBAN CLIMATE

### Vulnerability to Extreme Temperatures

*Exposure*

*Sensitivity*

*Adaptive Capacity*

### Urban Form Classification

*Vilnius LCZ Structure*

### Vulnerability Assessment

*Local Climate Zone Exposure*

*Local Climate Zone Sensitivity*

*Local Climate Zone Public Spaces*

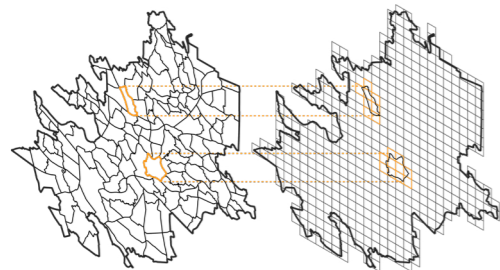
### Sites of Intervention

## Vulnerability to Extreme Temperatures

To analyse Vilnius's temperature vulnerability, each part of the vulnerability framework is examined and quantified separately. Due to the large diversity in type, resolution and units of aggregation of the data sources, a unified Vilnius city municipality grid, consisting of 100x100 m cells is applied in this study to equally distribute space throughout the city in order to be able to compare the findings collected inside the cells. This framework not only allows spaces to be examined through their levels of Exposure, Sensitivity and Adaptive Capacity, but also to translate them into Adaptation Goals concerning Focus, Urgency and Approach, providing the first indication into practical application of required interventions.

As the cells contain various built and natural environments that differ in density, form and natural elements, the Local Climate Zones (LCZ) that represent similar climate conditions are introduced to contextualise the vulnerability findings. This method examines vulnerability similarities emerging from the city's urban fabric, while also expanding the knowledge on the use of Local Climate Zones within Lithuania's climate context.

The following section describes vulnerability through Exposure, Sensitivity and Adaptive Capacity indicators which are used to analyse the current situation. The results of the Exposure level examination show that large commercial and concentrated industrial areas are most prone to overheating, while open and permeable landscapes have highest levels of cold exposure. Sensitivity analysis shows that the highest proportion and density of children are found in the peripheries, while the elderly are situated in the intermediate city districts. Finally, Adaptive Capacity findings show that the inner core of the city has the largest potential for improvement.



**Figure 48.** Overlaying grid layers with collected concept indicator findings



### Exposure

Where are urban areas with excessive temperature extremes?



### Sensitivity

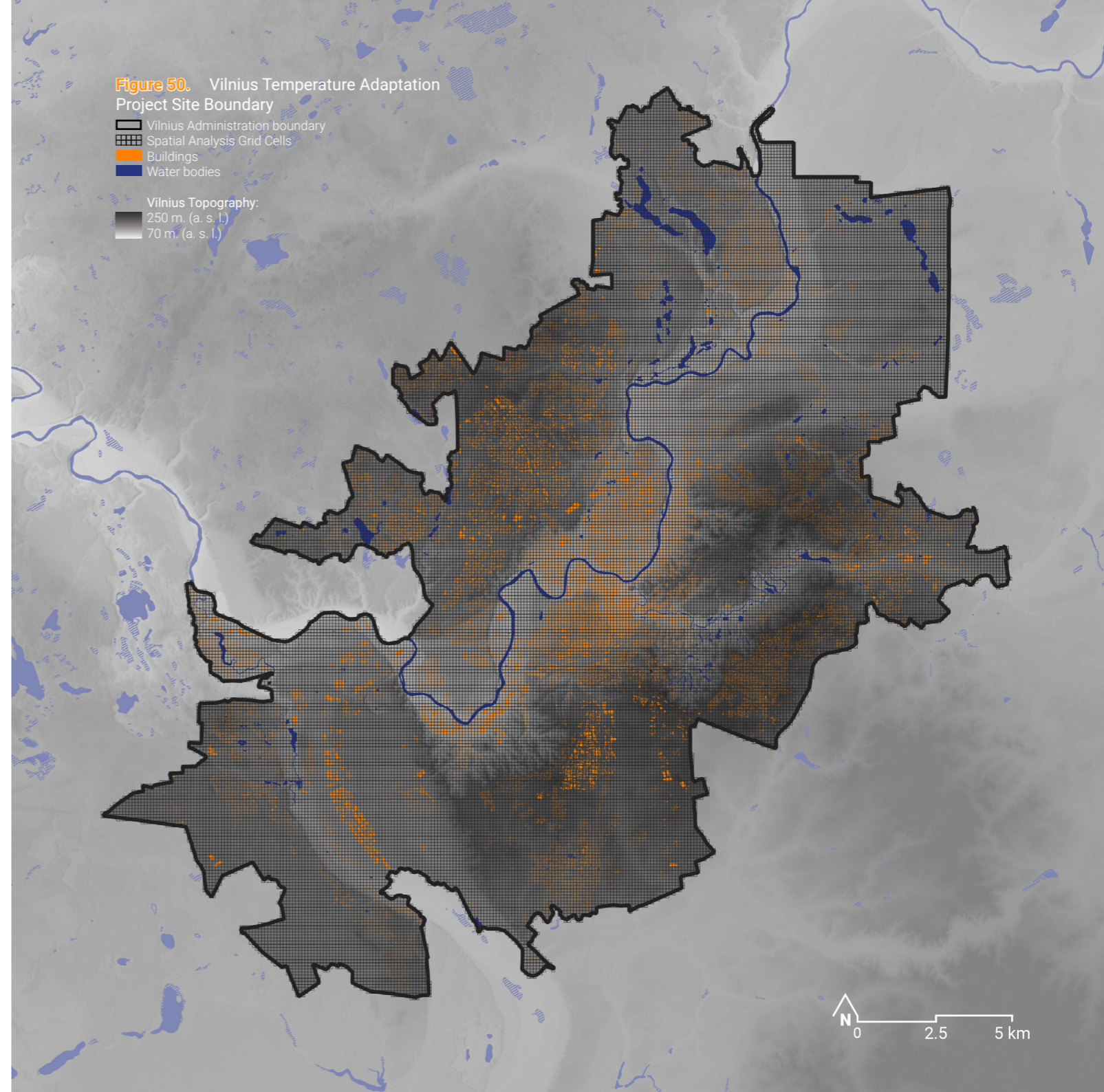
Where are urban areas with high children and elderly demographic populations?



### Adaptive Capacity

How are land-use distributed and what proximities are between these urban areas?

**Figure 49.** Concepts used in the Temperature Vulnerability Analysis: Exposure x Sensitivity x Adaptive Capacity



**Figure 50.** Vilnius Temperature Adaptation Project Site Boundary

- ▭ Vilnius Administration boundary
- ▣ Spatial Analysis Grid Cells
- Buildings
- Water bodies

Vilnius Topography:  
 250 m. (a. s. l.)  
 70 m. (a. s. l.)

## Exposure

Land Surface Temperature (LST) in this study functions as representation of the temperature distribution (exposure) within urban spaces from a climate meso-scale understanding. The method used to extract and calculate LST using satellite imagery was acquired from scientific papers automating surface temperature mapping through geoprocessing tools (Grajeda Rosado et al., 2020; Kumar et al., 2023; Singh, 2017).

The satellite data, which provide thermal infrared and reflectance bands, required for detecting surface temperatures, are acquired from open-access European space agency's (Esa) Landsat-8 program. Two images at the spatial resolution of 30 m captured during a heatwave on August 18th, 2022, and a cold spell on January 25h, 2014, are selected. The obtained data is pre-processed in QGIS.

The calculation includes obtaining top atmospheric spectral radiance (TOA), which is then transformed into brightness temperature (BT). Brightness temperature is adjusted to account for surface emissivity (E), which depends on land cover type, such as vegetation, water, or urban structure. Emissivity is determined by the normalised difference vegetation index (NDVI), which is extracted from the same satellite data.

The final LST integrates brightness temperature, the Boltzmann constant, and the natural logarithm of emissivity to produce accurate temperature readings.

The calculation is visualised as a map of temperature variations similar to thermal images, although in a larger scale and lower resolution.

### Data Calculations:

#### Top atmospheric spectral radiance (TOA):

$$L\lambda = 0.000342 * Band(10) + 0.1 - 0.29$$

#### Brightness temperature (BT):

$$BT = \frac{1321.0789}{\ln\left(\frac{774.8853}{L\lambda} + 1\right)} - 273.15$$

#### Normalised difference vegetation index (NDVI):

$$NDVI = \frac{NIR (Band (5)) - R (Band (4))}{NIR (Band (5)) + R (Band (4))}$$

#### Proportion of Vegetation (PV)

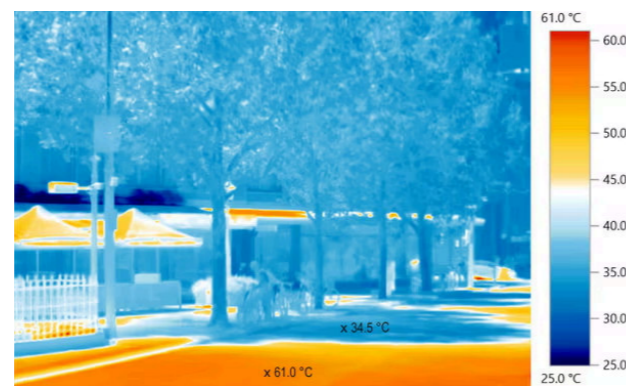
$$PV = \left(\frac{NDVI - NDVI min}{NDVI max + NDVI min}\right)^2$$

#### Surface Emissivity (E):

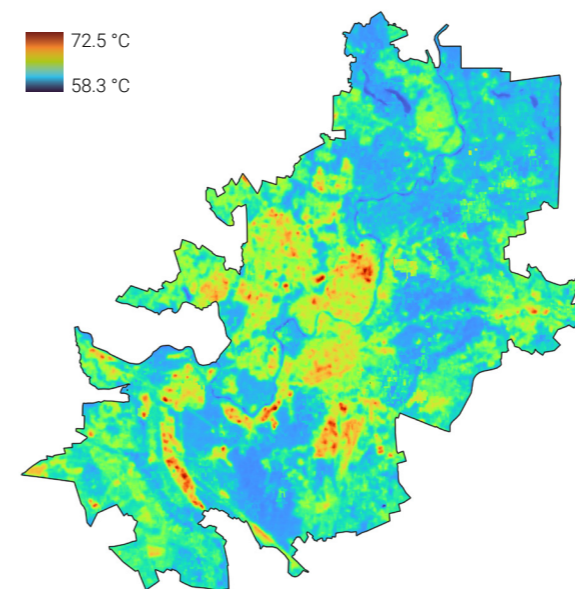
$$E = 0.004 * PV + 0.986$$

#### Land Surface Temperature (LST):

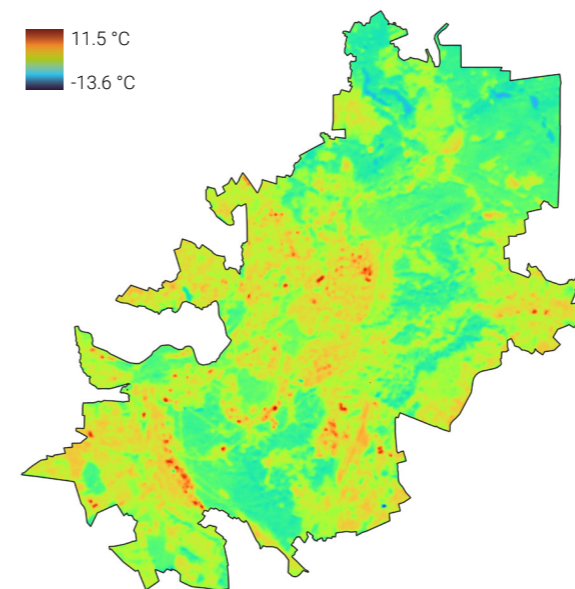
$$LST = \frac{BT}{1 + (10.895 * BT) / 14380 * \ln (E)}$$



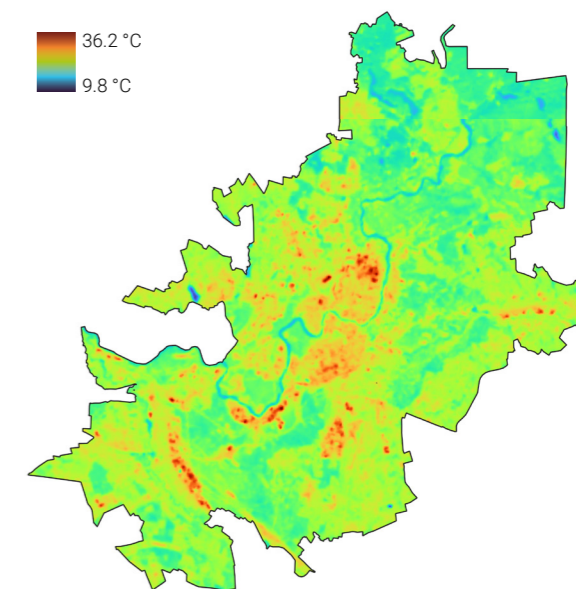
**Figure 51.** Thermal images taken in a heatwave (City of Melbourne, 2017).



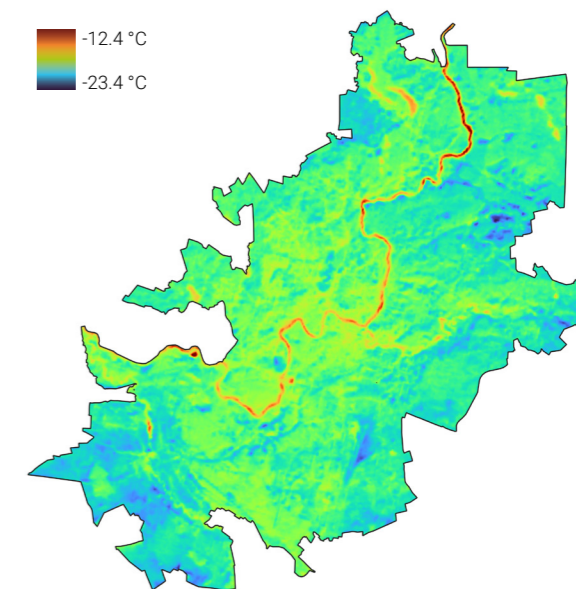
**Figure 54.** Land Surface Temperature captured during a Heatwave - 18/08/2022



**Figure 52.** Land Surface Temperature captured during a cold day - 11/03/2022



**Figure 55.** Land Surface Temperature captured during a warm day - 11/05/2021



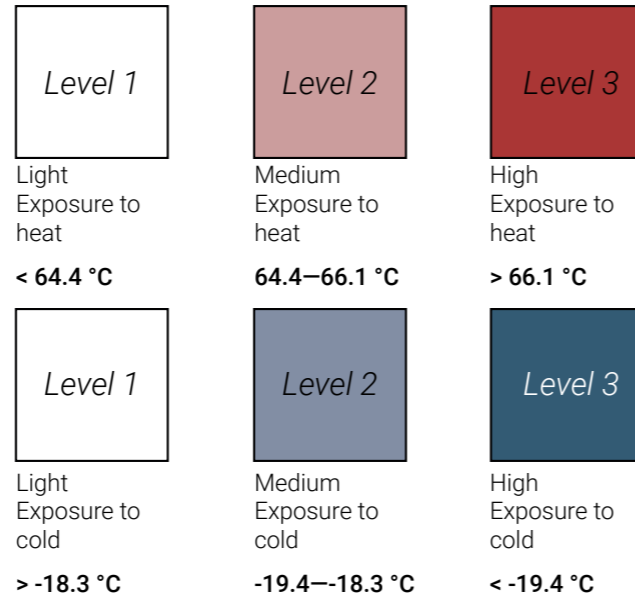
**Figure 53.** Land Surface Temperature captured during a Cold spell - 25/01/2014

**Exposure levels**

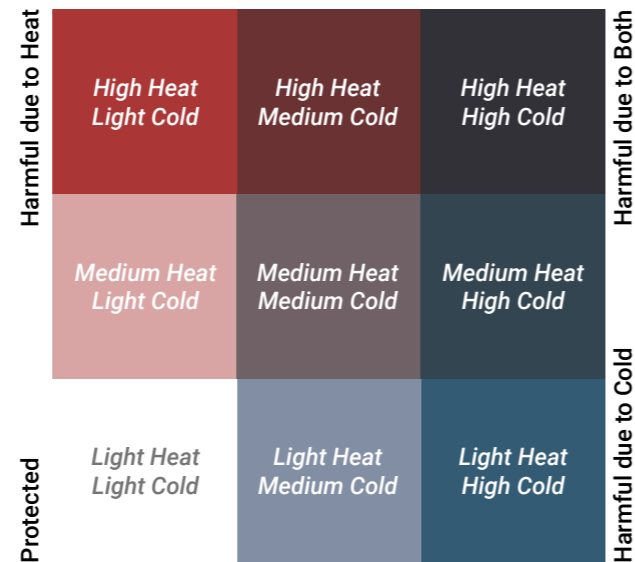
To evaluate and compare the calculated results, two extreme scenarios of surface temperature are chosen. The mapped information is aggregated to a cell grid, consisting of 100 by 100 metres, to calculate the average (mean) temperature within an area. This allows a better readability and comparison of temperature distribution between equal size cells.

To classify the level of exposure, temperature values were analysed using spatial data analysis software GeoDa. By limiting the analysis to cells containing the built environment, absorption and remittance of temperature can be compared between the different built densities and forms. In these areas, the observed temperatures ranged between 59.7°C to 71.7°C during heatwave and from -22.4°C to -10.3°C during a cold spell. Temperature frequency was plotted to illustrate the spread, as seen in histogram figures 57 & 58. These distributions were classified by the Natural Breaks (Jenks) method, which groups data with similar values, while also maximising the differences between each class. These three classes both for the heatwave situation and the cold spell were translated into levels of exposure with level 1 showing low exposure, while level 3 - high exposure.

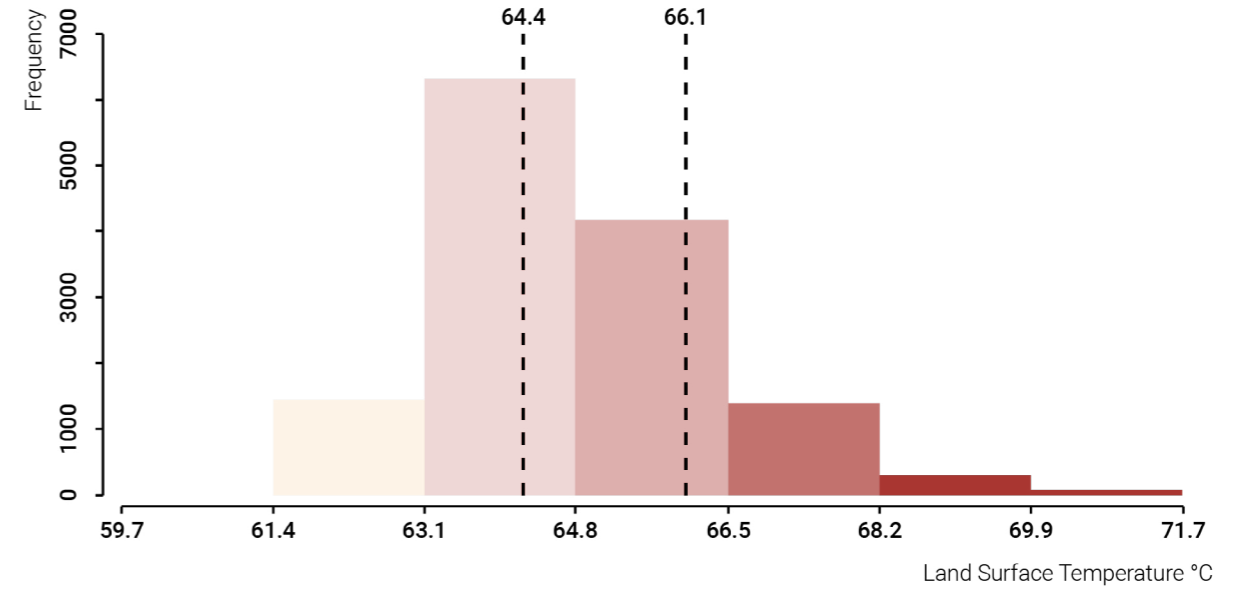
Based on Yang & Bou-Zeid's (2018) research about the Urban Heat Island effect, which found that increased heat in the city leads to lower cold exposure, a diagram is drawn to examine the possible link between the two temperature extremes in Vilnius urban spaces. A hypothesis formed from urban climate readings that these two values will have a negative correlation is tested and proved with some exceptions, showing that generally, residential areas that exhibit high exposure to heat during summer will have lower exposure to cold.



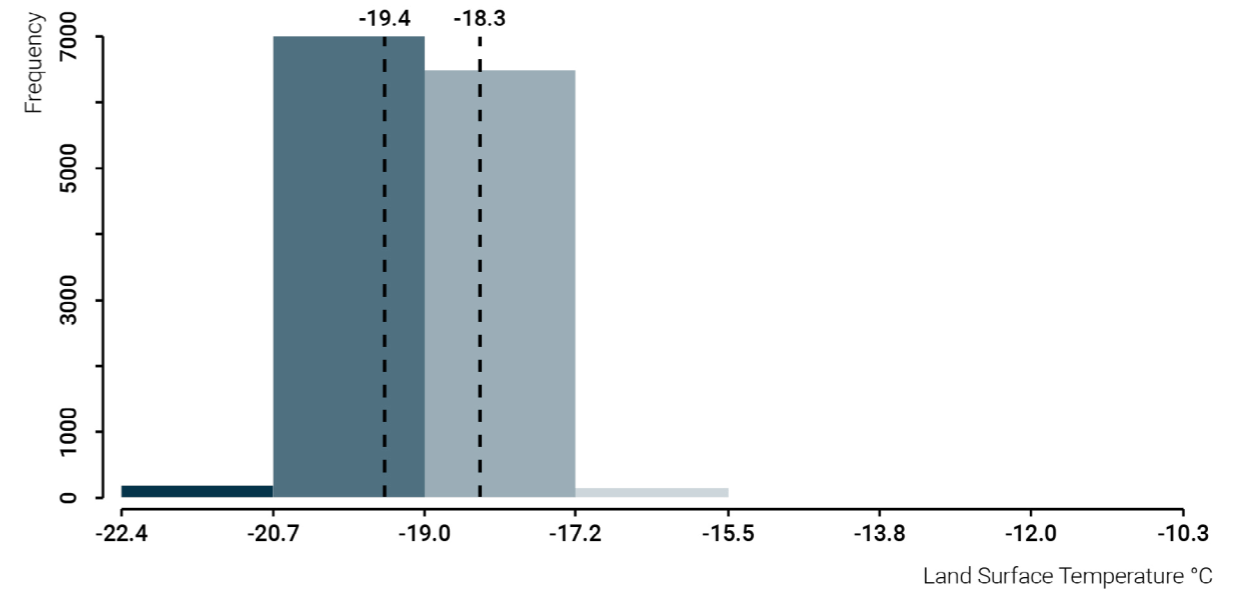
**Figure 56.** Exposure Classification



**Figure 57.** Exposure Overlap Diagram



**Figure 58.** Heatwave LST Histogram, illustrating the cell frequency of recorded temperature within urbanised areas. The dashed lines place Natural Breaks (Jenks), which divided heat recordings into 3 levels of exposure.



**Figure 59.** Cold wave LST Histogram, illustrating the cell frequency of recorded temperature within urbanised areas. The dashed lines place Natural Breaks (Jenks), which divided cold recordings into 3 levels of exposure.

## Exposure | Synthesis Map

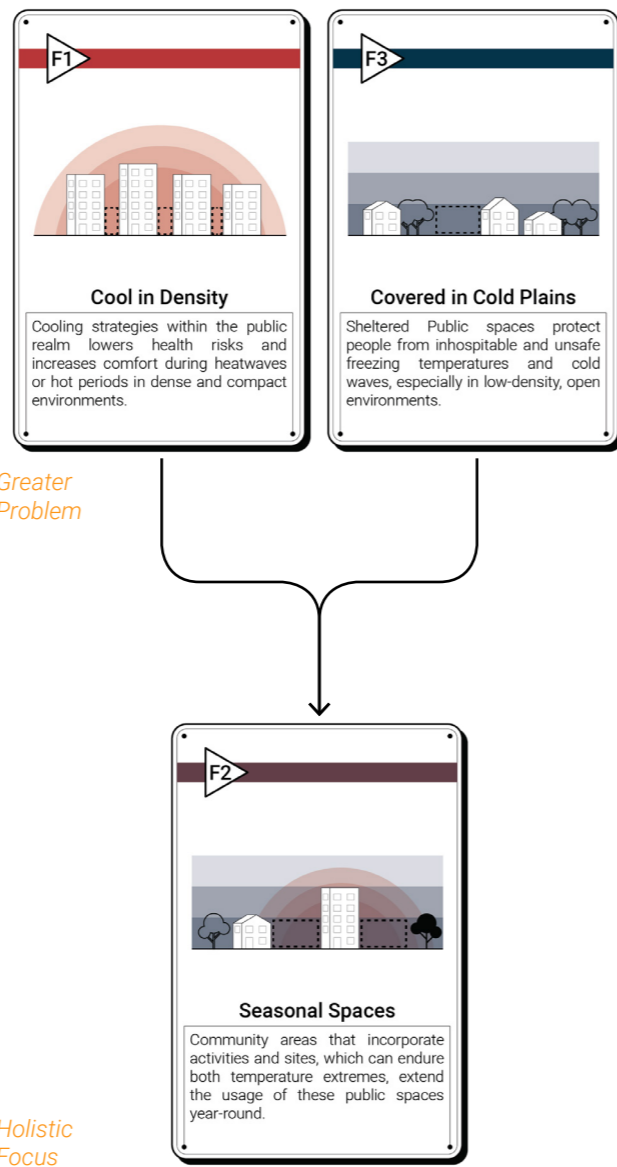
With the Exposure diagram, each grid cell was colour coded with its relevant exposure level. The created exposure map, seen in figure 60, illustrates exposure levels across Vilnius administration borders, including both built environments and natural features, such as rivers and forests.

The distribution of heat exposure, during a summer heatwave, seems to follow the Urban Heat Islands effects principles, where concentrated urban environments are all indicating at least medium levels of exposure. The lowest level of heat exposure can be seen on the periphery of the city, covering the urban sprawl, with more compact urban setting also indicating a higher heat exposure. On the other hand, the highest levels of exposure are seen in large commercial areas and especially in concentrated industrial areas.

The distribution of cold exposure, during a cold spell, provide new insights for urban climate studies. While the principal distribution follows an inverted distribution to heat, as highest exposure levels area situated outside the city, some overlapping on single-family housing districts and collective gardens, there are some divergences. One major distinction are natural areas. Water bodies, such as the river and lakes, evaluate the highest temperatures indicating the lowest exposure to cold. Additionally, forests do not imply the highest exposure levels, illustrating that, similarly to water bodies, although not to the exact scale, regulate the cold's effect in extreme situations. On the contrary, spaces that indicate the lowest temperatures were open and permeable landscapes. Industrial areas also overlapped with these extremes. This demonstrates, that built structures that lack quality vegetation, are susceptible to both temperature extremes.

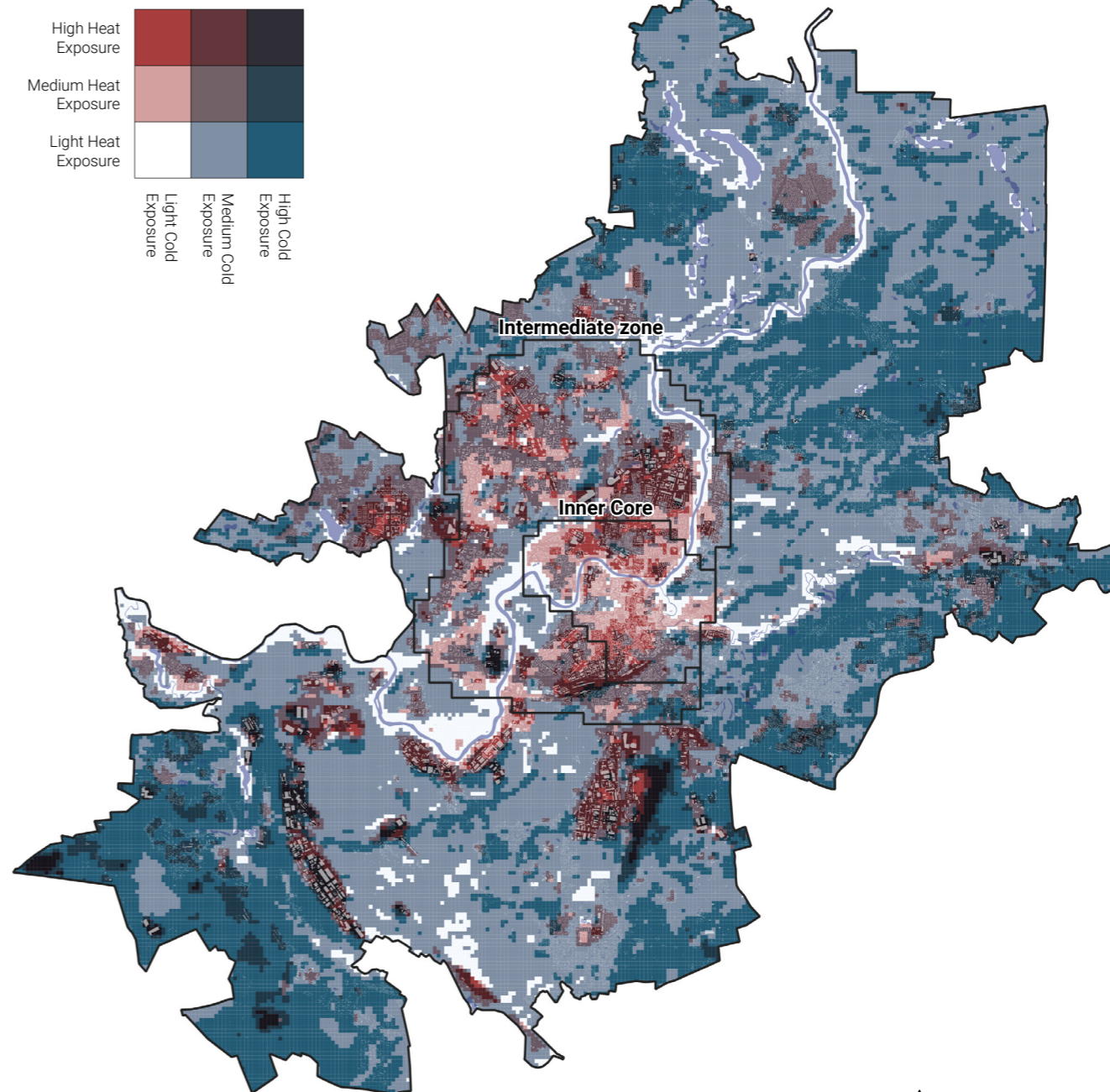
### Focus Goals

From these results, the level of exposure is used to frame Focus Adaptation Goals. The primary goal for spaces highly exposed to heat is Cool in Density, for areas highly exposed to cold it is Covered in Cold Plains, while those exposed to both require Seasonal Spaces. These goals are indicated by colour in specific areas within the exposure map.



**Figure 60.** Patterns relating to Temperature Adaptation Focus Goals

**Figure 61.** Temperature Exposure Map



## Sensitivity

In this thesis sensitivity is measured by the proportion of children and elderly in the given area. This indicator is widely used in research to construct part of the vulnerability index, for both heatwaves and extreme cold spells (López-Bueno et al., 2022; Wolf & McGregor, 2013). The main reasoning behind this is that these groups have a lesser ability to regulate body temperature, compared to healthy adults, resulting in worse health effects of extreme temperatures (Seltenrich, 2015). An additional reasoning, linked to urban spaces, is that these groups have lower operational resources and have limited movement capabilities, making them more dependent on their surrounding spaces. Therefore, the study of sensitivity is limited to residential urban environments, where these demographics spend the majority of their time.

The age ranges of these population groups were taken from the 2021 population census's age structure, where children are considered up to 14 years old, working population from 15 to 64 years old, while 65 and above years old are elderly (Official statistics portal, 2021). It is important to analyse the proportion of these demographics in each urban block as well as the density, because, as shown in the Vilnius Population Density map, areas signifying higher densities overall will also show higher concentrations of children and elderly, leaving out low population densities that might have a disproportionate amount of people that belong to sensitive age groups.

In Vilnius, areas with the highest population density are concentrated in the intermediate city, located northeast of the city centre, however, due to vast urban sprawl, a large portion of city dwellers are living in low density environments on the city's periphery that also needs to be taken into consideration.



Figure 62. Sensitive Age Demographics

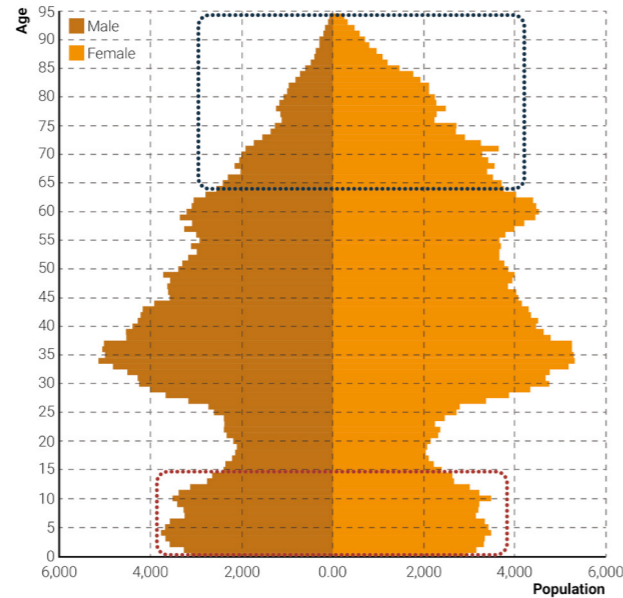
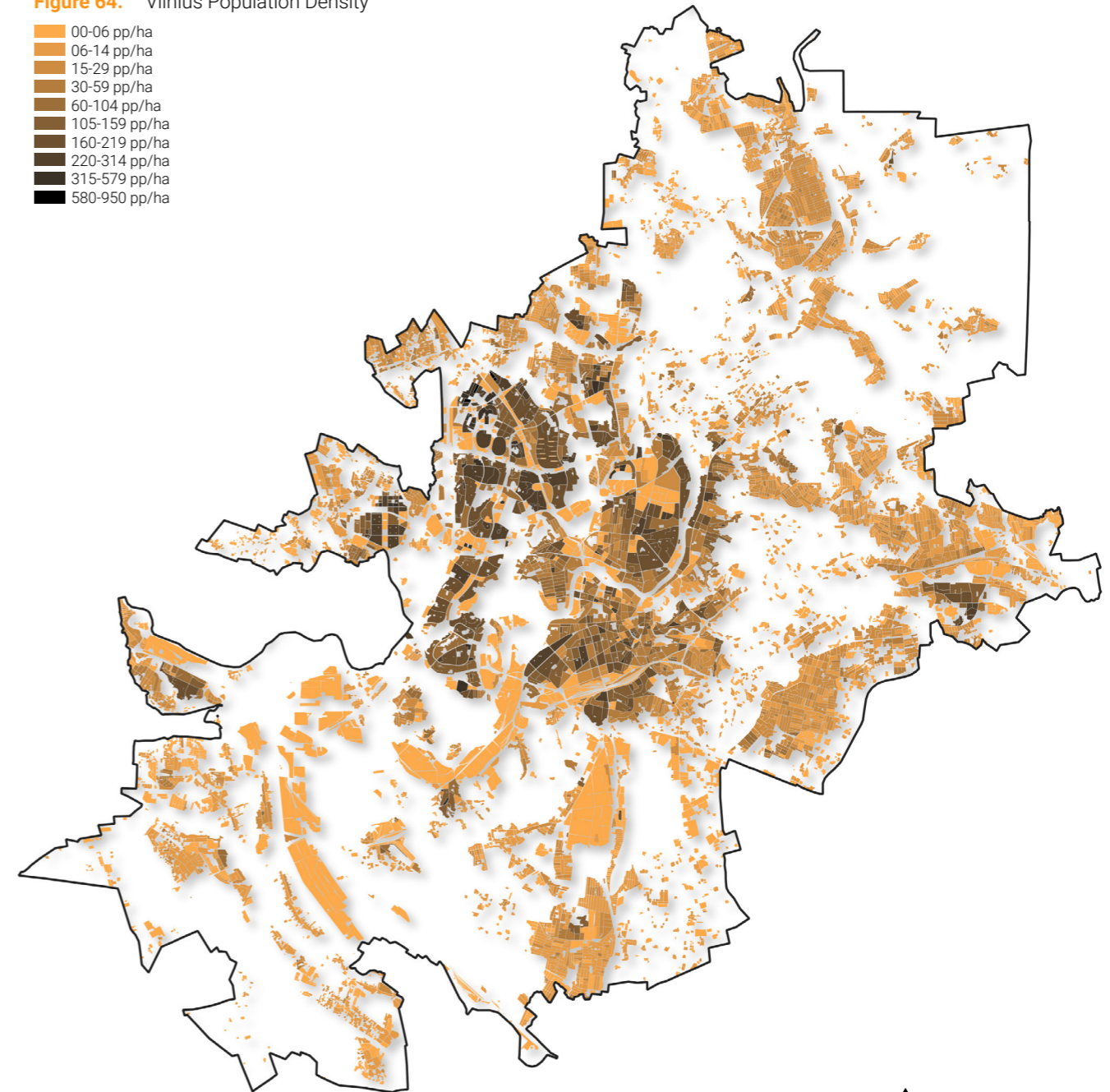


Figure 63. Vilnius Population Pyramid (OSP, 2024)

Figure 64. Vilnius Population Density

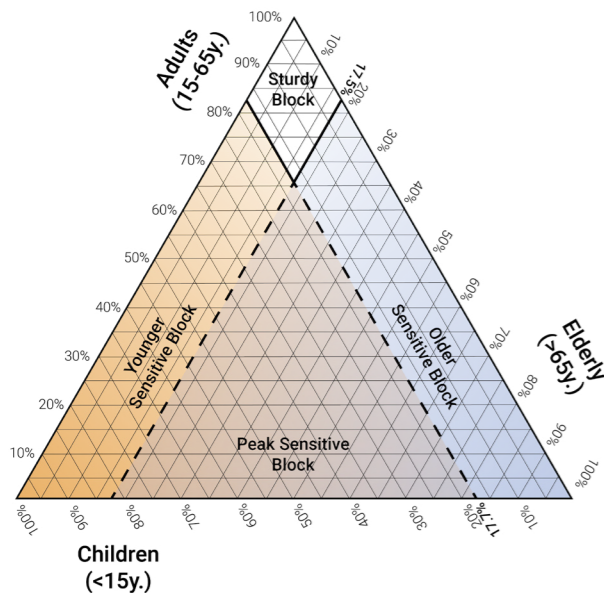
- 00-06 pp/ha
- 06-14 pp/ha
- 15-29 pp/ha
- 30-59 pp/ha
- 60-104 pp/ha
- 105-159 pp/ha
- 160-219 pp/ha
- 220-314 pp/ha
- 315-579 pp/ha
- 580-950 pp/ha



**Urban Blocks Sensitivity**

To more carefully analyse sensitive group dispersion throughout the city, an urban block ternary graph, shown below, was developed to describe an urban block with registered residents its proportions towards children and elderly. This approach allows to structurally identify on areas, which have higher populations, compared the city's average, of children, describing these blocks as young, or elderly, describing these ones as old. Both parameters of population density and percentage are important in these definitions.

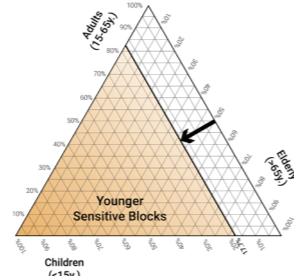
The boundary lines, which indicate the city's average proportion of young and elderly people, were calculated from the 2021 census data, marking the line for children as 17.7%, while for elderly 17.5% (Official statistics portal, 2021).



**Figure 65.** Urban Block Sensitivity Ternary Diagram/ Graph

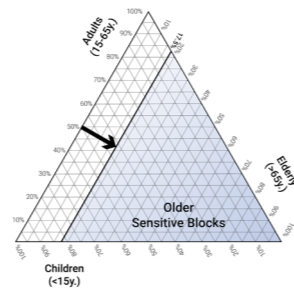
**Young Blocks**

Urban blocks, that have a larger children population percentage than 17.7% are considered as young blocks. These areas imply desirable living environments for young families to stay or move into. These blocks require public services, such as kindergartens, primary and secondary schools, while also providing safe environments for kids to play. Newly built environments, that possess dwellings dedicated for more than one resident, also illustrate this characterisation.

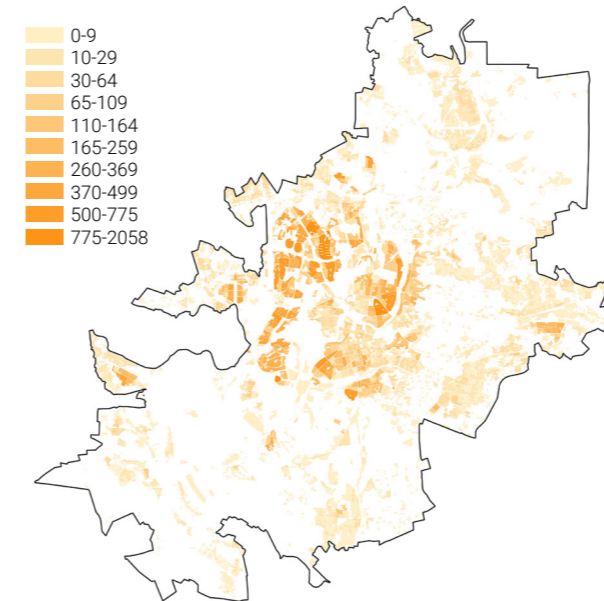


**Old Blocks**

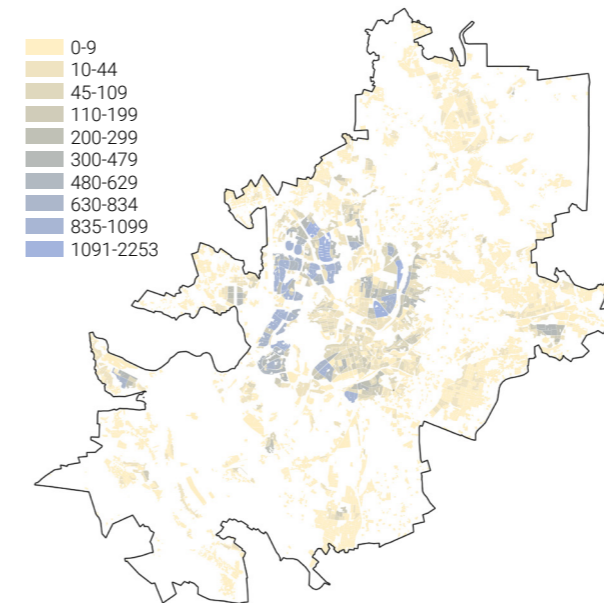
Urban blocks, that have a larger elderly population percentage than 17.5% are considered as old blocks. These areas imply dated and underdeveloped environment, where young families and adults are relocating from or not attracting new residents, while older people, which are less likely to move, remain in the areas. These spaces require public spaces safe for elderly to move through with short distances to amenities, and areas dedicated to meet and socialise. An additional requirement for community resilience, is to ensure that these blocks do not become a ghetto for elderly people. Future considerations should incorporate redevelopment of these areas to attract younger residents, that have higher resources and can assist previous residents.



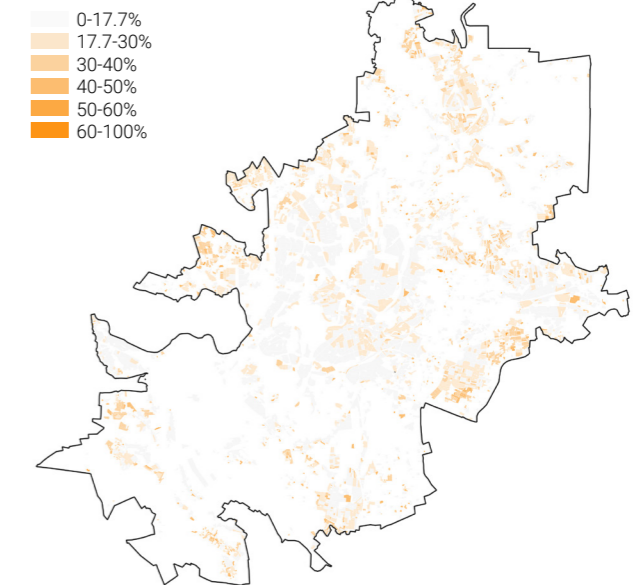
**Figure 66.** Number of Children (0-14y.) population density



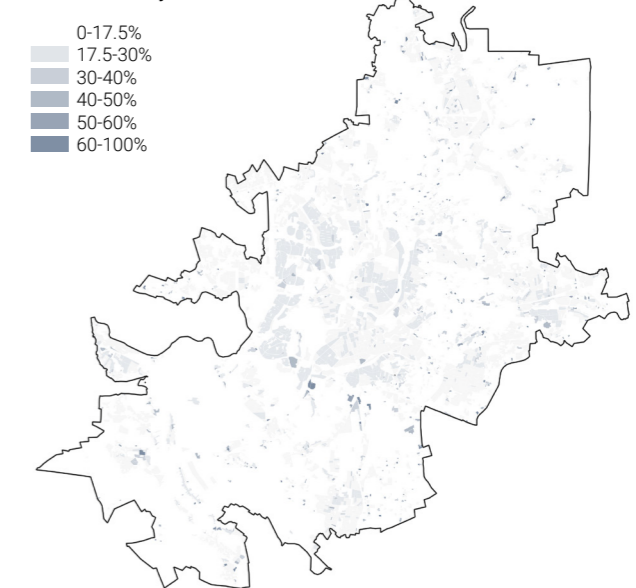
**Figure 68.** Number of Elderly (+65y.) population density



**Figure 67.** Percentage of Children (0-14y.) in a block, No. of Children / Residents =



**Figure 69.** Percentage of Elderly (+65y.) in a block, No. of Elderly / Residents =



## Sensitivity | Synthesis Map

By mapping the densities of children and elderly only in areas where their demographic proportion passes the set threshold for their respective age groups, a sensitivity synthesis map was created. It illustrates concentrations of population which establish urgency to adapt the spaces used by each demographic, while their overlaps show areas where an integrated approach for both groups is needed. While population density overall illustrated where dense environments are situated within a city, by limiting this view, new insights are gained of which densities are linked to which population groups.

From the age group sensitivity map, shown in figure 70, a clear separation can be seen between young and old neighbourhoods. The core of the city, having just a few disproportionate young and old blocks, are mostly populated by working age adults. This distribution can be presumed, as this area consist of high numbers of employment opportunities and establishes a particular lifestyle, with a lively nightlife and smaller dwellings, that are unpopular with families. The intermediate zone, especially the old soviet micro-districts illustrate high numbers of elderly residents. This indicates that Vilnius's neighbourhoods with high population densities are at a decline, driving people, that grew up there, away, while simultaneously not attracting new residents. This makes these districts particularly sensitive to temperature extremes, as not only the residing population is highly affected by these hazards, but the adjacent districts also representing similar demographic groups makes this whole part of the city limited with their community social capital to adjust to extremes. On the other hand, dense peripheries situated in the north, west and north-west signify neighbourhoods with high percentage counts of children, implying that they are chosen by new families. The further developments within the urban sprawl illustrate high distribution of children and elderly alike, requiring a temperature adaptation approach that considers both groups of people.

### Urgency Goals

From this analysis, the level of density and proportion of sensitive groups is translated into urgency and used to frame Adaptation Goals. The primary goal for spaces with high proportion of children is defined as Safe Children, for spaces with high proportion of elderly is Risk-Free Elderly. Lastly, in response to areas with high proportions of both demographics, the goal is Resilient Communities.

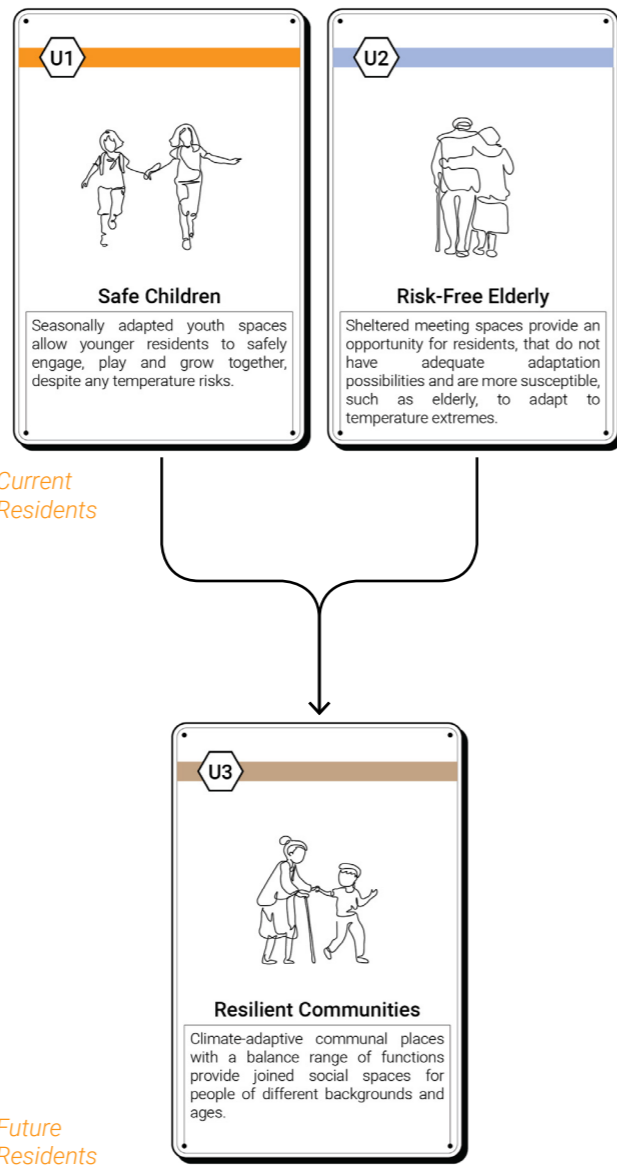
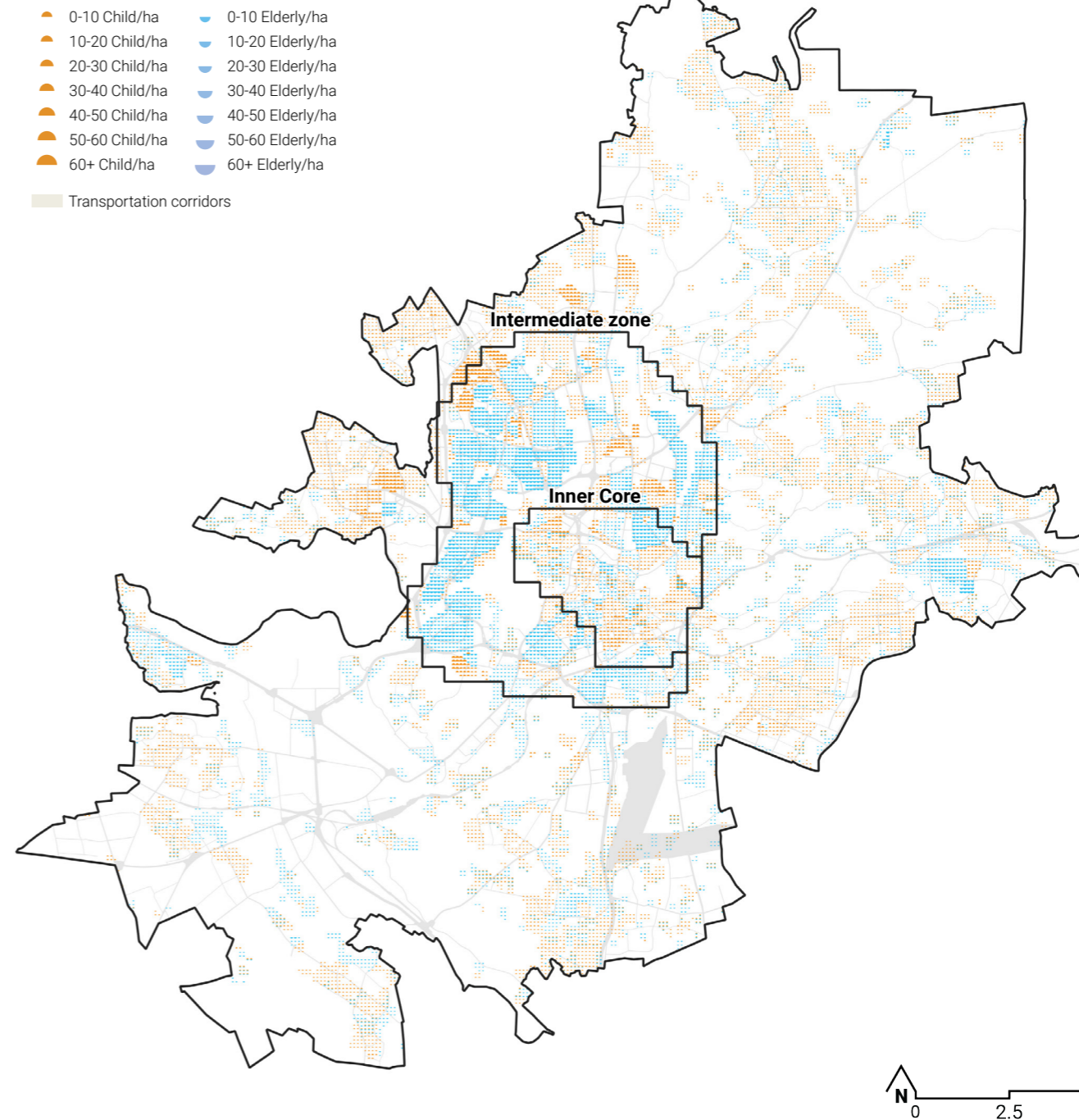


Figure 70. Temperature Adaptation Urgency Goals

Figure 71. Age Group Sensitivity Map



## Adaptive Capacity

### Proximity

Lastly, adaptive capacity is explored through proximity and accessibility to resources, which in this project is considered other public spaces, that are less vulnerable to specific temperature extremes. Adaptive capacity in theory can be divided into two sections, the individual's knowledge, willingness and capital to actively adjust their environment, and the resources that are available and nearby during a climate hazards. This thesis argues that availability to reach these resources is the foundational requirement, while knowledge and willingness to access these spaces are strengthening factors for their utilisation.

Proximity between spaces is measured employing Euclidean (straight-line) distances. This choice is reasoned by the understanding that walking paths to public spaces or shelters do not necessarily follow roads, allowing individuals to take more direct routes. To classify adaptive capacity, three distance zones are established, each representing varying levels of capacity and suggesting different planning and design approaches. The distances chosen were adapted from papers on urban accessibility. High accessibility or adaptive capacity is defined as 300 metre distance or around a 3–5 minute walk, moderate adaptive capacity is defined as 800 metres or a 9–12 minute walk, while everything further than 800 metres is considered limited adaptability, as these distances do not encourage walkability (Gunn et al., 2016).

### Approach Goals

By defining these three proximities, the thesis identifies a scale of adaptive capacity that informs four targeted interventions. These interventions were developed as Approach Goals. However, the required approach of these interventions is linked the proximity levels I-III. The approaches are explained as follows:

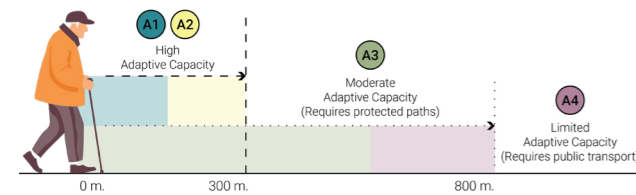


Figure 72. Adaptive Capacity Extents

### I. High Adaptive Capacity ( $\leq 300m$ ):

At this distance, access to adaptive public spaces is immediate and possible even under severe temperature conditions. This proximity emphasises the importance of ensuring that these shelters are well-designed, functional, and capable of fulfilling their intended purpose. These spaces can either be outdoor spaces (A1) or indoor buildings (A2).

### II. Moderate Adaptive Capacity (300m–800m):

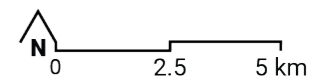
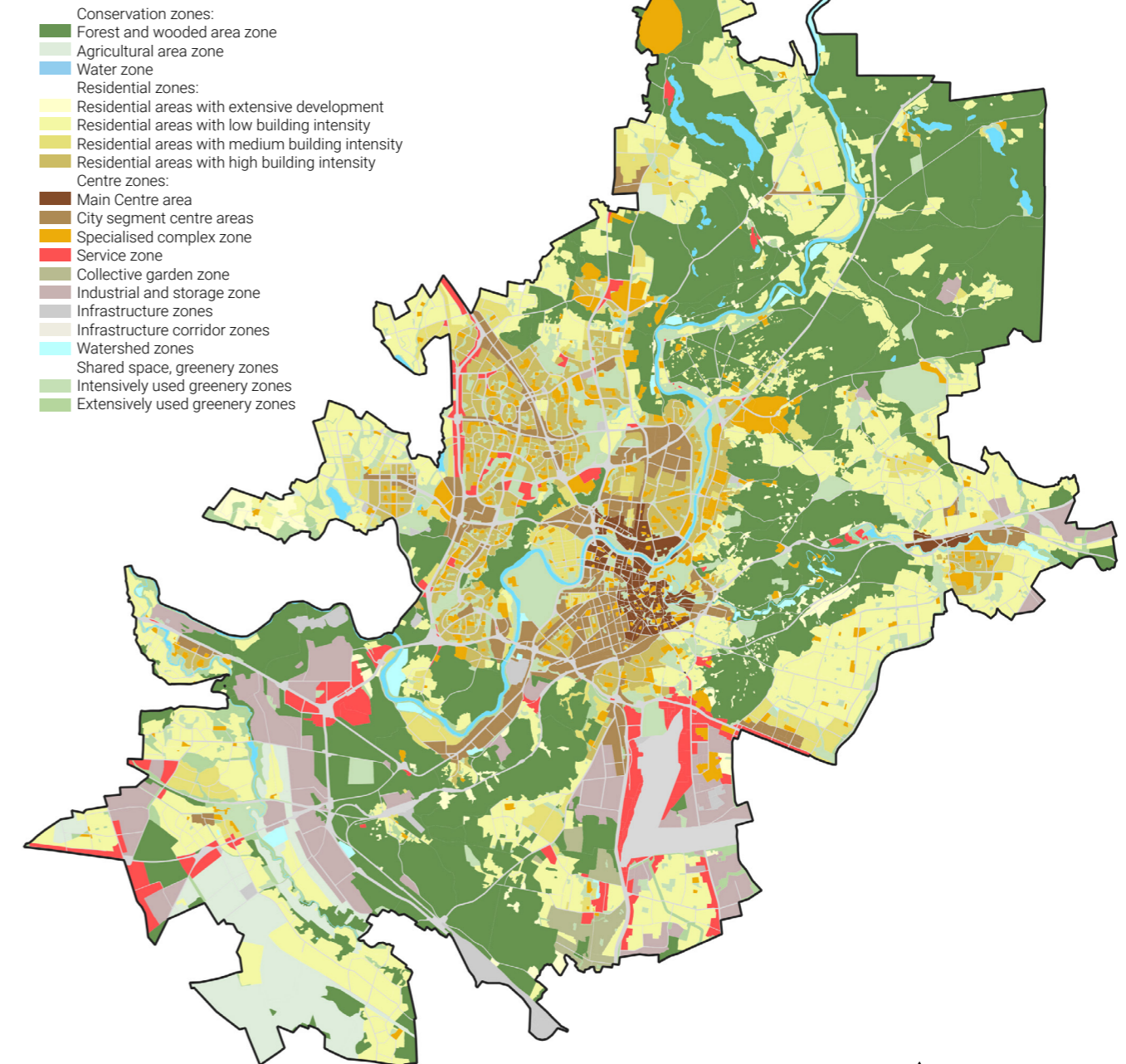
While access to adaptive public spaces remains possible, this service zone introduces additional considerations. Beyond ensuring the quality and function of the space, pathways leading to these spaces must also be designed to minimize exposure to temperature extremes. These are linear spaces that not only connect shelters to residents but also create and expand comfortable outdoor green spaces (A3).

### III. Limited Adaptive Capacity ( $> 800m$ ):

At these distances, reliance on existing adaptive public spaces becomes less practical due to increased travel times and the heightened risk of exposure during extreme temperature events. To reach spaces further than 800 metres, alternative modes of transportation is required. The study prioritises public transport or slow mobility, as owning a vehicle can be considered as high adaptive capacity, allowing an individual to transport themselves quickly and of their own intention, while more socio-economically underprivileged people, that are more vulnerable to temperature extremes, are more dependent on these types of mobilities (Wolf & McGregor, 2013).

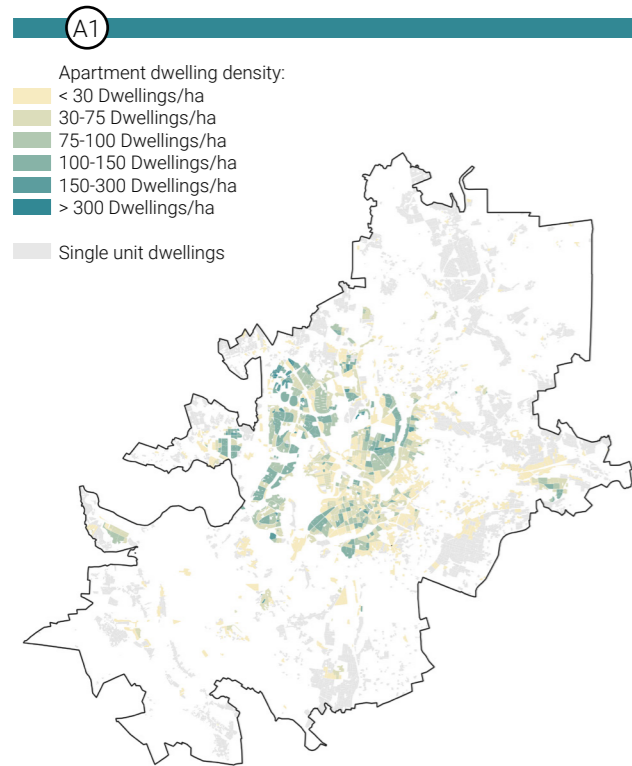
The four Approach Goals are linked to specific spaces that if utilised would protect the person from a temperature hazard or would allow to reach an area in which they would be protected. The creation, improvement and ensuring the knowledge of these shelters increase a person's adaptive capacity and allows to better manage a temperature extreme. The specific types of spaces are indicated and explained further in the project.

Figure 73. Vilnius 2021 masterplan, illustrating functional zoning and land-use (adapted from Vilnius city municipality, 2021)



*Outdoor collective spaces as temp. adaptation shelters*

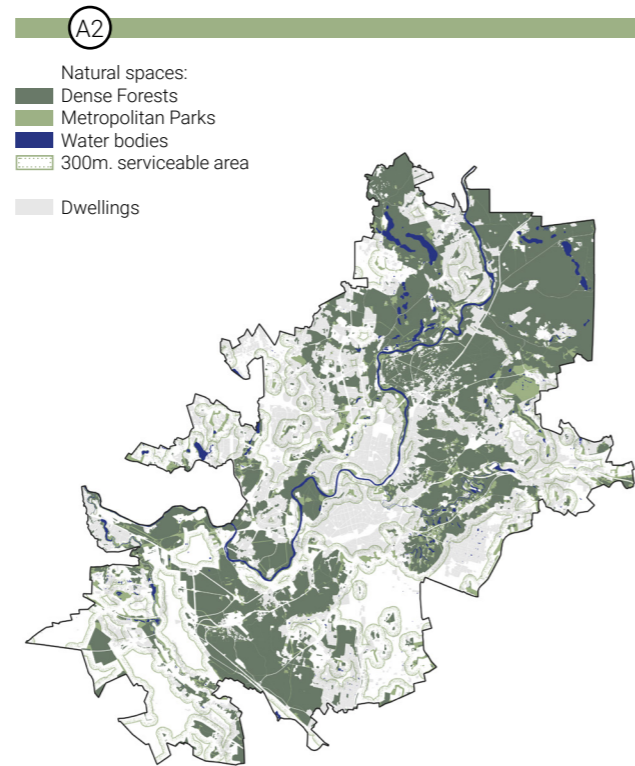
Collective outdoor spaces that are maintained by the residents, such as inner courtyards in residential blocks, have potential of becoming social spaces adapted to temperature hazards, as the communities can transform these spaces and manage hazards together, through social capital (Guardaro et al., 2022). To find these spaces semi-public spaces, an indicator of apartment dwelling density is examined, as residents usually share the land around their apartment building. While high dwelling density, does not correlate to stronger communities, the adapted spaces would provide larger benefits for larger groups of people.



**Figure 74.** Map of important collective outdoor spaces, examined through apartment dwelling density.

*Nature as pathways to temp. adaptation shelters*

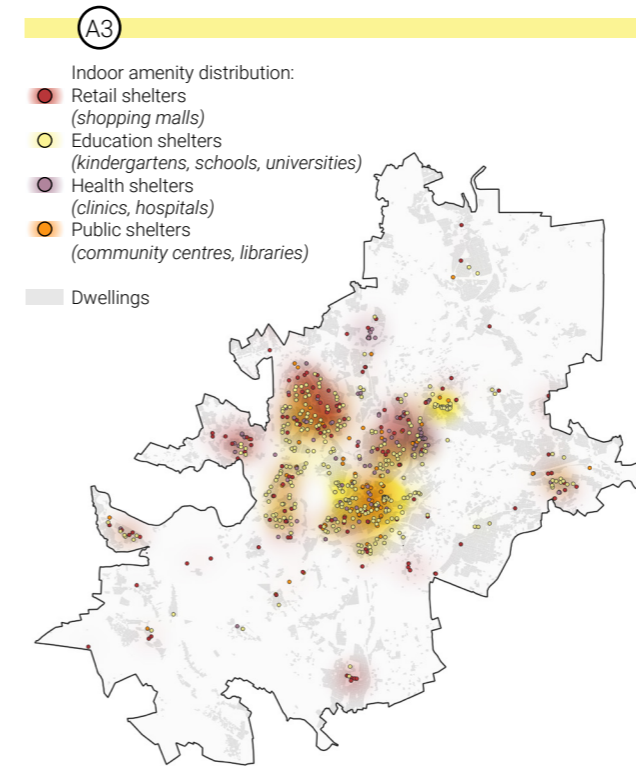
Natural water features, such as rivers, lakes and wetlands, or dense forests mitigate extreme heat and provide slightly better regulated microclimates in cold conditions. Dense vegetation and strategic planting of deciduous and coniferous trees can enhance thermal comfort by providing shade, evaporation or protection from wind. These interventions not only benefit one specific space but can also expand to larger structures within the urban fabric, creating protective paths for people to reach more robust temperature shelters.



**Figure 75.** Map of natural dense vegetation and water bodies with their service area of 300m.

*Public buildings as temp. adaptation shelters*

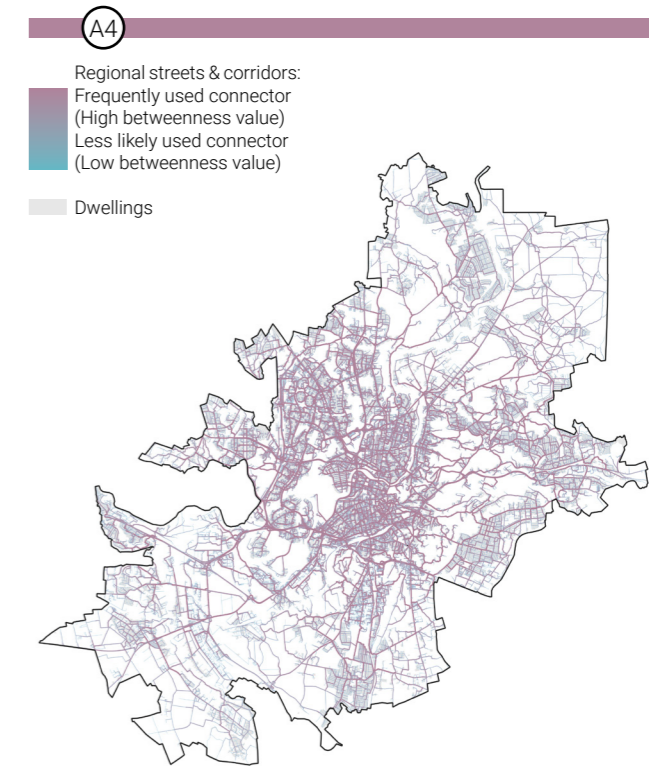
Indoor public spaces, such as hospitals, libraries, and even schools can serve as important climate shelters during temperature extremes. By creating thermal regulated buildings, that are used by the community, they can support social cohesion and ensure a more efficient use of energy, as not every household requires air conditioning and increased heating. However, these spaces require accessibility and participation of their surrounding communities, as it would provide another emergency refuge function for the building. Public spaces situated near these buildings can be better integrated with them to encourage people to utilise them.



**Figure 76.** Map of (Potentially) accessible indoor public buildings within the urban fabric.

*Mobility corridors as pathways to temp. adaptation shelters*

During temperature extremes, movement is an essential part of adapting to harsh conditions. As not every urban space can be adapted to fully protect their residents, clear movement corridors and transport line can allow residents to reach regional robust shelters. For this reason, regional streets or frequently used city connectors, should prioritise public mobility. Transportation systems designed with thermal comfort in mind encourage public transit use during extreme weather, reducing dependence on private vehicles. Additionally, interchange nodes, such as bus stops, are gathering nodes, making them important social public spaces, that provide access to further public spaces.



**Figure 77.** Map of regional streets that support movement in the city, assessed through Network Betweenness calculations.

## Adaptive Capacity | Synthesis Map

### Results

By combining all possible spatial approaches that increase adaptive capacity, an adaptive capacity synthesis map was created. It illustrates the current adaptive capacity approaches within the city, to enhance the residents' resilience to extreme temperatures. Their overlap shows areas, where many approaches can be taken to deal with temperature hazards, meaning higher adaptive capacity. However, this map emphasises the possible approaches, which might require improvement or redevelopment to fully facilitate adaptation. Each of four approaches requires detailed analysis, when examining a particular site, as outdoor spaces be overexposed to temperature extremes, indoor shelters non-accessible, natural spaces unaccommodating for people and main movement routes designed for only cars. Although the distribution of these of these possible approaches already informs how residents can use the city's spaces to adapt during climate hazards. The city's inner core, while lacking in larger natural spaces, has a dense system of indoor public spaces, possible inner courtyards transformations within residential blocks and high density of regional streets, being highly connected to its surroundings. The city's intermediate zone is almost fully covered by collecting outdoor spaces as these are older soviet-built residential micro-districts with

large areas of open spaces. Here indoor public spaces are sparser, as well as the regional street network is less dense, in some cases having only one or two main connections. The city's periphery shows the least adaptive urban environment, where urban sprawl is dependent on critical streets and indoor public amenities, while greenery and nearby forests become the primary adaptation spaces.

### Approach Goals

From this analysis, four approach pattern goals were developed. Each urban spaces requires to consider each goal independently. The primary goal for developing or improving collective outdoor spaces is defined as Community Refuge, while for spaces leading to nature, as Comfort Trails. For adjacent indoor public buildings, that could be built or integrated as shelters, the goal of Shelter-in-Place was defined, while for urban spaces leading to regional indoor shelters, the goal of Sanctuary Routes was created. All of these approaches increase the areas adaptive capacity. To create a hierarchy between the different approaches, they are linked to the extent of temperature extreme's risk, where Community Refuge goal tackles low risks, while Sanctuary Routes address rare high-risk temperatures.

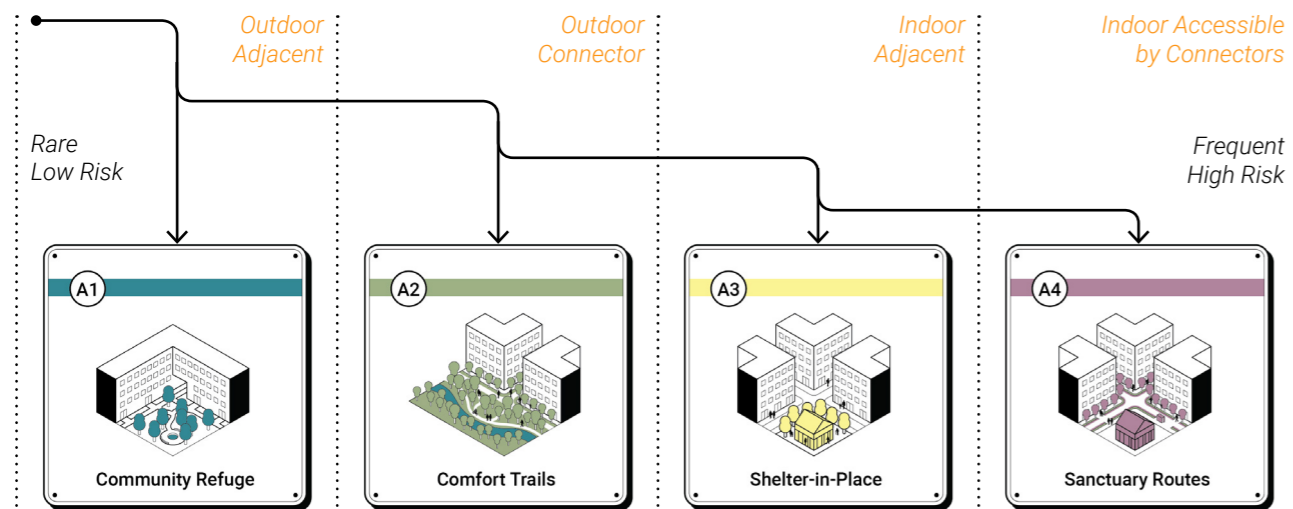
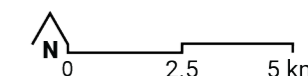
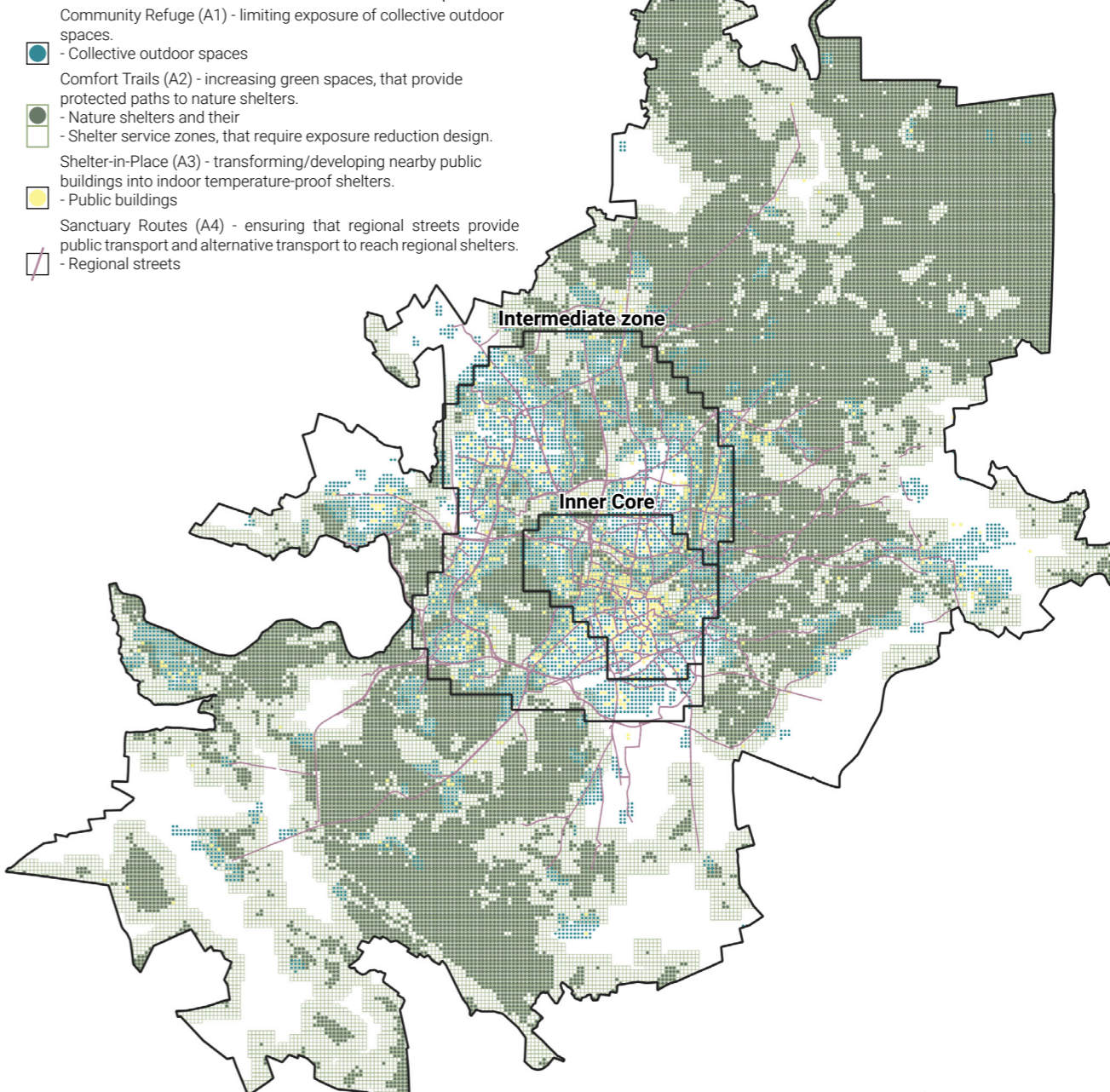


Figure 78. Temperature Adaptation Approach Pathway

Figure 79. Map of possible spatial adaptive capacity approaches to enhance residents' resilience to extreme temperatures



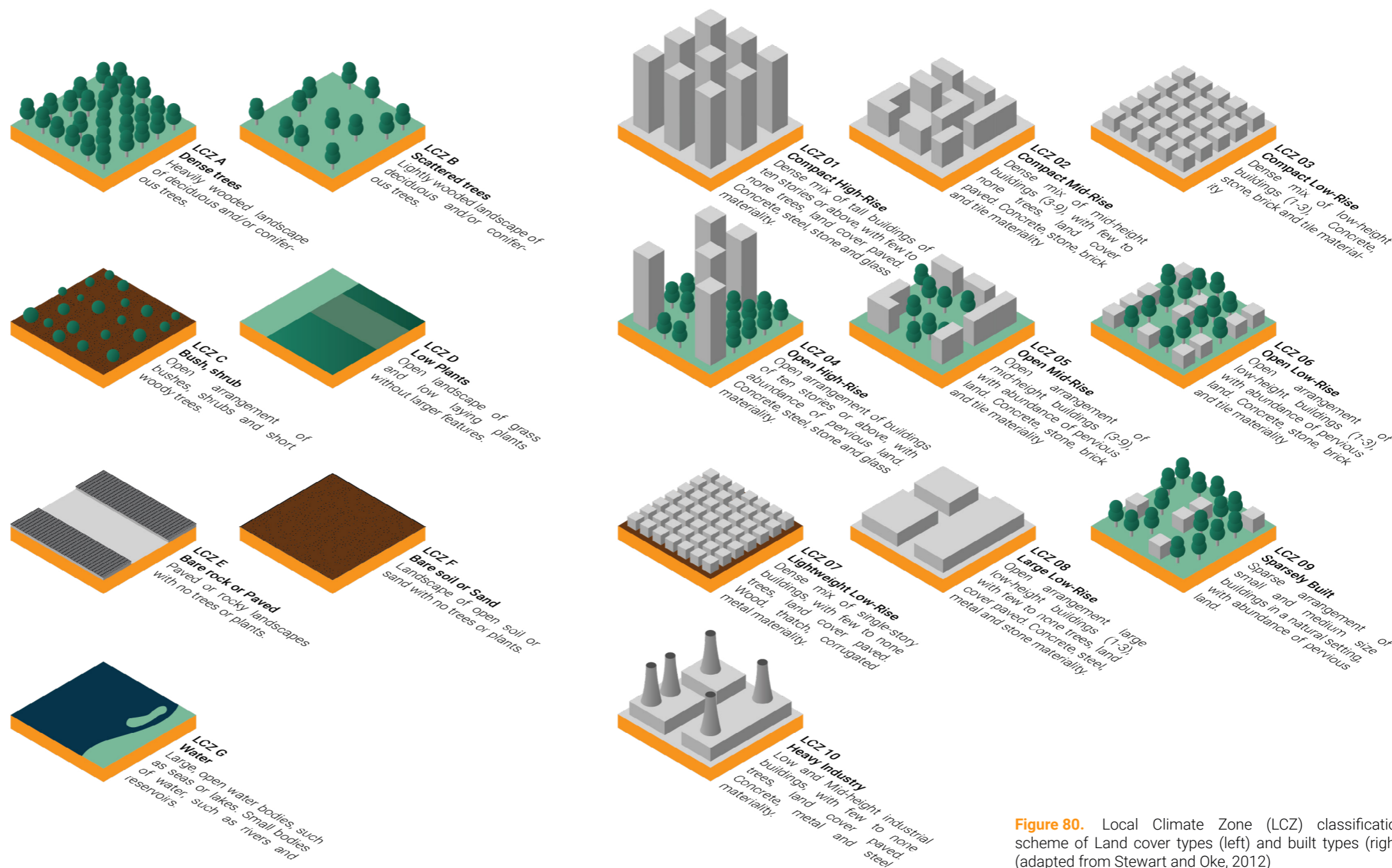
## Urban Form Classification

In order to adapt public spaces, it is first necessary to contextualise them within different urban climates. An examination of urban morphology is needed to interpret the temperature distribution within the city, as it depends on urban climate zones. Classification of urban spaces based on built and natural environment characteristics helps understand how local thermal conditions are produced by similar climate contexts. This enables distinct adaptation strategies developed for a specific urban climate zone to be transferred to other zones with similar climate conditions. For this study, the Local Climate Zone (LCZ) classification system developed by Stewart and Oke (2012) was applied for its versatile application and transferability, as it offers a common language for urban climate research. By mapping Local Climate Zones in Vilnius, the collected findings of vulnerability are systematically analysed to inform adaptation strategies.

### Local Climate Zones

The LCZ classification system is a standardised framework for categorizing urban and rural landscapes based on their thermal and physical characteristics. It divides urban areas into distinct units that share similar surface cover, structure, and human activity levels. The system consists of 17 zones, which are further divided into land cover types, illustrated on the left side of figure 77, and built types, illustrated on the right side of figure 77. Each zone's characteristics differently influence local temperatures and microclimate variations (Stewart et al., 2014).

As traditional methods of broadly defining urban and rural areas were often lacking specificity, this led to difficulties in assessing climate impacts of the built environment (Stewart & Oke, 2012). The expansion of more detailed typomorphologies allowed a more accurate assessment and mapping of the Urban Heat Island (UHI) effect by identifying areas with distinct thermal behaviours. This assessment can also be broadened to examine the other side, such as areas that are unaffected by the UHI effect and lack protection from extreme cold. LCZs are also used for climate modelling, allowing researchers to incorporate localised land cover and urban morphology data into simulations of climate change impacts (Stewart et al., 2014). Lastly, the classification system is valuable for urban adaptation assessments, helping cities understand their vulnerability to extreme weather events.



**Figure 80.** Local Climate Zone (LCZ) classification scheme of Land cover types (left) and built types (right) (adapted from Stewart and Oke, 2012)

## Vilnius Local Climate Zones Structure

### Vilnius Climate Classification

To classify the urban spaces of Vilnius into Local Climate Zones, the World Urban Database and Access Portal Tools (WUDAPT) online generator was utilised. This method provides a standardised approach to mapping urban morphology and land cover based on satellite data, which can be applied across various geographic regions.

The process began by selecting exemplary training sites in Google Earth, representing different LCZ classes, within Vilnius. The sites were carefully chosen to have distinct characteristics of each relevant LCZ, to maximise algorithms accuracy. These training sites were uploaded into the WUDAPT generator, which applied machine learning algorithms to classify the entire city based on surface reflected infrared and visible light wavelengths, as well as structural characteristic patterns (Demuzere et al., 2021).

To ensure accuracy, the generated LCZ map was validated and manually cross-checked comparing them to satellite imagery. The validated results were then averaged within the previously used cell grid, providing a dataset for further analysis.

### Results

The final LCZ map, shown in figure 81, offers new insights into Vilnius' urban structure and serves as contextual areas to position public spaces.

Of all the available Local Climate Zones, Vilnius was found to contain 7 built types and 5 land cover types. Out of these, the majority of Vilnius is comprised of 4 built types: compact mid-rise, open mid-rise, open low-rise and large low-rise, with additional sparsely built zones situated on the peripheries. Compact high-rise and open high-rise, while part of the city's structure, present comparably little coverage areas, questioning their ability to create a separate climate zone, instead of differently exposed areas within other LCZ. The mapped proportion of land cover types indicate an extremely large number of forests or wooded areas nearby developed environments and only a few open fields (low plants) to the south.

From the classification system, there were quite a few zones not applicable to Vilnius's structure, such as LCZ C (bush, shrub) and LCZ F (Bare soil and sand), from the land cover

types and classes, such as compact low-rise, lightweight low-rise and heavy industry, from the built types. This illustrates high levels of greenery within Vilnius administration limits, as well as a lack of heavy industry zones showing that the city mostly holds light manufacturing, which means less emissions of anthropogenic heat.

Local Climate Zones are further assessed in terms of vulnerability, through exposure, sensitivity and adaptive capacity, which helps to narrow down the zones in terms of their relevance and adaptation potential. As the focus of this thesis is on temperature vulnerability for public spaces and people, exposure is examined in all LCZs, while sensitivity is studied in LCZs only where people are residing. These examinations allow the study to narrow down to the three most relevant Local Climate Zones of Vilnius that require attention: compact mid-rise, open mid-rise and open low-rise. These are then further examined through their public space distribution hinting to possible adaptive capacity approaches, as they require multi-functional public spaces to provide social, recreational, functional and commercial activities resilient to temperature extremes. From the narrowed down LCZs, typical neighborhoods are chosen to be examined as intervention sites.

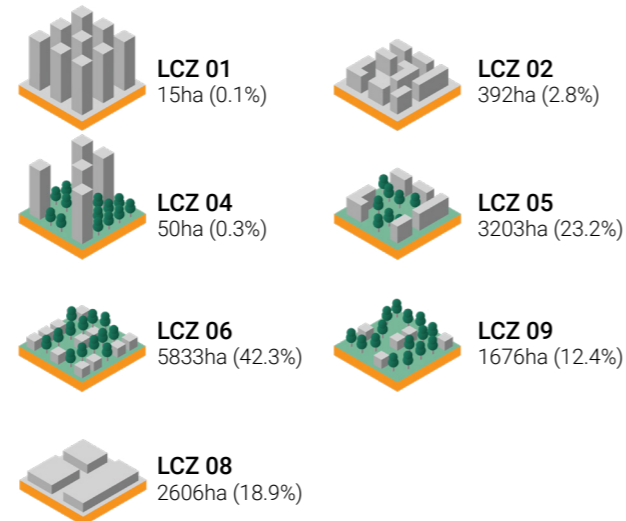
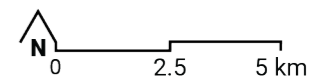
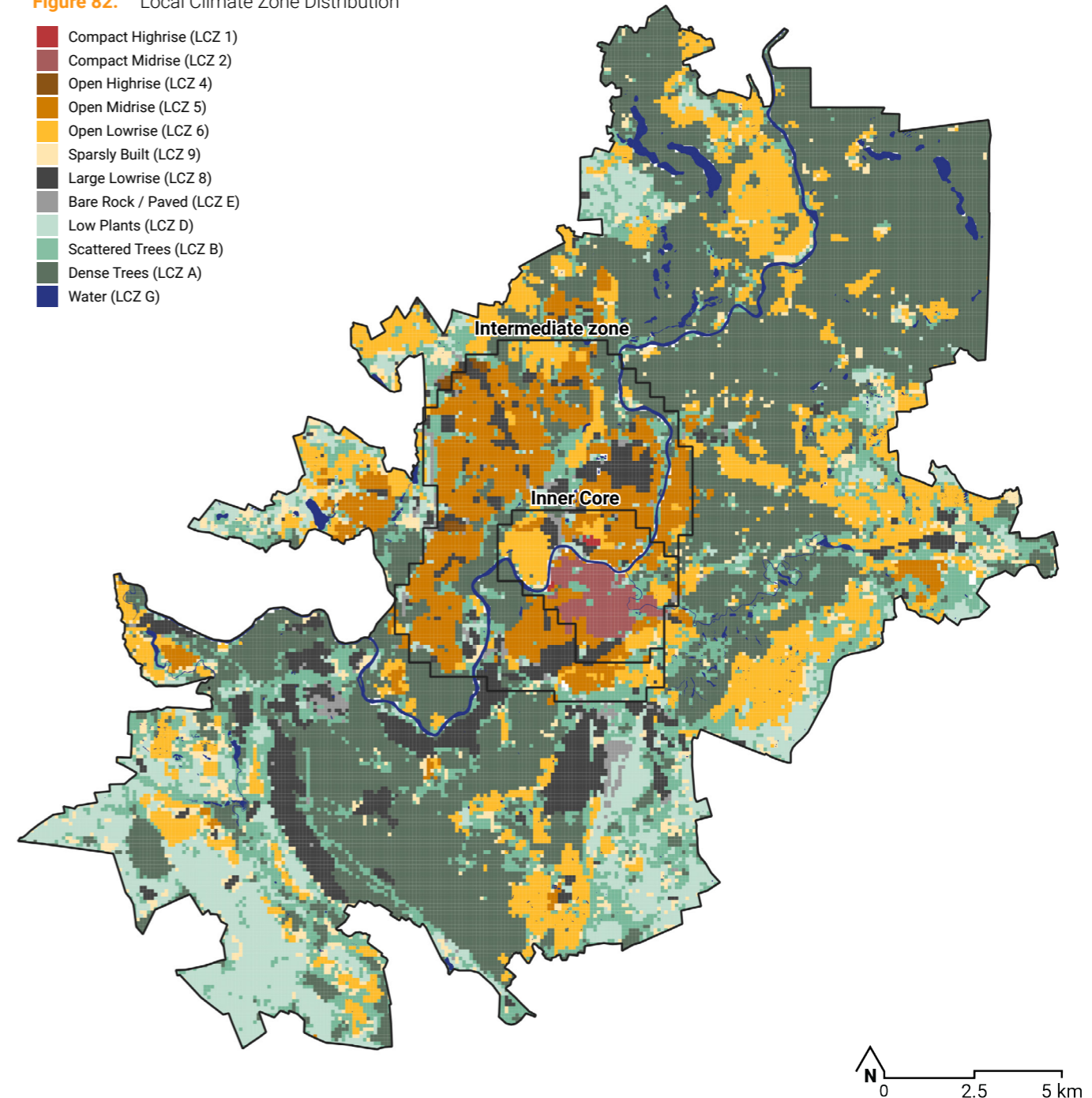


Figure 81. Residential LCZ in Vilnius

Figure 82. Local Climate Zone Distribution



## Vulnerability Assessment

### Local climate zone exposure

By linking exposure, sensitivity and adaptive capacity to each local climate zone, a spatial evaluation can be developed to compare the context performances.

To focus on temperature extremes, the LCZs were examined through their levels of exposure by calculating an average exposure level for both heat and cold. The findings illustrate, that between the largest sample groups of LCZ 2, 5, 6 and 9 there is a possible negative correlation between heat and cold as built density decreases and vegetation increases. However, another large set, the large low-rise built type, does not seem to follow this correlation, exhibiting high levels of both heat and cold exposure. LCZ 1 and 4, also seem to disregard this pattern, although these zone samples are small in Vilnius, in some cases extending to only 200 metres, which lowers the confidence in their exposure accuracy.

Additionally, land cover types, which can be examined as adaptive capacity resources, illustrated new findings. While all natural environments together with permeable low built density areas exhibited light heat exposure, these LCZs extended across all cold exposure levels. The most effected spaces were low density sprawl and open landscapes, while dense forests, seemingly to regulate their environment, illustrated only medium exposure. The LCZ effected the least by both extremes were water bodies. This can be explained through higher heat capacity, as these zones increase and decrease their temperature slower than other surfaces, making them temperature extreme mitigating elements within the city.

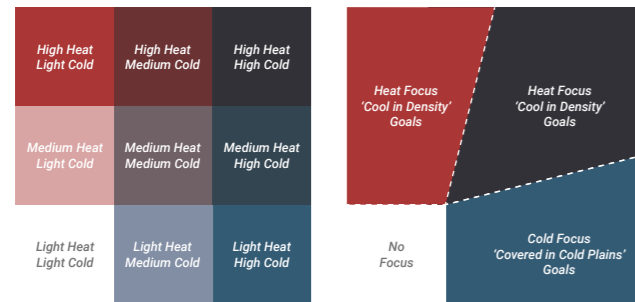


Figure 84. Exposure Overlap Diagram translated towards Focus Adaptation Goals

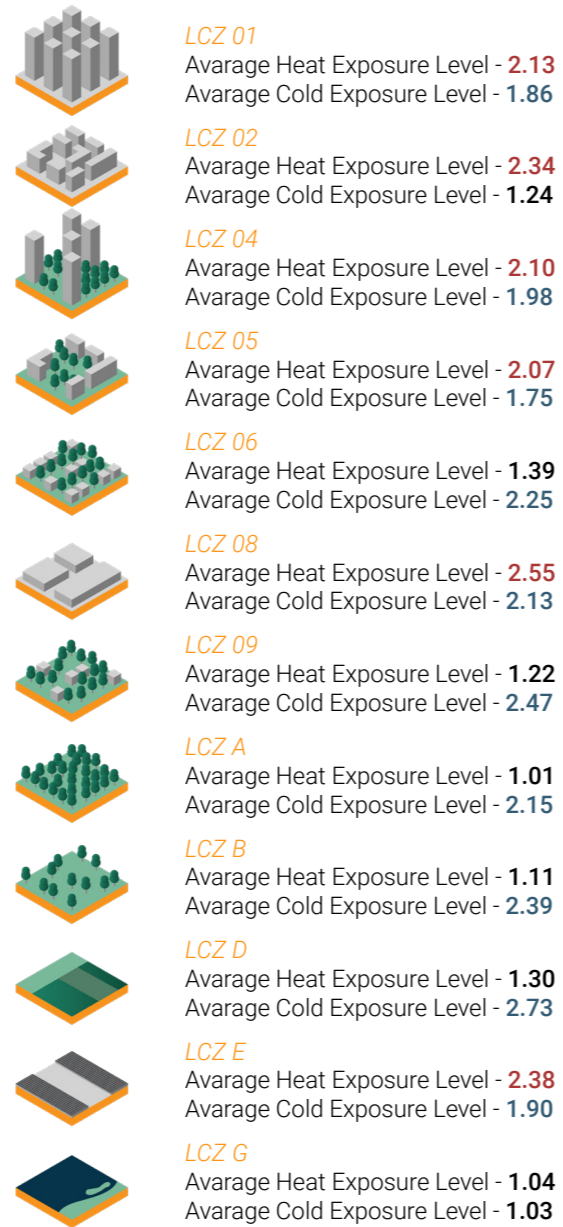
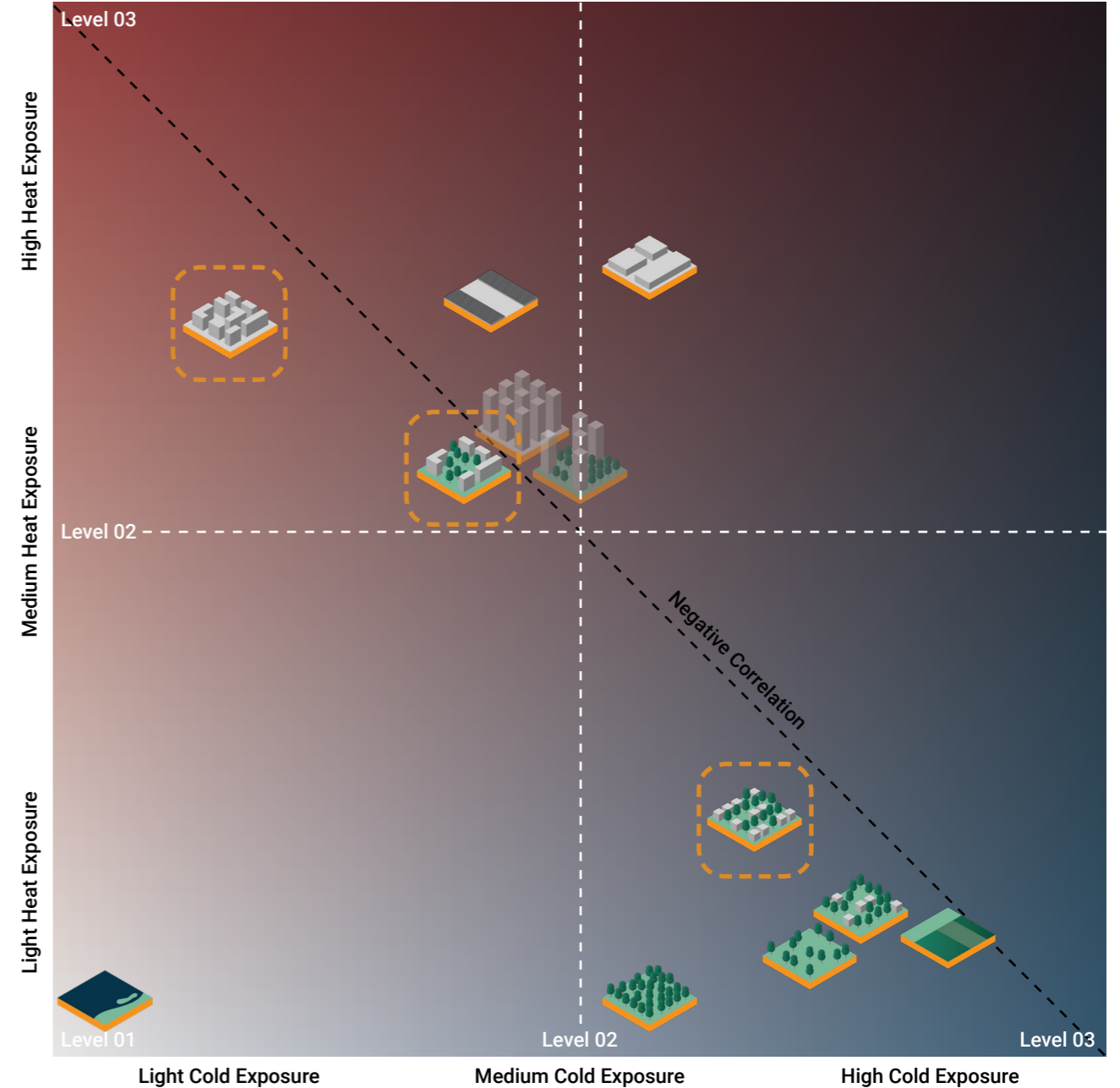


Figure 83. Levels of Exposure of each Local Climate Zones

Figure 85. Levels of Exposure of each Local Climate Zones, represented in a spatial matrix



Local climate zone sensitivity

The three most prominent Local Climate Zones in Vilnius were further examined through their levels of sensitivity by plotting the city's urban blocks or built-up spaces within the sensitivity ternary diagram. The plotted findings were distinguished by population density, illustrated by the circle's size, to consider the density of inhabitants in different environments. The built-up spaces were linked to a specific LCZ morpho-typology, to understand the predominant resident sensitivity of different urban forms.

In Vilnius by the official statistics portal (2021) census data, built-up spaces, that poses higher proportion of children compared to the average data, are concentrated in low density open low-rise environments, signalling an urban sprawl generated by young families. Additionally, the compact dense mid-rise inner city also indicated higher children proportion, requiring adapting the public spaces with children in mind.

On the other hand, high elderly built-up spaces were fully concentrated within dense open mid-rise environments. This can be historically explained, as the majority of these urban forms are last century soviet built modernist micro-districts, which today younger generations are choosing to avoid, leaving only older residents (Pakalnis, 2016). There is an exception for open low-rise zones, where collective garden communities or integrated villages have isolated elderly residents in very low density spaces, limiting their adaptive capacity. These spaces require to transform public spaces with functions catered to elderly.

This examination allowed to better understand the demographic distribution between the most prominent LCZ cases, while also comparing to the whole city's demographic data. While each built-up space requires its own Adaptation Urgency Goal, in every larger settlement there will be general patterns of resident distribution, allowing to better prioritise Adaptation Goals for specific urban forms.

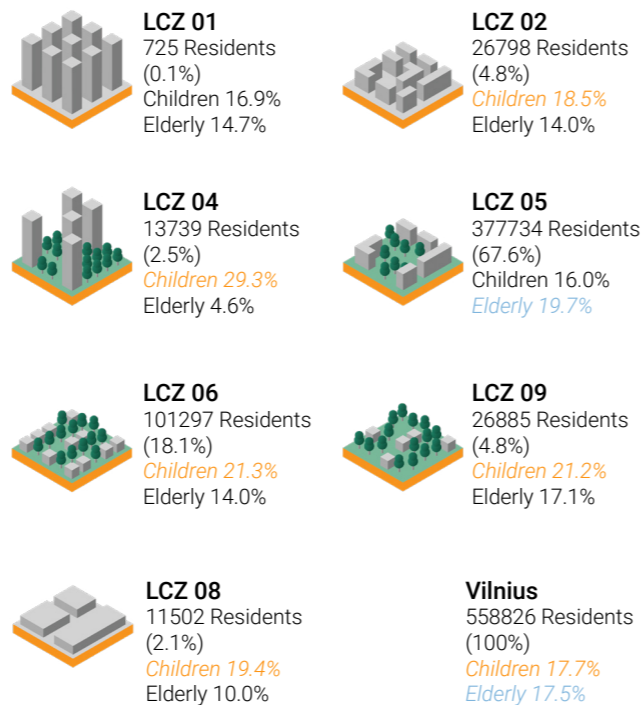


Figure 87. Levels of Sensitivity of each Local Climate Zones

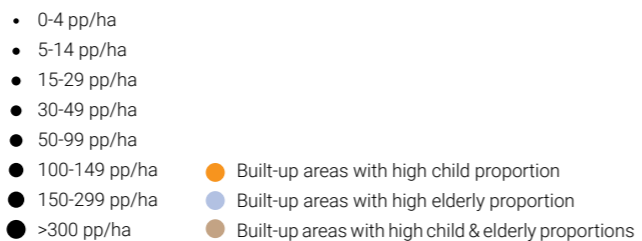
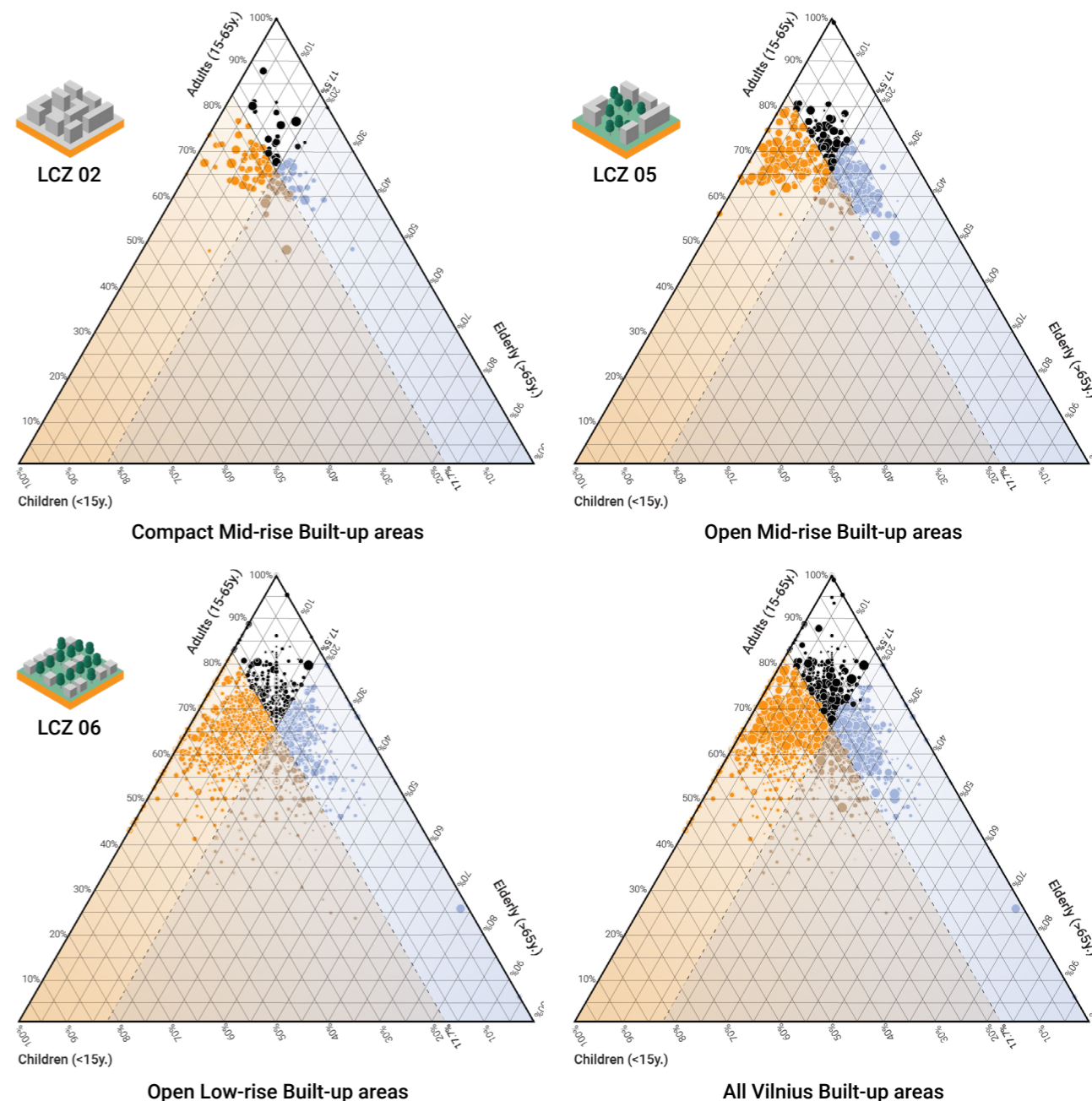


Figure 86. Demographic distribution of each built-up areas (blocks), represented in a ternary diagram



**Local Climate Zone Public Spaces (Adaptive Capacity)**

To understand the adaptive capacity of the dominant LCZ, a detailed categorisation of public spaces and their types was examined. This distribution of public spaces informs the designer to of the possible transformations of each site.

**Compact Mid-rise Public Space**

Compact mid-rise climate zones have a dense and enclosed space structure, where multiple public space functions are overlapping. Through the combination of gathering civic spaces, retail and third places, with extended interface spaces, this structure provides opportunities for social interaction and lively environments. The clear separation between private and public spaces, determine the majority of spaces to successfully balance spaces purposed for residents and visitors. However, some residential areas, which do not possess private outdoor spaces, share their living spaces with service areas and movement spaces, creating disparities for local residents.

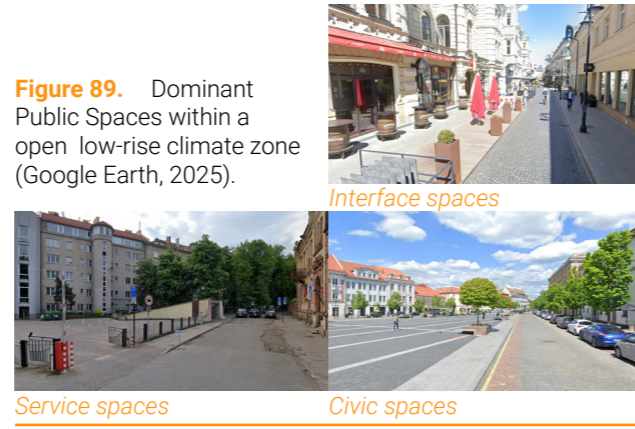
**Open Mid-rise Public Space**

Open mid-rise climate zones have usually have open uncovered public places, which distribute functions across the space. High activity nodes can be found around user selecting spaces and concentrated retail spaces. The most drastic segregation of public space functions can be found in soviet micro-districts. In these neighbourhoods, there is no private-public distinction, making most of these places as exposed leftover spaces.

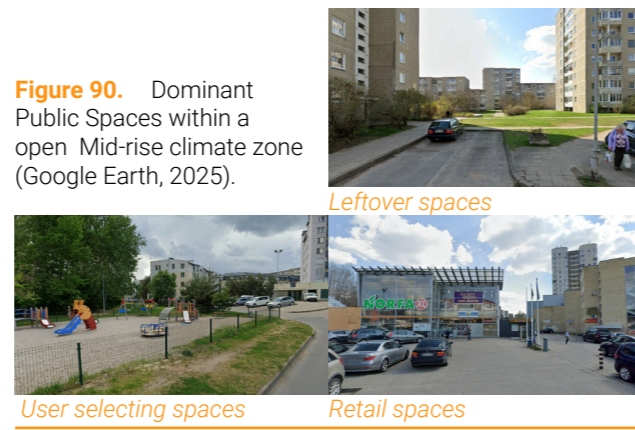
**Open Low-rise Public Space**

Open low-rise climate zones have limited public spaces to only allow people to traverse to and from their homes. Most of the outdoor spaces are privately owned and restricted, leaving only movement, interchange and conspicuous spaces, which act as local community spaces. As these spaces are designed with a car-centric viewpoint, it limits slower mobility, which deters people from accessing further situated communal spaces, without a vehicle. These places require small, localised centres, that provide essential amenities and social spaces. Interchange space are pivotal hubs for alternative movement through these neighbourhoods.

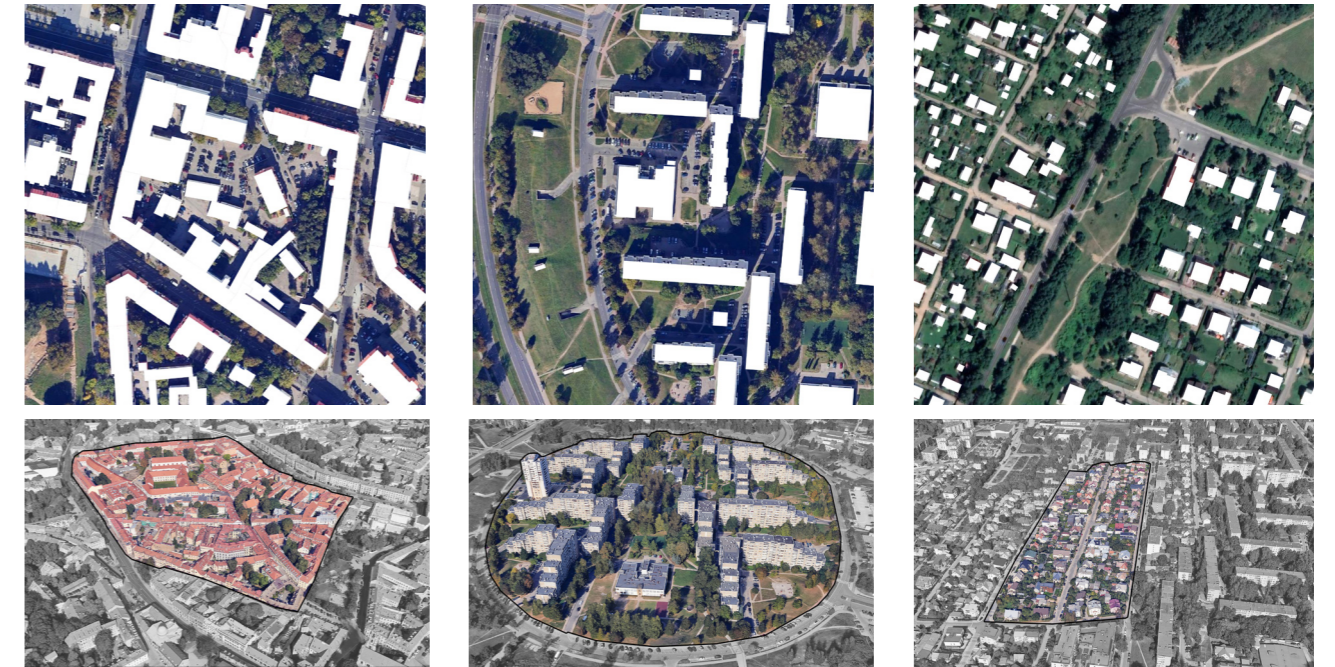
**Figure 89.** Dominant Public Spaces within a open low-rise climate zone (Google Earth, 2025).



**Figure 90.** Dominant Public Spaces within a open Mid-rise climate zone (Google Earth, 2025).

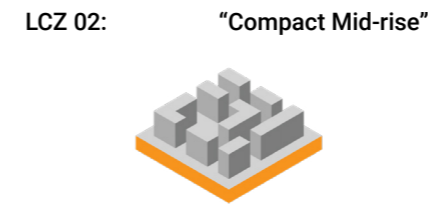


**Figure 88.** Dominant Public Spaces within a open low-rise climate zone (Google Earth, 2025).



**Properties (Stewart, 2011):**

Sky view factor	0.3-0.6
Canyon aspect ratio	0.75-2
Mean building height	10-25 m
Terrain roughness class	6-7
Building surface fraction	40-70 %
Impervious surface fraction	30-50 %
Pervious surface fraction	<20 %
Surface admittance	1,000-2,200 Jm <sup>2</sup> s <sup>1/2</sup> K <sup>-1</sup>
Surface albedo	0.10-0.20
Anthropogenic heat flux	<75 W m <sup>-2</sup>

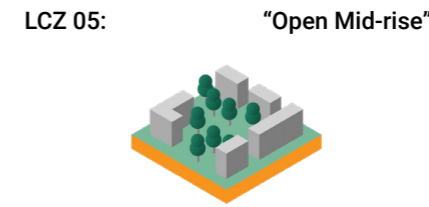


Function: Commercial, industrial, Residential

**Figure 93.** Exemplary LCZ – Vilnius Oldtown (Google Earth, 2025)

**Properties (Stewart, 2011):**

Sky view factor	0.5-0.8
Canyon aspect ratio	0.3-0.75
Mean building height	10-25 m
Terrain roughness class	5-6
Building surface fraction	20-40 %
Impervious surface fraction	30-50 %
Pervious surface fraction	20-40 %
Surface admittance	1,000-2,200 Jm <sup>2</sup> s <sup>1/2</sup> K <sup>-1</sup>
Surface albedo	0.12-0.25
Anthropogenic heat flux	<25 W m <sup>-2</sup>

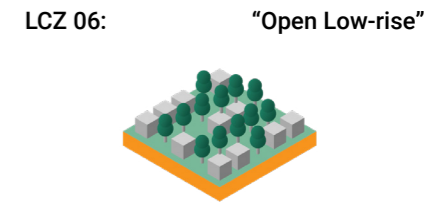


Function: Residential, commercial, institutional.

**Figure 92.** Exemplary LCZ – "Pašilaičiai" district (Google Earth, 2025)

**Properties (Stewart, 2011):**

Sky view factor	0.6-0.9
Canyon aspect ratio	0.3-0.75
Mean building height	3-10 m
Terrain roughness class	5-6
Building surface fraction	20-40 %
Impervious surface fraction	20-50 %
Pervious surface fraction	30-60 %
Surface admittance	1,000-2,200 Jm <sup>2</sup> s <sup>1/2</sup> K <sup>-1</sup>
Surface albedo	0.12-0.25
Anthropogenic heat flux	<25 W m <sup>-2</sup>



Function: Residential, commercial.

**Figure 91.** Exemplary LCZ – "Wooden Šnipiškės" residence (Google Earth, 2025)

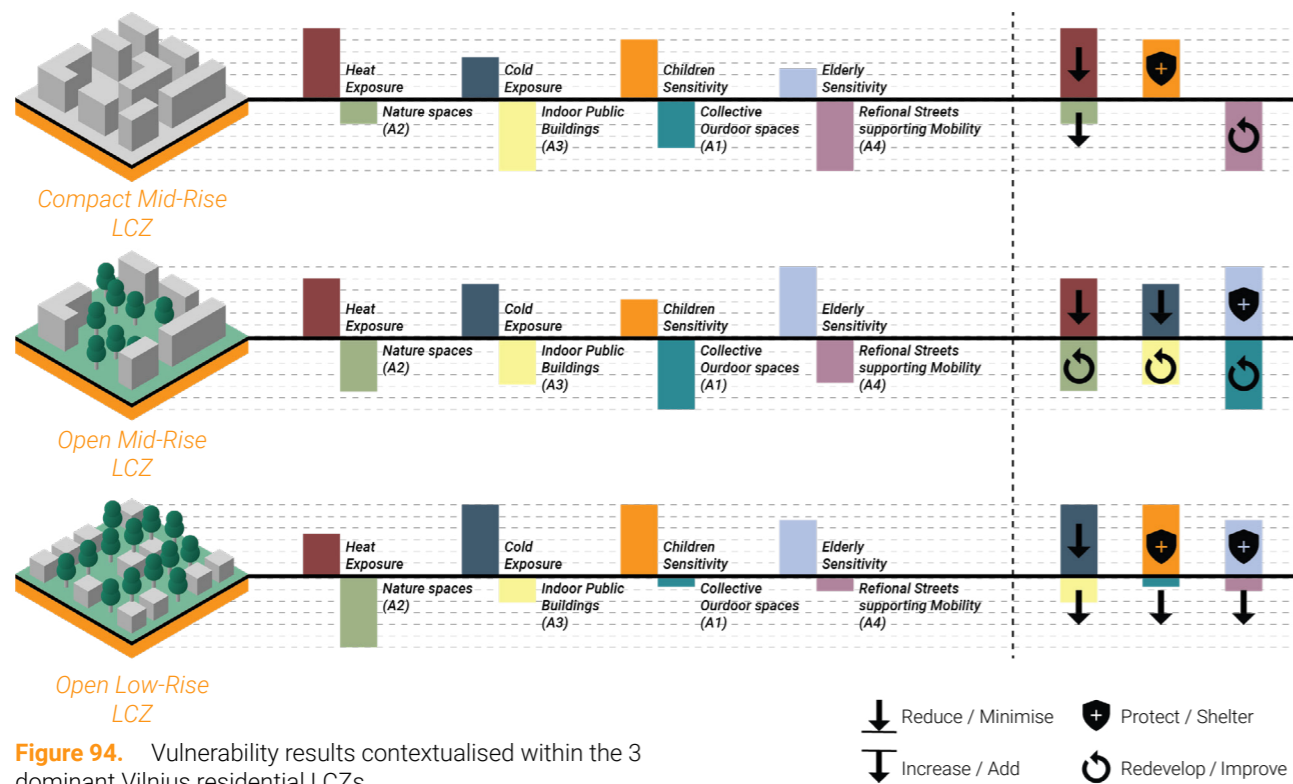
## Vulnerability Conclusion

### Local climate zone vulnerability

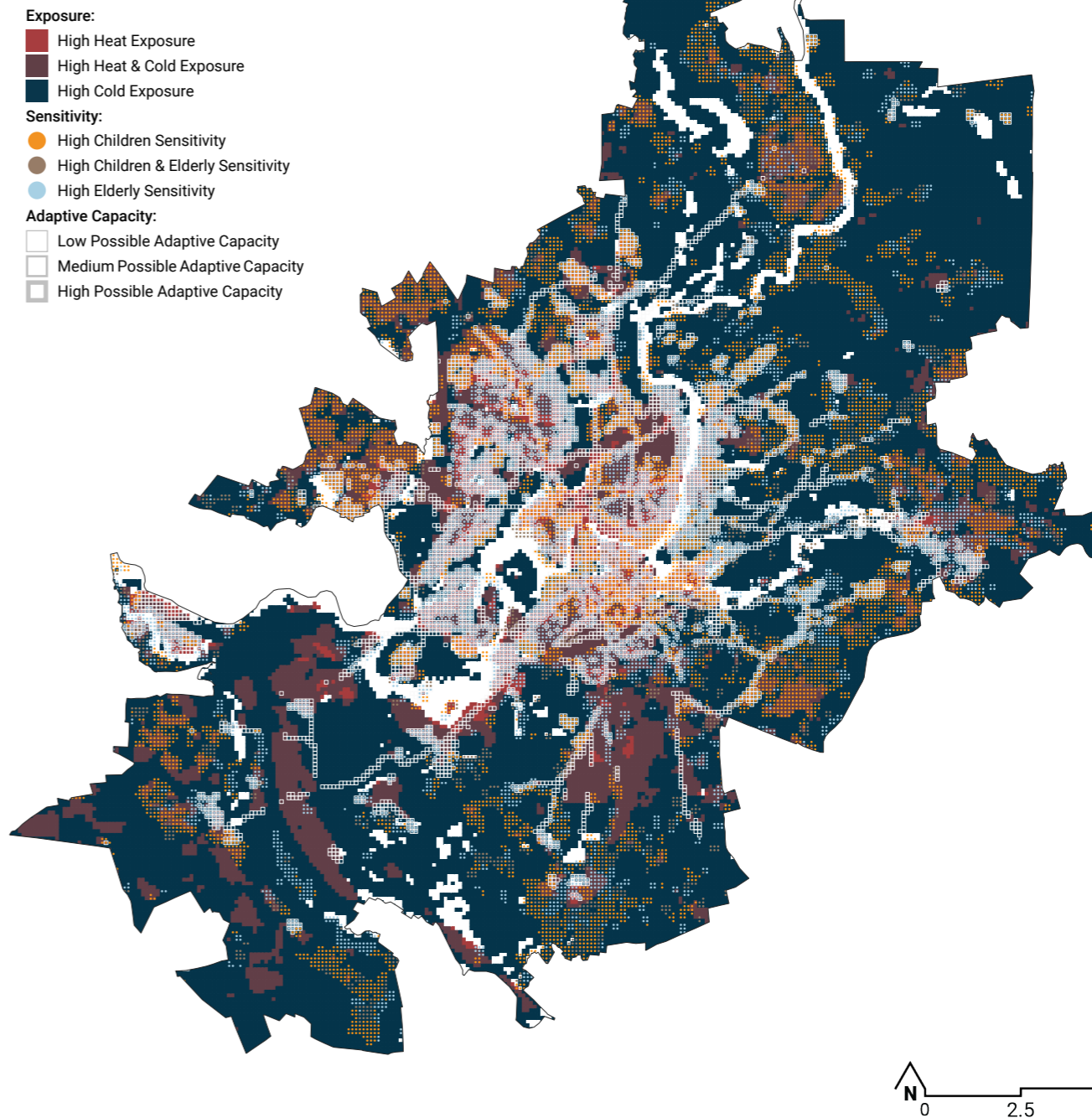
Lastly, Local Climate Zones with similar microclimate characteristics were examined through all the concepts of vulnerability together, shown within the three dominant residential LCZs below. The compact urban core requires to focus on heat mitigation by increasing natural spaces, as other adaptation approaches were already seen in these spaces. Open Mid-rise environments in the intermediate city, had the highest Sensitivity due to the largest proportion of elderly, although the space showed all four possible adaptation approaches. To adapt these environments, both indoor and outdoor community spaces require to be redeveloped and improved to withstand future temperature extremes. Lastly, low-rise urban periphery indicated both sensitive groups and a focus tilted towards cold stress.

Additionally, these environments showed the lowest adaptive capacity with limited amenities and sprawling disconnected spaces, requiring increasing the adaptive capacity through all approaches, apart from increasing natural spaces.

To conclude on Vilnius's vulnerability to temperature extremes, the separation of the problem into three aspects of Exposure, Sensitivity and Adaptive Capacity, revealed that vulnerability is not a one risk factor and it can be present in different forms. By analysing the urban environment from a meso-scale, it showed that public spaces are vulnerable to temperature extremes across the whole city, although in diverse ways.



**Figure 95.** Vilnius map of vulnerability to temperature extremes, illustrated through the 3 main aspects of vulnerability



## Sites of Interventions

### 3 Contexts to Explore

From the vulnerability assessment of the dominant Local Climate Zones in Vilnius, it became clear, that each zone requires different adaptation measures. To further analyse the implications of public spaces adaptation, three case studies were chosen within the relevant urban climate contexts. The specific neighbourhoods were chosen to tackle alternative focuses on extreme heat, extreme cold, and both challenges together. Additionally, neighbourhoods with higher sensitivities were chosen to have a range of public space adaptation urgencies related to children, elderly and both sensitive demographics.

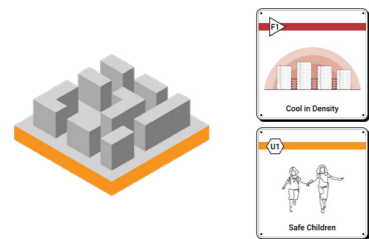
Each chosen site should be examined, of all four possible adaptation approaches and determined which would be the most applicable and provide the most benefits concerning well-being and thermal comfort.

#### Overheating Compact Mid-rise

The vulnerability analysis informs that compact mid-rise zones require to focus on heat. The areas illustrate high children sensitivity, urging the adaptation strategies to consider these residents. Lastly, limited adaptive capacity to green spaces, requires approaching the interventions through urban greening.

#### Typical Case reflecting the LCZ 2

A part of the Naujamiestis district, situated in the Local Climate Zones and Case Studies map, was chosen as the case study for Compact Mid-rise LCZ, as this area exhibited increased heat exposure and children sensitivity.



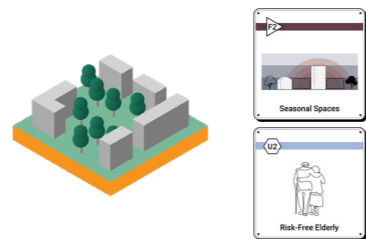
**Figure 96.** Compact Mid-rise context type and its required focus, urgency in Vilnius.

#### Inadequate Open Mid-rise

For open mid-rise zones the focus is placed on both extremes. Districts indicate high elderly sensitivity, urging the adaptation strategies to consider these residents. These zones exhibit high possible adaptive capacity due to large collective spaces and proximity to indoor public spaces, requiring to ensure that these shelters are accessible and available.

#### Typical Case reflecting the LCZ 5

Karoliniškės neighbourhood was chosen as the case study for Open Mid-rise LCZ, as this area exhibited exposure to both extremes and elderly sensitivity was highest within the city.



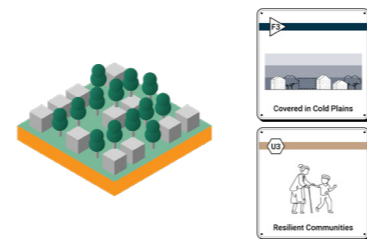
**Figure 97.** Open Mid-rise context type and its required focus, urgency in Vilnius.

#### Cold Open Low-rise

Open low-rise zones are highly affected by cold extremes, shaping their focus to cold. The peripheries reveal that both sensitive age groups are residing here, highlighting the high urgency. Limited public spaces indoor and outdoor, requiring approaching these spaces through local poly-centric community development.

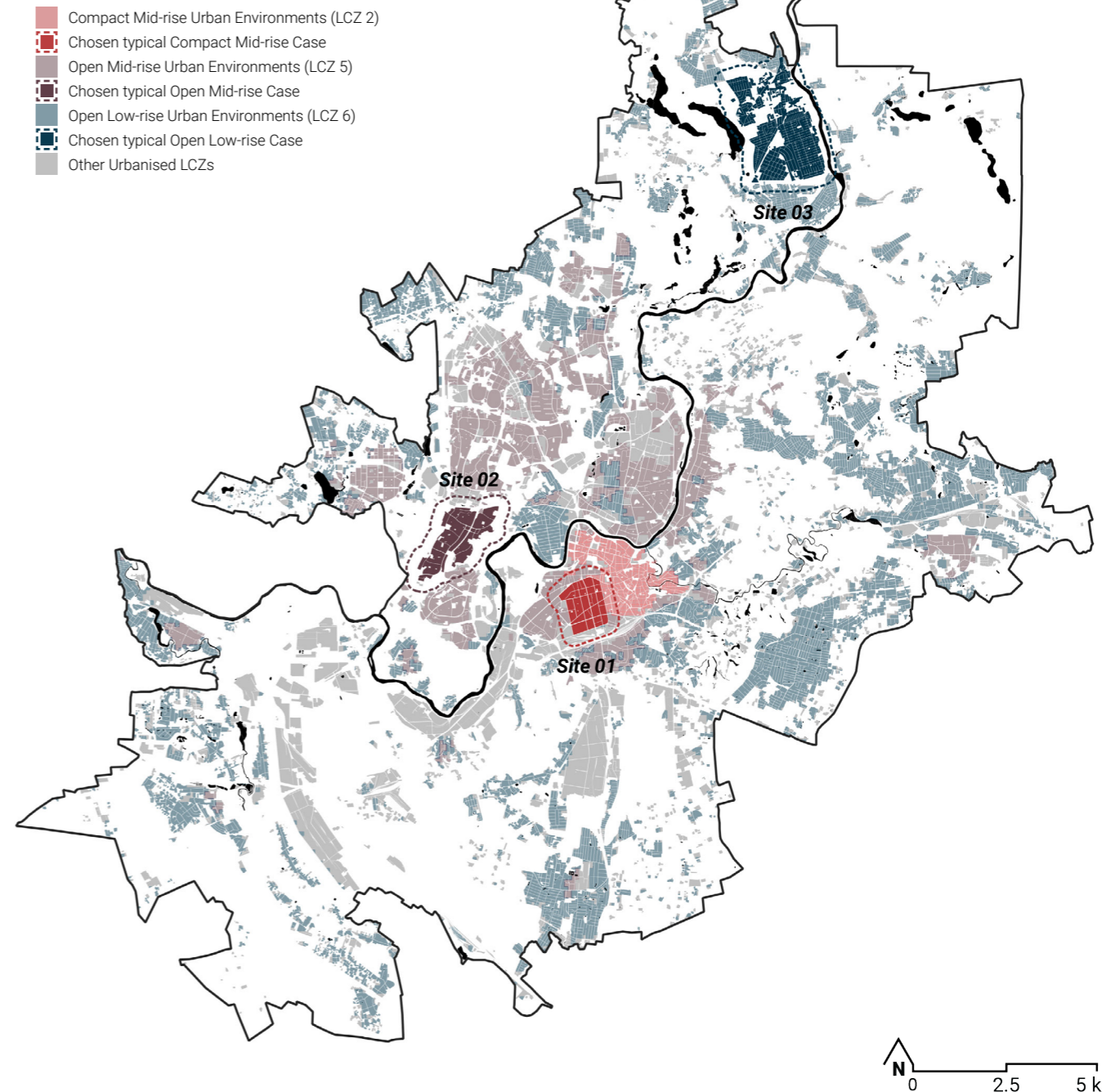
#### Typical Case reflecting the LCZ 6

Northern Verkiai territory was chosen as the case study for Open Low-rise LCZ, as this area exhibited high exposure to cold and urgency for both sensitive demographic groups.



**Figure 98.** Open Low-rise context type and its required focus, urgency in Vilnius.

**Figure 99.** Local Climate Zones and Case Studies, requiring attention in Vilnius



# 05

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## Patterns of Climate

### Patterns for Climate Adaptation

*Design Solutions*

*Design Solutions as Pattern Cards*

### Exposure Reduction Patterns

*Designing for Heat & Cold*

### Social Well-being Patterns

*Socially Valuable Spaces*

### Urban Adaptation Capacity Patterns

*Urban Shelters & Coping Networks*

### Pattern Language Atlas

*Developing the Pattern Atlas*

*Utilising the Pattern Atlas*

## Patterns for Climate Adaptation

### Design Solutions

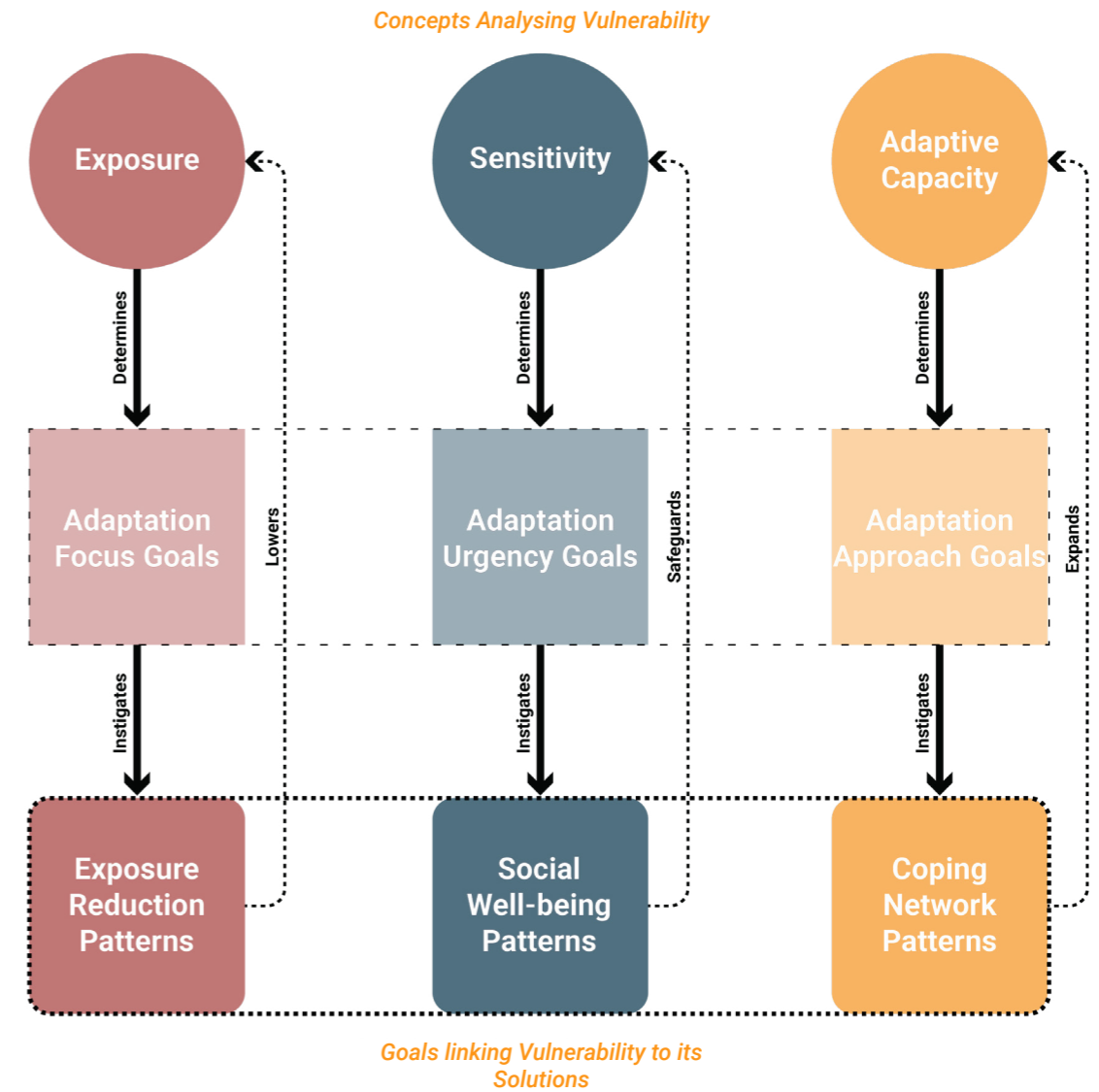
In order to identify interventions to adapt public spaces to extreme cold and heat, a study was carried out to list and understand potential design solutions. Through literature review, possible solutions were extracted fitting the goals derived from analysis of Exposure, Sensitivity and Adaptive Capacity. As multiple solutions were found addressing the Focus, Urgency and Approach Adaptation Goal categories, a system of cataloguing them in relation to their corresponding challenges and spaces was needed. Pattern language emerged as a structural method to map potential design interventions and their potential units of application. This method provided a categorised set of strategies and technologies proven to be effective to manage urban temperature extremes, which could be used to analyse the current public space adaptation capabilities and to further adapt the problematic spaces.

Christopher Alexander's Pattern Language approach was chosen to represent the possible design solutions for its ability to analyse and catalogue complexity. As stated by Salinger (2008) pattern language emerges for two distinct goals: one being to understand and, if required, to change a complex system, the other being to create a design tool, with which something functional and spatially coherent can be built. To tackle the challenges of urban climate, both of these ambitions are required to deconstruct the system into understandable parts and then be able to implement changes to it.

All relevant design measures were broken down in terms of their core spatial elements and their effects on exposure, sensitive demographics or adaptive capacity were identified. This dissection produced a set of patterns, that applied would have a significant influence on the urban system. Exposure Reduction patterns were created in response to the Focus Goal to help urban environments mitigate extreme temperatures based on their level of exposure. Social Well-being patterns implement the Urgency Adaptation Goal by emphasising the user-selected spaces that provide social and physical benefits for sensitive demographics. Finally, the Coping Networks patterns address the Approach Goal by improving urban accessibility and people's mobility with the aim of increasing adaptive capacity.



**Figure 100.** Design solutions classified to Exposure Reduction, Social Well-being and Coping Networks.



**Figure 101.** From Concepts to Goals to Solutions, linking adaptation design solutions to the study's conceptual framework

*Design Solutions as Pattern Cards*

The design of the pattern as a card was inspired by previous studies working with pattern language (Bechmann, 2023; Croxford et al., 2020; de Meijer, 2024). The two card sides emphasise different application of the pattern, with the card face face-side, including the sketch, title and the main statement, allowing designers and non-designers alike to discuss the possibility and implication of the pattern, as it states a simplified design component open to interpretations. The back side defines the pattern with empirical justifications and expresses spatial implications of its implementation, which can be used to precisely design and plan adaptive spaces. The exemplary project or literature cites, where the empirical justification has been taken from.

Each pattern is linked to specific adaptation goals derived from the previous chapter on Urban Climate Analysis. The patterns' primary adaptation purpose is indicated within the top-left square, in which it states the number and the category of either Exposure Reduction (E), Social Well-being (S) or Coping Networks (C). These three categories are respectively linked to Focus, Urgency and Approach Adaptation Goal groups. However, the patterns were identified to also influence other goals, which were marked in the top-right position, indicating each specific Adaptation Goal, with triangles representing Focus, hexagons – Urgency, and circles representing Approaches. Each goal is colour coded, illustrated below.

*Adaptation Focus Goals:*



*Adaptation Urgency Goals:*



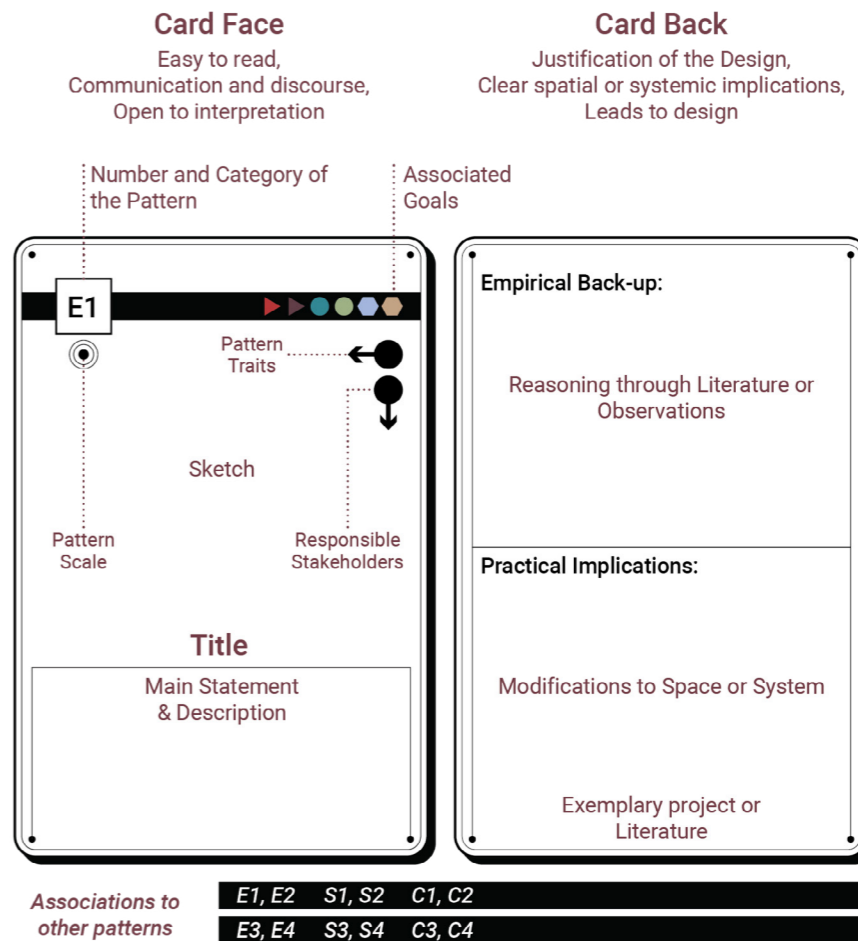
*Adaptation Approach Goals:*



**Figure 102.** Linking Adaptation Goals to Patterns

The patterns are also arranged into three main properties marked as circle diagrams below the pattern's number and goals. These properties relate to the pattern scale, implementing Stakeholders and category specific traits. Urban climate scales are used to illustrate pattern impact extent, various stakeholder diagrams specify, which groups is responsible to ensure the pattern is implemented and maintained. Exposure Reduction (E) traits list, which climate factors the design influences, Social Well-being (S) traits explain the social spaces arrangement, and lastly, Coping Network (C) traits describe the adaptation type. These traits are further explained in the report.

This approach differs from a standard toolset, as it also focuses on the relationships and categories between the patterns, highlighting synergies and conflicts between them. The relationships between patterns were observed by comparing if the two patterns provided benefits when applied together, they solved the same issue, they hindered each other or whether one pattern was required to apply the other, creating links that emphasised their complementary, alternative, conflicting or embedded patterns. These relationships became an essential part of the pattern atlas after the pattern language workshop evaluation, described in the Evaluation chapter of the thesis. These relationships were indicated in the Pattern Language Atlas below each pattern card.



**Figure 103.** Designing the Solution Pattern to be able to utilise it as a communication tool as well as a bridge between research and design.

Urban Temperature Adaptation Dimension	Urban Planning & Design Scales					
	Point	Building	Street Canyon	Block	District	City
Urban Climate Scale	Micro	Micro	Local	Local	Meso	Meso

Stakeholders Responsible for Pattern Implementation					
Stakeholders	Local Residents	NGO's	Private Sector	Public Services	Municipality

**Figure 104.** Pattern related to Urban-Climate scales and responsible implementation Stakeholders.

## Exposure Reduction Patterns

Temperature exposure analysis revealed that some urban environments are more prone to trap and store heat, while others quickly dissipate it. Because of this, the adaptation process needs to focus on either one temperature extreme before the other or areas that required a dual approach. Therefore, three Focus Adaptation Goals were created: Cool in Density, Covered in Cold Plains, and Seasonal Spaces for areas exposed to extreme heat, cold, and both, respectively. Exposure Reduction patterns were created in continuity to these Focus goals to help urban environments mitigate extreme temperatures.



### Designing for Heat & Cold

While in theory temperature adaptation is understood as a system's or population's adjustment to a hazardous situation rather than minimising the hazard, in practical terms, reducing heat or cold stress and exposure, which can be considered hazard mitigation, complement adaptation strategies, which put more emphasis on human behaviour, land use and anthropogenic heat (Palme & Salvati, 2021). To tackle the issue of temperature exposure, a complementary temperature concept is introduced in response – thermal comfort. As urban form, land cover and amount of vegetation can influence a specific microclimate's extent of the temperature extreme, they directly influence people's thermal comfort through environmental factors.

A literature review examining various heat adaptation action plans and cold mitigating design strategies, was undertaken to collect and categorise available design options as patterns (see full atlas in the appendix). When examining exposure patterns, environmental factors gave new insights for the design solutions, as they illustrated their versatility for both extreme temperatures or limited benefits for only one temperature extreme and drawbacks for the other.

Solar radiation and wind patterns have contradicting influences on heat and cold extremes, as during a heatwave solar radiation has to be minimised and ventilation increased, while during a cold spell solar radiation gains require to be optimised, and cold winds blocked. The major heat-reducing design strategy is focusing on limiting solar radiation through

shading and vegetation, increasing surface albedo and sky view factors (C40 Knowledge Hub, 2019). On the other hand, solar access during colder periods in high-latitude city cores was found to be an unreachable goal due to the low angle winter sun requiring large open spaces (Chapman et al., 2018). For this reason, limiting wind is the most important factor when designing outdoor winter microclimate.

Additional environmental factors such as rain and humidity require consideration during hot periods, while problems with ice, snow and shorter darker days require attention during cold periods. All these climate factors became traits for the Exposure Reduction patterns, as each design solution would targeting one or a few of these factors.



Figure 105. Investigated Action and Adaptation Plans for heat mitigation & Design Guidelines and Strategies for cold urban environments (The City of New York, 2017; City of Edmonton, 2017)

Figure 106. Sample of patterns related to Heat & Cold Exposure Reduction (All patterns can be seen in the Appendix)

Climate-Sensitive Considerations		Exposure Reduction Factors					
		Sun Light	Wind	Humidity	Rain	Snow/Ice	Dark
Climate Extreme	Heatwave	Reduce ☀️	Increase 🌬️	Increase 💧	Store ☁️		
	Cold Spell	Increase ☀️	Reduce 🌬️			Store/Remove ❄️	Address 🌑

Figure 107. Relevant climate factors when designing for heat or cold outdoor comfort

## Social Well-being Patterns

Analysis of temperature sensitivity indicators revealed age group distributions with some neighbourhood populated with larger percentages of elderly, while other have larger proportions of children. While adaptation is important for both demographics, the types of spaces these neighbourhoods should adapt and improve differ, creating specific urgencies for one group or the other. In response to this, three Urgency Adaptation Goals were created according to population distribution: Safe Children, Risk-Free Elderly, and Resilient Communities for areas with high proportions of children, elderly citizens, and both demographics, respectively. Social Well-being patterns address these Urgency Adaptation Goals by emphasising the user-selected spaces that provide social and physical benefits for sensitive demographics.



### Socially Valuable Spaces

To transform public places into temperature adaptive spaces, strategic interventions are needed, prioritising some spaces over others. As this thesis focuses on adapting spaces for people and increasing their social and physical well-being, it is important to preserve already existing urban spaces that foster these values and increase their temperature coping mechanisms.

Various groups of people are subject to different levels of impacts. Social well-being spaces shows how these groups position themselves in the neighbourhood. By focusing on redeveloping user-selected spaces that encourage interaction, provide meeting spaces or activities that improve the residents' mental and physical health, the usability of these spaces can be extended by protecting them from temperature extremes.

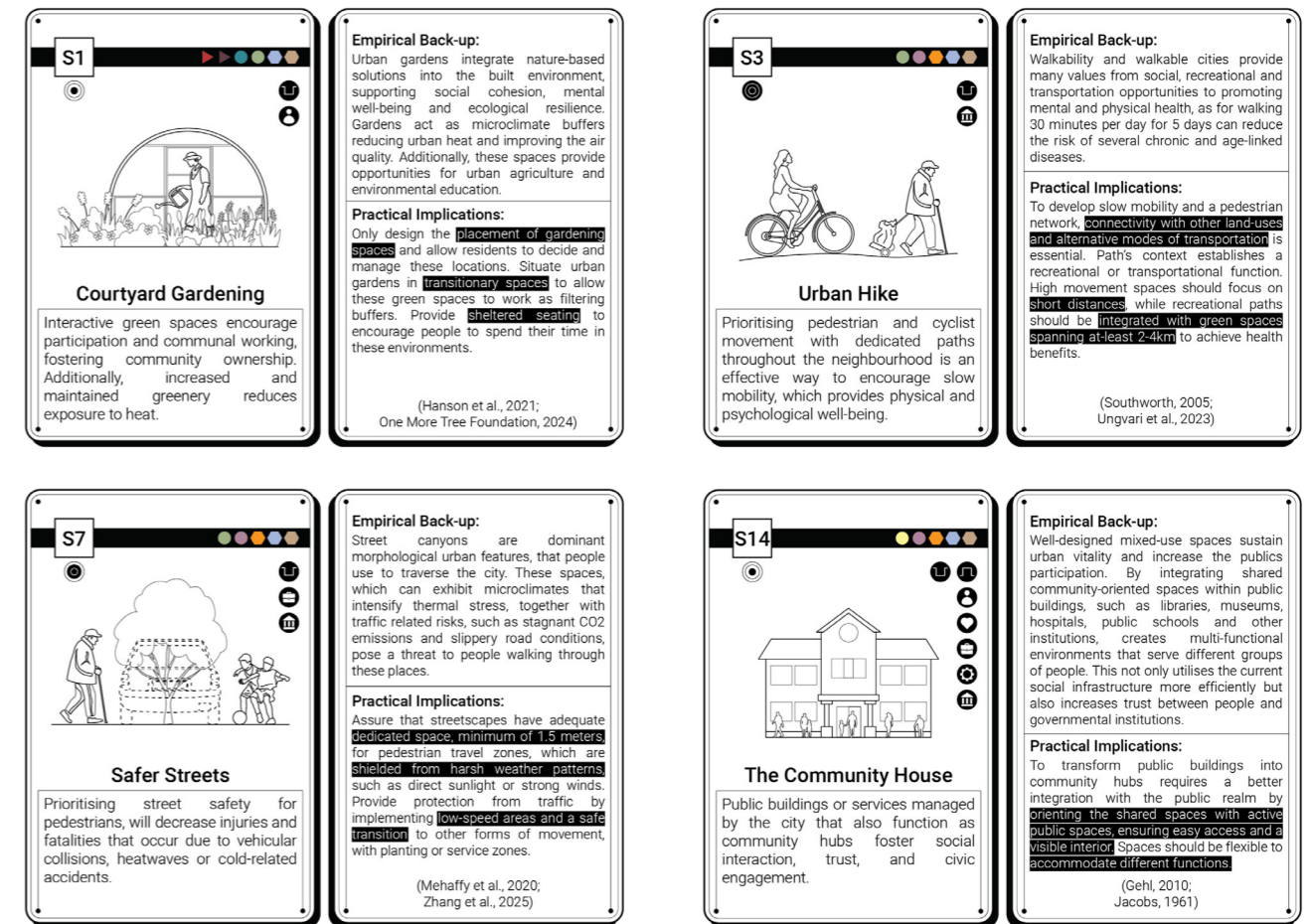
Each neighbourhood, depending on its demographic's socio-economic status and available space, places value on different public spaces. Patterns, related to social cohesion, illustrated in the next page, were developed through literature review of public space theories and fieldwork observations were used to validate these patterns (Carmona et al., 2021; Gehl, 2010; Mehta, 2014). While all of these spaces provide benefits, a generic implementation of all these patterns would not provide equal benefits. A detailed analysis of

current spaces can show how people spend their time and which spaces most require intervention. Spaces that have high participation or are carefully maintained by the locals, illustrated in the photos, reveal the active patterns that are already in place.

The arrangement of these social spaces was also examined considering their cover and openness to environmental factors. Three spatial arrangements were listed to describe if the space is enclosed indoors, exposed outdoor or situated in-between the threshold. These arrangements became the Social Well-being (S) pattern traits.



**Figure 108.** Fieldwork observations of valued public or private spaces to understand which areas require safeguarding from temperature extremes (Photo above - made by author; below - Kalinskas, 2016).



**Figure 109.** Sample of patterns related to increasing Well-being and social cohesion (All patterns can be seen in the Appendix)

Social Well-being Space Traits			
Social Space Arrangement	Indoor Space	Outdoor Space	Threshold Space

**Figure 110.** Social Space arrangement considering the cover or openness to environmental factors.

## Coping Network Patterns

In order to see how Adaptive Capacity can be realised spatially, Approach Adaptation Goals were created based literature on accessibility and climate shelters. Community Refuge, Comfort Trails, Shelter-in-Place, and Sanctuary Routes are offered as four possible approaches to shelter populations ranging from bottom-up outdoor shelters for low-risk temperature extremes to district public indoor shelters for extremely hazardous temperatures. While the previous meso-scale analysis suggested possible Approach Goals to increase adaptive capacity, local adaptation planning should consider the possibility to incorporate all four approaches to create a comprehensive coping network. The Coping Networks patterns address these Approach Goals by improving urban accessibility and people's mobility with the aim of increasing Adaptive Capacity.



### Urban Shelters & Coping Networks

As adaptation to temperature depends on human behaviour, temperature extremes either require people to move to a more thermally comfortable area or an active element that would temporarily transform the exposed space. To adapt urban structures to extreme temperatures, Coping Network patterns were developed, which incorporate policies that encourage or allow adaptation, behavioural changes that would increase the space's Adaptive Capacity, and, lastly, environmental or spatial transformations that transform how people use the space or include temporary changes which increase the space's coping capacity.

All these patterns were developed by analysing heat adaptive planning strategies, where safeguarding the population during a climate hazard is the primary goal (Gabbe et al., 2021). The corresponding action plans emphasise the importance of cooling spaces, such as quality natural spaces or mechanically air-conditioned community spaces, awareness of these spaces and their accessibility. By integrating the "15-minute city" principles for proximity and reach into capacity patterns, as movement throughout the city also becomes an integral part of adaptation. All of this

determines the development of accessible and reachable climate refuges or "shelters", as it is defined in this thesis (Palme & Salvati, 2021).

For example, the previous analysis of Vilnius suggests that the adaptive capacity based on accessibility and proximity is limited. While the city has many forests and green spaces within it, as well as a few projects that bring attention to heat, such as the cooling mist spray structures, the preparedness and planning is lacking. Cold extreme shelters are limited to two homeless shelters in the city that provide heat, even though 30% of all Lithuanians could not adequately heat their homes in 2024 (Noel, 2025).

These patterns offer the chance to rethink the cities' coping capabilities to temperature extremes and increase them by implementing adaptive spaces within the current urban structures. As well as allowing urban designers to plan for the future, these patterns also bring out the question of "climate commons" and our reinterpretation of climate safe spaces.



**Figure 111.** Investigated alternative cooling and heating adaptations approaches, such as homeless shelters providing heating (Žiūra, 2021b).

**C3**

**Neighbourhood Resources**

Sharing resources, that allow active adaptation to temperature extremes, in public spaces ensures that the most sensitive groups have equal opportunities to adapt.

**Empirical Back-up:**  
Access to communal tools and items, such as shading devices, movable seating, fans, thermal blankets, snow shovels or communal gardening tools, increases a neighbourhood's adaptive capacity to respond to climate stresses. The concept of "sharing city" has illustrated how a circular approach can increase inclusivity and sustainability, which can be extended towards risk management.

**Practical Implications:**  
Encourage the use of adaptable easy-to-use collective objects such as portable shade structures, water dispensers, misting devices, and weather protective gear. Establish lending systems and sharing storage areas for people to trade tools, clothing and equipment that provide heating or cooling. Encourage residents to co-manage these resources, promoting inclusive access.  
(de Jong, 2025)

**C4**

**Neighbourly Help**

Having an active and connected community ensures that during temperature extremes sensitive groups can quickly receive help and support from trusted people.

**Empirical Back-up:**  
Strong social networks are crucial for community resilience and adaptability, particularly during climate hazards. Research shows that social connection is a strong variable in many health outcomes for vulnerable individuals, as they are able to receive timely assistance. To increase the response rate from isolated people, there must be trust and familiarity.

**Practical Implications:**  
Adopt community building initiatives like neighbourhood groups, buddy systems or local care networks to ensure communication and support. Establish protocols for checking in on elderly or isolated residents during extreme temperatures. Encourage shared communication platforms to organise help quickly. Communal spaces can host events that strengthen trust and connections before hazards occur.  
(Kafeety et al., 2020)

**C7**

**Help from the City**

Municipality assigned subsidies and budgets for public space adaptation are essential for vulnerable spaces, that are limited in their ability to transform their spaces.

**Empirical Back-up:**  
Studies highlight that adaptation is capabilities of different regions and neighbourhoods vary due to unequal due recourses and capital. Similar to the climate finance's principle of "common but differentiated responsibility and respective capabilities", public subsidies and targeted funding can empower and allow local vulnerable stakeholders to adapt their spaces to temperature extremes.

**Practical Implications:**  
Municipalities should establish dedicated funding programs aimed at supporting the adaptation of under-privileged and sensitive neighbourhoods. These could include grants for local communities or assistance programs offering adaptation expertise. Participatory community projects could be developed together with municipal projects to share materials and transform spaces simultaneously.  
(UNFCCC, 2025)

**C9**

**Cooling Centre**

Air-conditioned spaces that provide refuge from heat and supply water to the public reduce the risk of heat-related harm and mortalities.

**Empirical Back-up:**  
Enclosed spaces with regulated temperature prevent or reduce the negative health impacts of severe heat. Additionally, here people can learn about the impacts of heat and the measures they can take to address these.

**Practical Implications:**  
As these interior spaces incorporates mechanical cooling systems, such as air conditioning or geothermal cooling, energy efficiency must be considered. Renewable energy production especially during heatwaves, can utilise solar energy to operate the shelter. Passive design, suitable materials and insulation's careful implementation minimises the energy demand required to maintain these structures. These spaces can be set up in response to heat waves or integrated in the interior public structures.  
(Anticipation Hub, 2024; COMPAC, 2024)

**Figure 112.** Sample of patterns related to increasing Adaptive Capacity (All patterns can be seen in the Appendix)

Coping Networks Traits			
Adaptation Type	Policy Implementation	Behaviour Change	Environment Transformation

**Figure 113.** Various Coping Network Patterns that increase Adaptive Capacity

## Pattern Language Atlas

### Developing the Pattern Atlas

While the adaptation goals are established and could be expanded in future studies to include alternative approaches or other sensitive groups such as people with pre-existing health conditions or impoverished people, the collection of Exposure Reduction, Social Well-being and Coping Networks solution patterns functions as an open-ended Pattern Atlas set, which is changing and increasing with each design iteration and implementation.

When developing these patterns, many possible creation or transformation options were identified to further increase the set. Three creation options, deriving from literature, observations or precedent studies, were the most recurring. The specificity of a pattern was the most difficult task, as the patterns could be merged if they were too vague, split if they were too definitive, or cloned if similar alternatives could be used.

Urban climate scales were also informative, as design solutions could be upscaled or downscaled depending on the required development or the gained effect. The differentiating scales also allowed previously conflicting patterns, such as Channelling Wind (E7) and Green Windbreaks (E17), to operate together, as one design creates ventilation corridors through the street canyon on a local scale, while the other creates small microclimates sheltered from wind throughout the canyon.

The most practical pattern transformation for my thesis was produced by merging multiple relevant patterns, linking Exposure Reduction, Social Well-being and Coping Networks pattern categories to create new patterns, that acted as adaptation strategies. These new patterns are more site-specific and act as development guides for a particular city or neighbourhood type.

### Utilising the Pattern Atlas

The design patterns utilised in this thesis build upon the Alexander's Pattern Language method to include a more guided approach to use and combine the possible patterns (Alexander et al., 1977).

A large set of design patterns focused on one specific problem can lead to a comprehensive design that tackles the problem from different scales and points of view or can bring out a discourse on the prioritisation of one solution over others to optimise the possible outcome. However, when tackling multiple problems, as in this case, working on adapting to opposite temperature extremes, the large set of solutions can become overwhelming or contradicting. To overcome this challenge, the created patterns are linked to specific Adaptation Goals, which prioritise one Focus, Urgency or Approach Goal over the other. In this sense, the large set is reduced to patterns that only focus on the chosen problem, which later on can be extended with additional patterns that solve issues, which will emerge in the future.

In this thesis, the Pattern Language as a design method is applied in 4 steps:

1. **The initial urban analysis provides specific goals related to temperature Focus (triangle), sensitive group Urgency (hexagon) and possible adaptation Approaches (circle). These Adaptation Goals can be considered as the area's adaptation brief, which selects specific solution patterns linked to these goals.**

2. **The area's site analysis allows the designer to situate these goals to potential spaces for adaptation and select the most applicable solution patterns based on existing structure analysis and thermal comfort findings, narrowing down the list.**

3. **The chosen patterns are implemented or merged to create a new, integrated, site-specific pattern, which adapts the current environment to a specific temperature extreme considering a sensitive group of people that are residing in the area.**

4. **Lastly, if a new pattern is developed, it is included into the Pattern Atlas to be implemented in other contexts.**

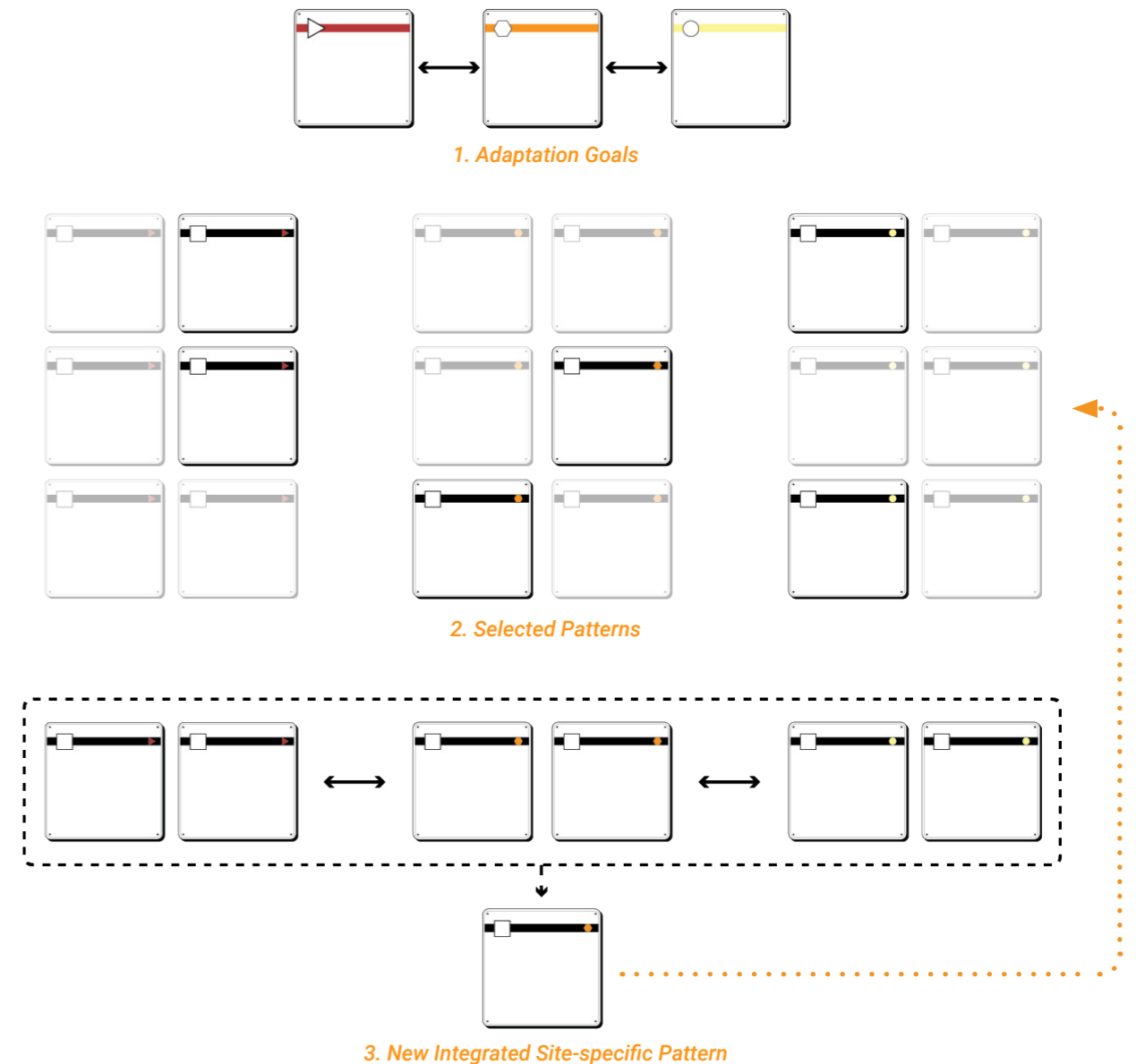


Figure 114. Pattern Implementation Framework

# 06

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## Adaptation

### Public Space Adaptation Guide

#### Site 01 | Naujamiestis Neighbourhood

*Context*

*Analysis*

*Transformation Vision*

*Adaptation Goals*

*Conclusion*

#### Site 02 | Karoliniškės Residential Micro-District

*Context*

*Analysis*

*Transformation Vision*

*Adaptation Goals*

*Conclusion*

#### Site 03 | Verkiai Collective Gardens

*Context*

*Analysis*

*Transformation Vision*

*Adaptation Goals*

*Conclusion*

### Pattern Implementation

## Public Space Adaptation Guide

To apply the developed pattern atlas in order to adapt public spaces to temperature extremes a systematic methodology has to be taken with precise guidance. 5 analysis steps, through Local and Micro scales, were performed to position the Adaptation Goals and choose the most relevant solutions. Additionally, these steps reveal the potential spaces for interventions, as particular spatial qualities and Adaptation Goals limit and emphasise public spaces with the largest adaptation benefits.

The three Local-scale analysis steps allow to understand a particular neighbourhood together with its surroundings by examining their Urban Structure, Temperature Vulnerability and Adaptation Potential. The first two steps, through mapping natural structures, land-uses, movement corridors, public buildings, as well as residing sensitive groups with heat and cold stress areas, informs designers which current structures can be transformed to temperature shelters and how can the residents reach these spaces, spatially positioning the Adaptation Goals. The third step, examining the Adaptation potential, through mapping of local and regional streets as well as shelter proximities and space visibility, provides the first solutions – Coping Network patterns.

However, the local scale does not fully inform about the neighbourhood's spatial qualities and nuances. For this reason, the last two analysis steps are examined through a small lens placed to understand the human and microclimate scales. The lens was set to a 400m. radius to examine the public space qualities through fieldwork within a walkable distance (Gunn et al., 2016). Here Social Well-being analysis, by recording observations of social interactions and user-selected spaces define, which spaces are important to adapt, provide Social Well-being patterns, while Thermal Comfort Analysis, by documenting urban forms, that influence the microclimate, as well as on-site temperature recordings, reveal the required Exposure Reduction patterns.

All these steps are fundamental to identify the potential spaces for application of the interventions. All the relevant patterns are then implemented within the interventions sites to develop an adaptation strategy and possibly comprise a new site-specific pattern, that can be implemented across similar urban forms.

Potential spaces for interventions and design explorations are performed for the three cases previously selected.



### Adaptive Capacity

What public spaces can function as Extreme Temperature Shelters?



### Thermal Comfort

Which public space forms influence climatic elements that shape thermal perception?

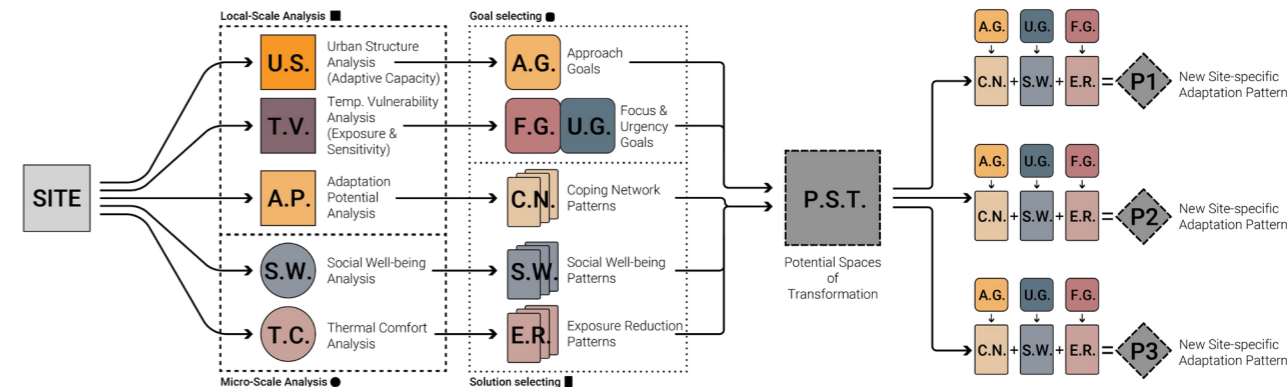


### Well-being

What public spaces can increase social cohesion and improve physical health?

Figure 115. Concepts used in the Public Space Adaptation: Adaptive Capacity x Thermal Comfort x Well-being

## Full Adaptation Design Step Diagram



### Local-Scale Analysis



Urban Structure Analysis

**Mapping:**  
Natural Structures  
Land-use Zoning  
Public Buildings  
Movement Corridors



Temperature Vulnerability Analysis

**Mapping:**  
Heat Stress  
Cold Stress  
Sensitive Residents  
Land-use Functions  
Residence Resilience



Adaptation Potential Analysis

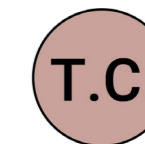
**Mapping:**  
Local Streets  
Regional Streets  
Shelter Proximity  
Visibility

### Micro-Scale Analysis



Social Well-being Analysis

**Mapping:**  
Social Interactions  
High Activity Spaces  
User-selected Spaces  
Valued Social Spaces



Thermal Comfort Analysis

**Mapping:**  
Heat entrapping Urban Forms  
Heat dissipating Urban Forms  
Temperature recordings of designated spots

Figure 116. Public Space Adaptation St Diagram, analysing space through scales (Local and Micro) to position the required goals for adaptation and choose the suitable adaptation patterns

Figure 117. Compact Mid-rise Neighbourhoods in Vilnius (Didžgalvis, 2023)



# Site 01

Naujamiestis

## Naujamiestis Neighbourhood

### Urban Context

Naujamiestis is a central district in Vilnius, located adjacent to the city's Old Town, and was developed in the 19th century, when the first city plans were initially drawn up, with the name translating to 'New Town' (Neakivaizdinis Vilnius, 2025). The district accommodated rapid industrial growth and railway infrastructure, as it grew along major transportation routes. The strict urban structure, which is characterised by perimeter blocks, narrow streets, and industrial sites mixed with residential housing, created a compact urban environment.

The limited greenery and comparably longer distances to densely vegetated natural environments, paved surfaces and car-oriented development demonstrates that the area is lacking in climate-responsive design. Although today the neighbourhood is gradually regenerating, by transforming the old industrial land-use to loft conversions and new housing developments. With these new developments there is an opportunity to transform the spaces around and inside the blocks to better adapt to futures climate challenges.

Additionally, these urban transformations are attracting young families into the area, requiring transforming the spaces to cater for more residential intentions and new demographics. Linking back to the assigned Focus and Urgency Adaptation Goals for the area, the neighbourhood will be explored focusing mostly on heat adaptation and developing spaces with children in mind.



Figure 118. Naujamiestis Neighbourhood Plan



Figure 119. Naujamiestis Study Area

## Urban Structure Analysis

To begin analysing the neighbourhood's urban structure and to select the most beneficial Adaptation Approach Goals, four systems were mapped.

Examining the areas' ecological structure, it illustrates that the urban context is adjacent to city's metropolitan Vingis park and is near the river Neris, however a large portion of the urbanised area is out of reach of these spaces, as they are located further than 800m. This becomes a problem, as small designated green spaces, shown in the land-use map, cannot always cope with extreme heat, making large portions of the area exposed to heat.

Urban blocks allocated as city segment centre areas allows mixed-used planning making the neighbourhood varied with residential, specialised, commercial, office and industry developments. The urban fabric contains high density of indoor public spaces, such as schools, shopping malls and health facilities. This makes this environment high in activity throughout the day, requiring considering both day and night temperature conditions.

Analysing the areas' circulation and mobility, the rigid street grid with two diagonal roads cutting it through stands out. The highly connected grid allows many possible paths across the neighbourhood, and an extensively covered public transport system allows moving through the district by bus.

The structure analysis reveals that this neighbourhood requires to tackle the Comfort Trails and Sanctuary Routes goals, as the area lacks in quality green spaces, while ensuring high mobility can provide people to reach other the large number of indoor public spaces.

- Natural areas / Forests
- Natural water bodies
- Buildings
- Contour line & Ground elevation

**Figure 120.** Environmental Analysis (Top Left Map)

- Forest and wooded area zone
- Agricultural area zone
- Water zone
- Conservation area zone
- Residential zones:
- Residential areas with extensive development
- Residential areas with low building intensity
- Residential areas with medium building intensity
- Residential areas with high building intensity
- Centre zones:
- Main Centre area
- City segment centre areas
- Specialised complex zone
- Service zone
- Collective garden zone
- Industrial and storage zone
- Infrastructure zones
- Infrastructure corridor zones
- Watershed zones
- Shared space, greenery zones
- Intensively used greenery zones
- Extensively used greenery zones

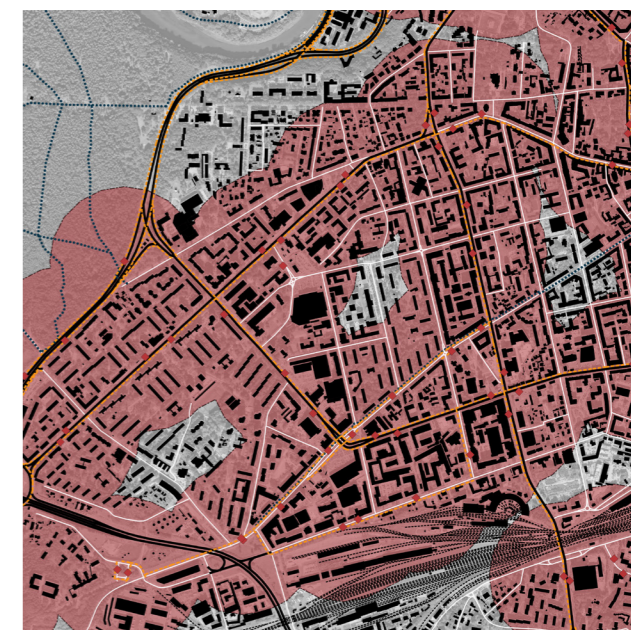
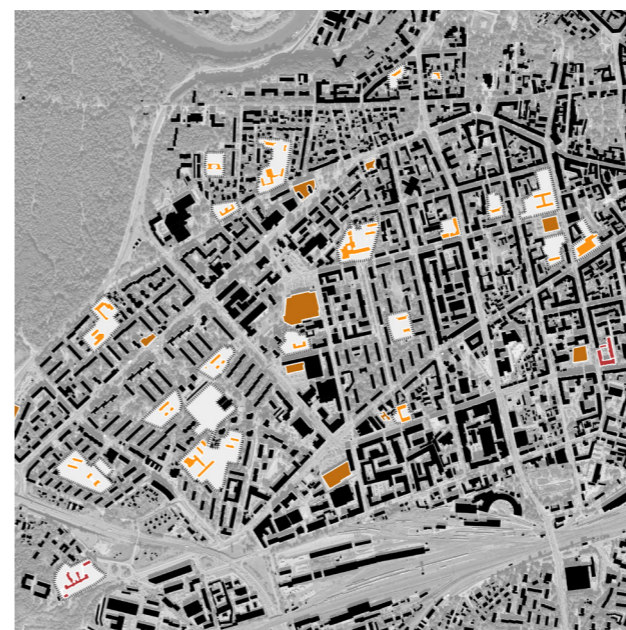
**Figure 121.** City Zoning Plan / Land-use Analysis (Top Right Map)

- Buildings
- Health Facilities (Shelter)
- Retail services (possible shelter)
- Public education buildings (possible shelters)
- Restricted education grounds

**Figure 122.** Public Service Analysis (Bottom Left Map)

- Primary roads / Arteries
- Secondary roads
- ⋯ Bicycle Paths
- - - Public transport lines
- ◆ Public transport stops
- Service area (300m.) of public transport stops

**Figure 123.** Circulation Analysis (Bottom Right)



## Temperature Vulnerability Analysis

When focusing specifically on temperature vulnerability, the areas urban form and exposure becomes a huge factor in adaptation to temperature extremes. The neighbourhoods' industrial blocks, characterised by their high compactness, large buildings and paved surfaces are the hotspots where heat is entrapped and stored. During a heatwave, when the prevailing winds are blowing from the south, this stored heat can be spread into the land-used through the wider streets. Additionally, when examining a cold spell situation, these industrial built-up zones are the least exposed to cold, while the large open rail yard, situated in the south is collecting heat during a hot day and quickly dissipating it during a cold spell, making a consistent problem year-round.

When examining sensitivity, the northern part of the neighbourhood possesses young block, as older blocks are being redeveloped and new families are moving here. The large future redevelopment of the railyard and its surrounding industries, either to loft conversions, rebuilt residential areas or refurbished workspaces, will bring in even more new residents into the area (Vilnius planas, 2022). This creates an urgency to develop the public space fit for children to travers.

- Education buildings (shelters)
- Low Cold Exposure / Stress
- High Cold Exposure / Stress

**Figure 125.** LST recordings during a coldwave (Top Right Map)

- Education buildings (shelters)
- 250 Residents/ha
- 0 Residents/ha

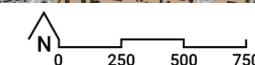
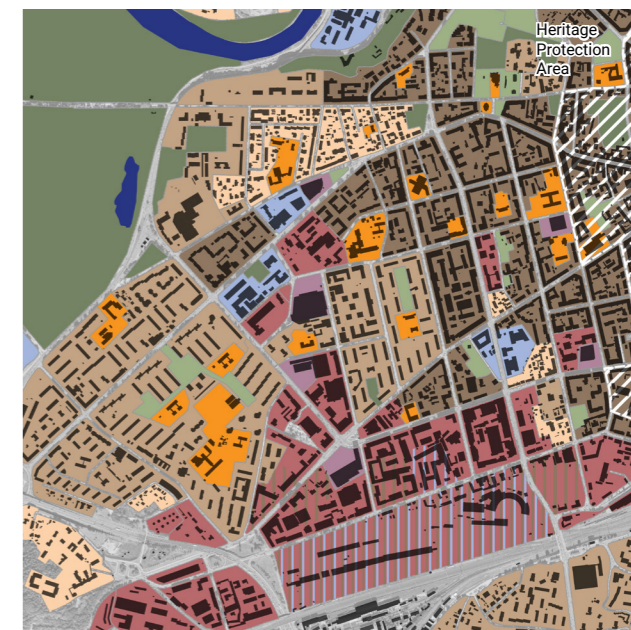
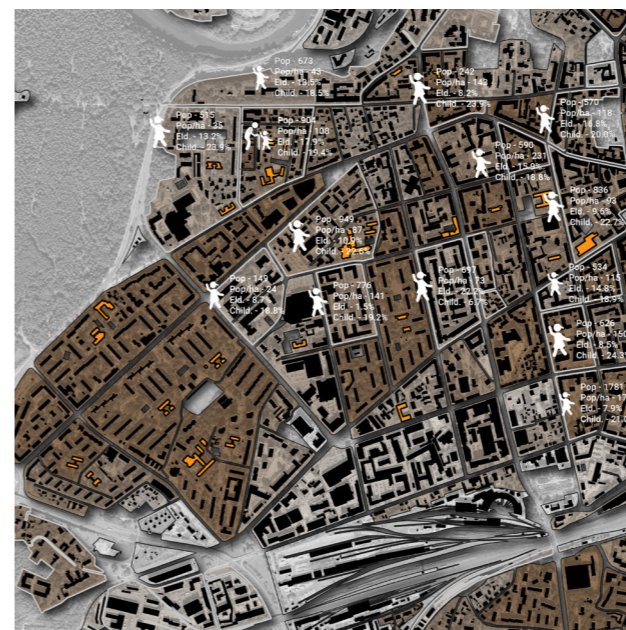
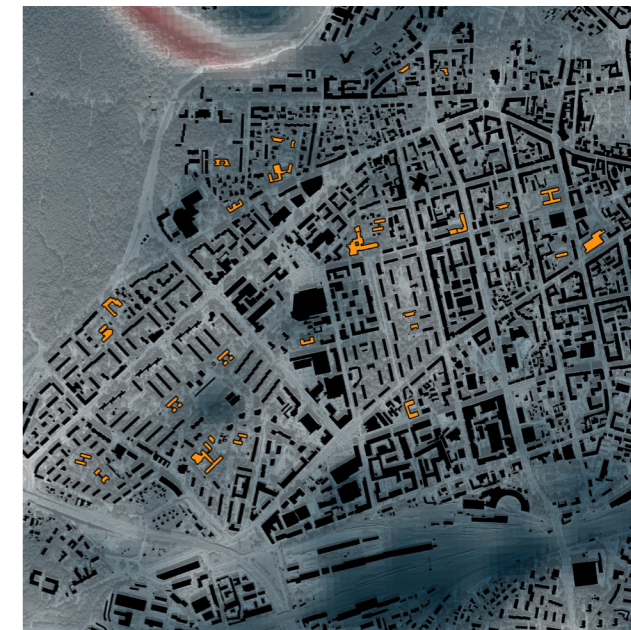
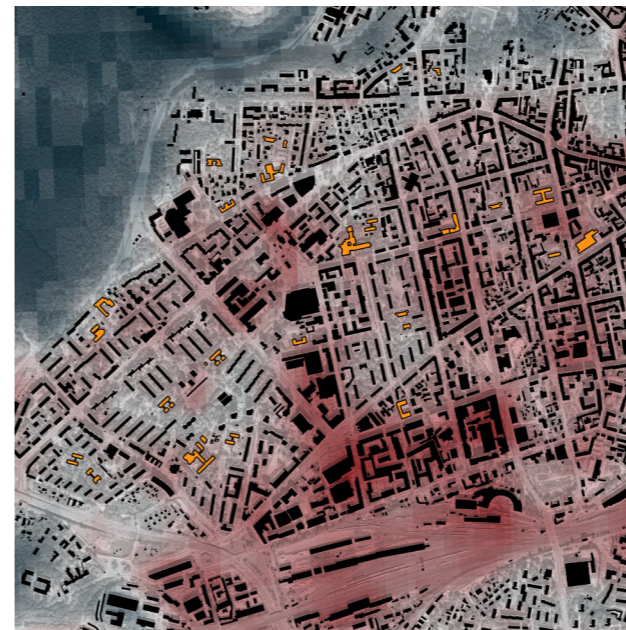
**Figure 126.** Neighbourhood sensitive demographics (Bottom Left Map)

- Education buildings (shelters)
- High Heat Exposure / Stress
- Low Heat Exposure / Stress

**Figure 124.** LST recordings during a heatwave (Top Left Map)

- Residential
- Villa structure (Open Low-rise LCZ)
- Open plan structure (Open Mid-rise LCZ)
- Perimeter structure (Compact Mid-rise LCZ)
- Commercial
- Office development (Open Mid-rise LCZ)
- Shopping centre (Large Low-rise LCZ)
- Industry (Large Low-rise LCZ)
- Recreation
- Forests or dense vegetation (Dense trees LCZ)
- Parks or plazas (Scattered trees LCZ)
- Education grounds (Open Mid-rise LCZ)

**Figure 127.** Land-use and built form - exposure indicator (Bottom Right)

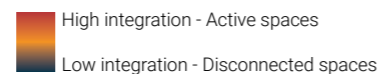


## Adaptation Potential Analysis

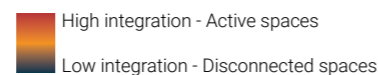
To understand the accessibility, mobility and shelter reach of the neighbourhood, a space syntax analysis was undergone. By calculating the street networks angular integrations of 300m. by foot and 5km. by car, the essential local: Čiurlionio, Kalinausko, Algirdo and Naugarduko streets, as well as regional: Savanorių, Žemaitės, Švitrigailos and Kauno streets were mapped. This distinction informs us, of which local streets are important to pedestrians and which regional streets requires strong public transportation links. By overlapping the regional streets with the current public transportation, these lines matched one-to-one, while examining the amenities on local streets, these lack pedestrian friendly designs.

As the neighbourhood is nearby the city's core, a large number of public buildings are scattered across the urban fabric providing a large number of possible indoor shelters with only a few areas requiring filling to cover the whole neighbourhood with accessible shelters. However, indoor shelters in this compact environment will have a clear drawback, especially during heatwaves, as many buildings incorporating air-conditioning units will intensify the nocturnal UHI effect increasing the need for cooling, making the problem even worse (Salamanca et al., 2014).

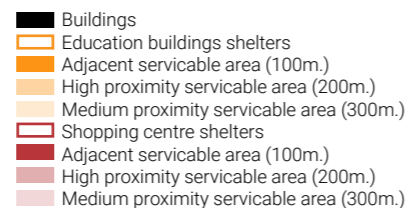
As shown in figure 131, the visibility analysis shows the distinctions between public and private spaces, informing about the responsible implementation stakeholders. An additional finding, from this analysis, was that high visibility areas can be linked to areas having high windspeeds and thus these wide visible straight street canyons may be utilised to channel wind to reduce heat exposure.



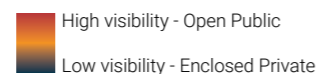
**Figure 128.** Local streets (Angular Integration by Foot - 300m.) (Top Left Map)



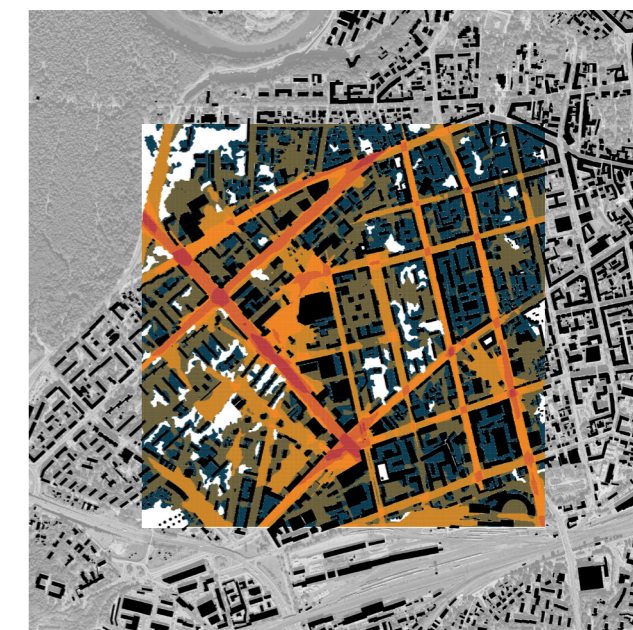
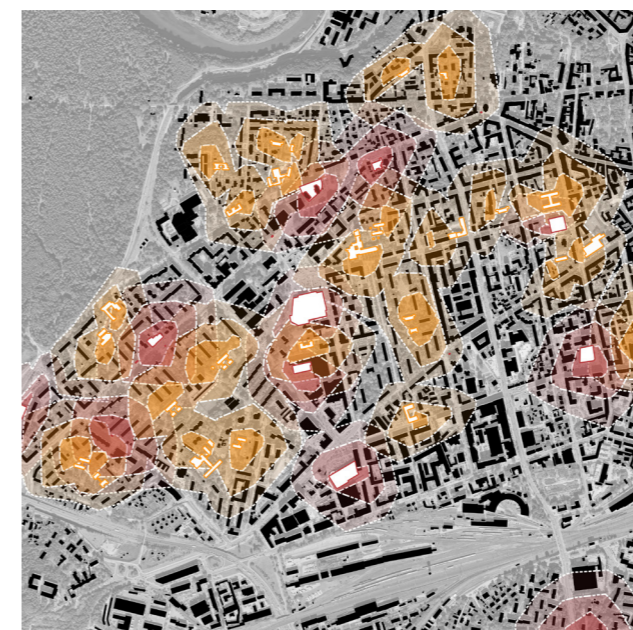
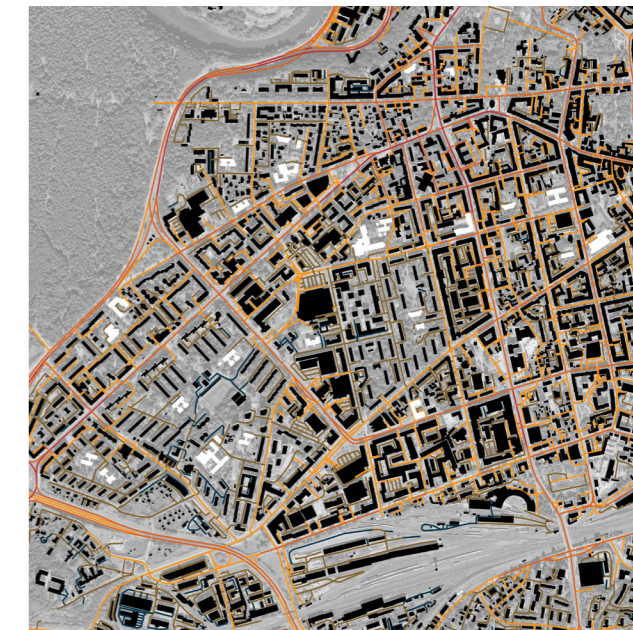
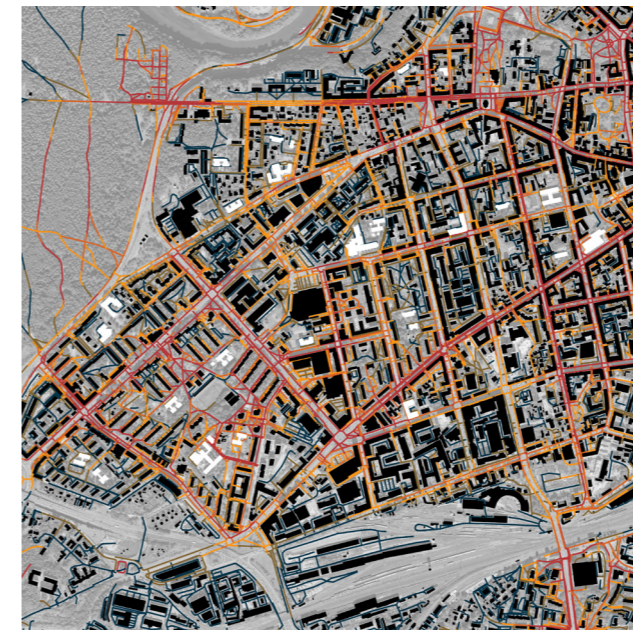
**Figure 129.** Regional streets (Angular Integration by Car - 5000m.) (Top Right Map)



**Figure 130.** Education buildings as temperature shelters (Bottom Left Map)



**Figure 131.** Neighbourhood visibility analysis (Bottom Right)



## Site's Spatial Qualities

### Spatial Qualities

To understand the spatial qualities of Naujamiestis a limited lens of 400m. was placed onto a previously used for industry urban block, which has seen gradual transformations, to analyse the impacts of temperature extremes and its relationships with the surroundings.

As the area has transformed into mixed-use functions with quite high built density, the objective would be to maintain these qualities and forms, while introducing adaptation strategies to carefully transform these typical spaces to be less exposed to extremes. This way, the refurbishment and re-use of old manufacturing buildings as residential apartments can be preserved. Although the public and spaces, inside and outside the urban blocks would require a reconsideration.

Today the inner courts are primarily used as service areas and large parking spaces, with no space for resident functions. Limited vegetation makes these environments encased in asphalt and tiles with narrow streets outside the blocks designed fully for the car, making these spaces dry and hot. Both of these qualities are further examined.

### A-A section

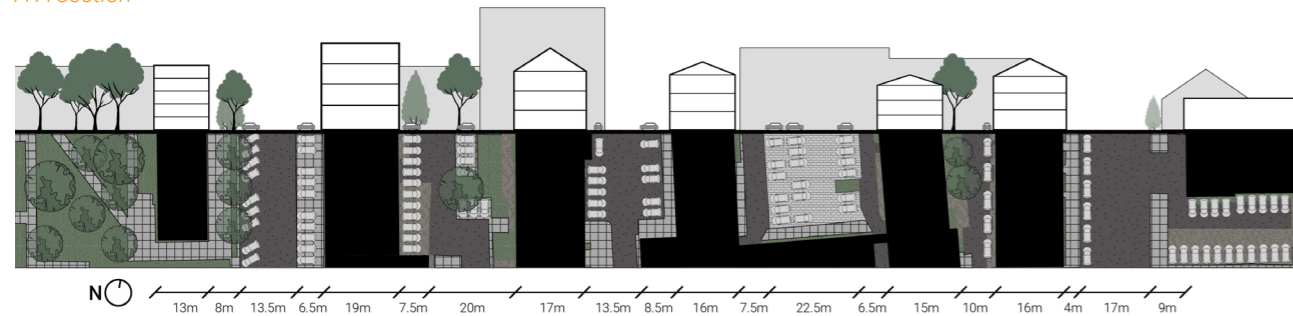


Figure 132. Naujamiestis mixed-used block section



Figure 133. Naujamiestis mixed-used block relationship to its surroundings

## Social Well-being Analysis

To understand the area's current social well-being patterns, insights were documented by walking through and mapping spaces dedicated for specific uses, observing of how people use the space, and which spaces are most frequently used, during fieldwork on the 17th of April. It was set during a warmer period within the marginal season, to see which activities persist in non-ideal temperature settings that can be further encouraged by providing even better thermal comfort factors.

### Valued Social Spaces

While within the block there are only a few shops and cafes that provide an interface space and the only activities seen are people, who work in the area, taking breaks or people moving through the space, the more public surroundings show a wider range of activities, such as resting, socialising, doing sports or children playing. An especially important public space seems to be the Amaty square, situated south to the analysed block, where the newly developed space incorporated children play areas and some sporting grounds. Naugarduko street, which cuts through the analysed block and Amaty square once a week is closed and becomes somewhat of a public extension of the square, where markets and events can happen. This closing of the street patches the two opposite blocks together into one, making the square more pronounced and part of the initial compact block, encouraging use and improved access.

More pedestrian friendly access to spaces nearby can increase the well-being of residents by encouraging the use of social spaces and building stronger community ties between further blocks. The relevant social well-being patterns are Sporting grounds (S6), Safer streets (S7), Play zones (S8) and Social Plinth (S12).

- |  |          |  |             |  |              |
|--|----------|--|-------------|--|--------------|
|  | Walking  |  | Smoking     |  | Kids playing |
|  | Standing |  | Dog walking |  | Skating      |
|  | Cycling  |  | Sitting     |  | Sports       |

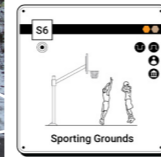
Actions observed illustrated in diagrams



**Figure 134.** Small cafes, restaurants and bars.



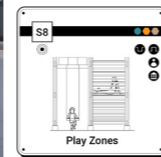
**Figure 135.** Limited sport areas



**Figure 136.** Safe streets (Buinevičius, 2020)



**Figure 137.** Children play areas



Main Block Social Well-being Spaces for Children linked to Patterns

- Buildings
- Education buildings
- Sitting and meeting spaces
- Sporting areas
- Play areas
- Fenced-off areas
- High interaction spaces
- Area of observation



**Figure 138.** Public space distribution and valued social spaces



## Thermal Comfort Analysis

To understand the areas' thermal comfort, urban forms that influence its microclimate were observed as well as temperature data was collected with a Kestrel Heat Stress WBGT Tracker to compare thermal recordings between nearby spaces. As the site is focusing primarily on heat adaptation, the fieldwork recording outdoor temperature readings was conducted on the 17th of April from 14:00 to 15:00, during a comparably warm day.

The most prominent urban characteristics in the surrounding area, that are exposed to heat during the day, are wide paved streets oriented north-to-south and open spaces with little to no shadows. These spaces are subject to direct solar radiation and require adequate shading to provide shelter. However other urban characteristics, such as crowded underground infrastructure and car-dominated space, limits the ability to additionally accommodate vegetation without changing the current allocated functions.

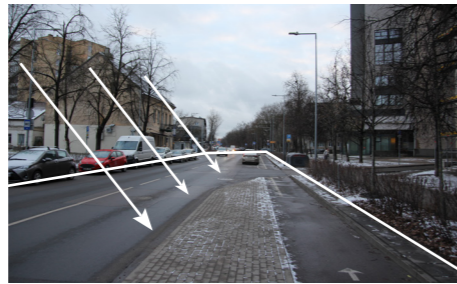
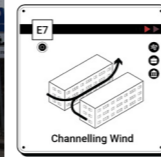
On the other hand, urban characteristics, that retain heat in the evening, are deep and compact canyons with little air movement, that provide better shading during the day but limit heat dissipation at night. This was measured during fieldwork, as the narrowest shaded inner courtyard space showed 21.3°C WBGT, a few degrees lower than spaces in direct sunlight. For these spaces, ventilation is essential to allow heat to disperse.

Additionally higher winds provide relief in high heat stress, as seen in the two north-to-south oriented street canyons, which had direct sun radiation although showed lower 23.1°C and 22.7°C WBGT compared to other spaces due to the channelled wind.

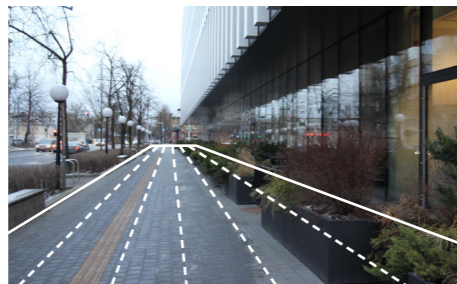
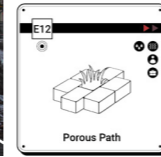
The relevant Exposure Reduction patterns that would improve the area are Filling Cold Pockets (E5), Channelling Wind (E7), Running Water (E9), Porous Path (E12), Green Shades (E15), Structural Shades (E16), Tunnelled Plinth (E20), Green Envelope (E23) and Shielded Parking (E24).



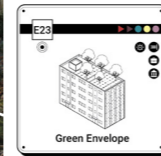
**Figure 139.** Deep and compact canyons



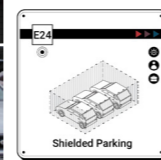
**Figure 140.** Large paved surfaces



**Figure 141.** Crowded underground infrastructure



**Figure 142.** Car dominated space



Main Neighbourhood form qualities that influence space thermal properties

- Buildings
- ▭ High heat absorption walls
- ▭ Downdrafts from tall buildings
- Trees and vegetation
- ▭ Paved surfaces
- ↔ Wind corridors
- WBGT recordings on site



**Figure 143.** Form properties that influence space thermal quality



## Potential Spaces of Transformation

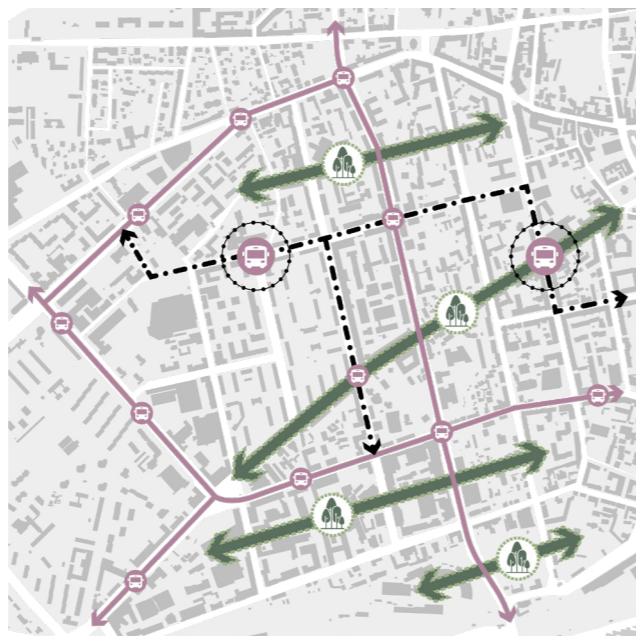
### Reducing Exposure in Public Spaces

The analysis informed the selection of the 2 primary Adaptation Approach Goals for the area, that would ensure better adaptation to temperature extremes for this neighbourhood, which are Comfort Trails (A2) and Sanctuary Routes (A4). The other two approach goals were omitted due to the limited transformation ability for inner courtyards, while Shelter-in-place could be considered as part of the current structure with many shops and cafes already spread within the urban fabric.

As the neighbourhood is situated far from any large natural space, Comfort Trails goal in this instance not only provides protected paths between more scattered green spaces within the district, but by connecting these ecological points, it develops a new structure, that acts as one connected In-fill Park.

Sanctuary Routes goal provides alternative adaptation measures, in areas where increasing vegetation cannot be implemented. This strategy ensures that the neighbourhood has many Heat-proof Canyons designed for separate modes of transport, that increase people's adaptive capacity to move to other areas, while mitigating heat exposure.

In a way, these two transformations are conflicting in their approaches, however a careful integration, can designate some urban spaces to cater to one strategy and others to the second one. And with these differing approaches a new synergy emerges, as spaces transformed to In-fill Parks can cool down air temperature, while streets transformed to Heat-proof Canyons filter and spread colder air throughout the neighbourhood's street grid. For this neighbourhood to adapt to temperature extremes, it requires directly reducing exposure in public spaces.



- Buildings, bordering the potential transformation spaces
- New construction buildings
- Comfort Trails Goal (A2):**
- Space to increase vegetation and reduce traffic within streets
- Space to increase vegetation and connect green zones inside courtyards
- Sanctuary Routes Goal (A4):**
- Space to increase public transport mobility and reduce heat exposure
- New public transport stops
- Roundabout fountains to increase humidity
- Parking streets to remove vehicles from block interiors
- Overhead shading structures in shallow street canyons

**Figure 144.** Naumiemi district's possible large-scale adaptations strategies



## Adaptation Design | Comfort Trails Goals

### New Developed Pattern – In-fill Parks

To develop In-fill parks, local streets, such as Naugarduko street, that are highly connected locally and have the potential for pedestrian traffic and becoming local centres, were chosen to be redeveloped as linear parks. This meant, that these spaces would be completely taken away from vehicles and the asphalt would be fully de-paved to create space for new dense vegetation. The only paved sections would be kept for cycling and sidewalks, as they are to ensure main pedestrian movements and to maintain the required underground infrastructure of a densely urbanised environment.

The incorporation of new parks, that cut across the district connecting to other previously isolated green zones, would provide spaces that drastically lower air temperature during a heatwave. By designing parks as strips oriented from east-to-west, they also act as air and temperature filters for prevailing winds blowing from the south, where industry is largely concentrated within this neighbourhood. This ensures better quality air and lower temperature for residential spaces nearby and to the north of these linear parks. Additional restructuring and removal of certain building sections, that are in the direction of the prevailing winds, would also allow wind to ventilate the inner courtyards of densely urbanised blocks.

These parks would also be accommodating specific functions, as streets nearby mainly residential blocks or open spaces would include resting spots, sports grounds or children play areas resembling more pedestrian leisure segments, while previously commercial streets or more enclosed street canyons would exhibit higher pedestrian visits, providing economic benefits for shops, restaurants and cafes. To further collaborate with shop owners, who could help funding these parks, some segments of the park could be designed as commercial, by designing permeable paving in the centre and giving these spaces for outdoor café extensions, outdoor market spaces or community events taking place between alleys of trees.



Figure 145. Design Precedent - Girona Street Green Axes in Barcelona (EMF + ESTEYCO + NABLACN STUDIO, 2023)

Figure 147. Public street before (above) and after (below) the transformation into an "Infill-Park" illustrated in plan

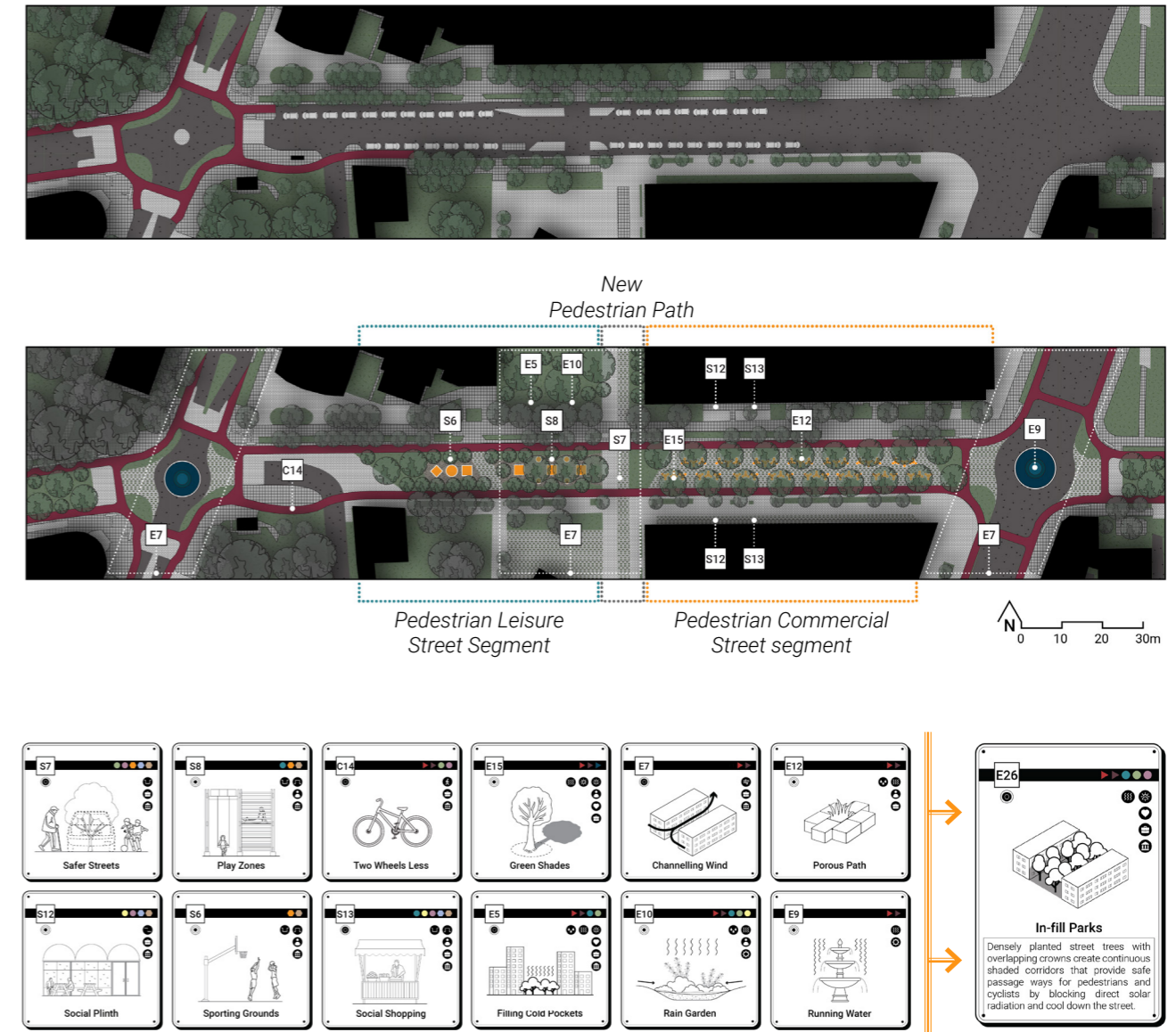


Figure 146. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Adaptation Design | Sanctuary Routes Goal

### New Developed Pattern – Heat-proof Canyons

To develop Heat-proof Canyons, it is important to understand that regional streets, which are used to access other districts are required to maintain as high mobility corridors. This means that these streets provide main access paths to regional shelters, such as metropolitan parks, swimming lakes or heated community centres, farther in the city. For people with limited mobility options, these corridors provide access to the city through public transport.

As people move through the city differently, movement corridors should limit their exposure to extremes. Usually, compact environments utilise the whole street width, leaving very little space for unsealed greenery, stunting tree growth and limiting evapotranspiration, which could cool down the environment. For this reason, the newly developed strategy considers this strict limitation and combines alternative heat adaptation solutions.

Firstly, main transport arteries, which has bus interchange stops and limited adjustable space, should incorporate roundabouts at intersections. These crossroads not only slow down traffic, creating safer crossings for pedestrians, they also provide spaces in the centre, which can be incorporated with water fountains. Here they would not perform a social gathering function but rather cool down interchanges through increased humidity. Placing them in open windy intersections, would distribute water droplets across the streets. While this design would mitigate heat, direct solar radiation would still make these arteries too dangerous for pedestrians, which is why alternative paths winding through the inner courtyards should be examined. Here deeper canyons would provide shade from buildings, paths could be kept at a minimum width, making some space for vegetation. Alternatively, close by buildings could offer an adjustable fabric sunshade, maintained by the residents. A fully covered hanging structure would bring in people, creating opportunities for developing an active plinth.

On the other hand, supporting streets should limit their streets to a maximum of two lanes and create parking spaces to free up courtyards from vehicles. Street parking spaces must have regularly spaces tree. To increase vegetation, green envelopes should become part of these canyons. If street

widths are narrow to fit these requirements, a recessed plinth could be designed to create additional space and provide a sheltered path for pedestrians.

With these street designs, in the future, when the number of personal vehicles will fall, they can be easily transformed into full In-fill Parks.



Figure 148. Design Precedent - Crocheted sunshades from recycled fabric in Alhaurín de la Torre (Noe, 2021)

Figure 149. Street transformation into "Heat-proof canyons" illustrated in sections

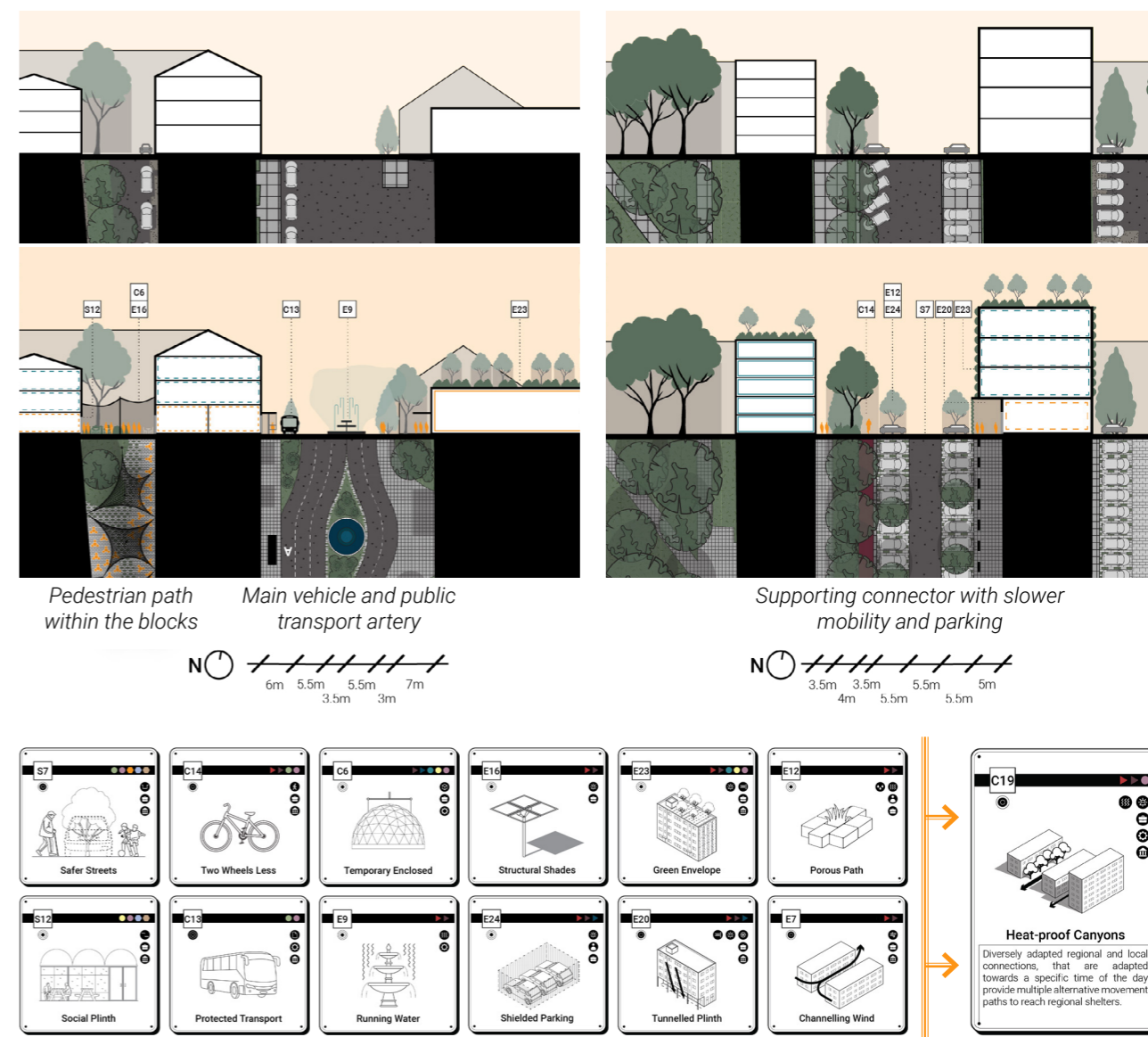


Figure 150. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Conclusion | Site 01

### Compact Mid-rise Climate Adaptation

To conclude on the newly developed adaptation strategies for a compact mid-rise LCZ, the newly developed adaptation patterns were compared to one another by their temperature extreme mitigation, implementation difficulties and were designated to an adaptation type related to the degree of future temperature risks and requirements, seen in the axonometric drawing on the right.

As all of these patterns are situated within a compact mid-rise zone, which has high built density and limited open undeveloped space. This means that financing adaptation strategies requires finding alternative to new residential developments. One feasible option would be cooperating with independent and larger commercial businesses in the area, through private-public relationships. As extreme temperature adaptation strategies creates more robust and comfortable urban environments, the higher pedestrian activity and foot traffic would bring in more clients for the businesses. The shared adaptation cost between local businesses and the city would ensure stronger adaptation capabilities and more attractive spaces, creating beneficial outcomes for all parties. The financing would entail renting

larger outdoor spaces for commercial purposes, increasing ground floor retail spaces and collecting adaptation funding.

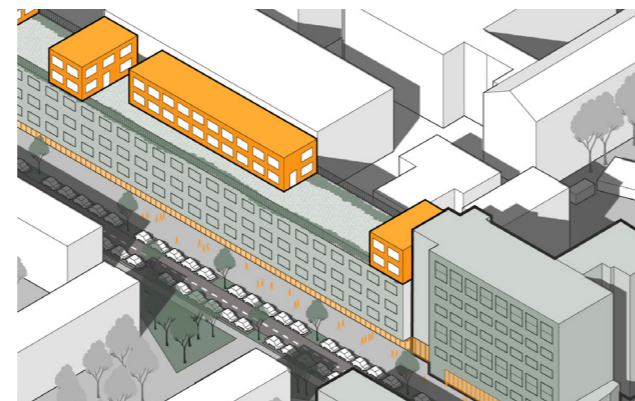
Alternatively, spaces around former industrial buildings could be adapted together with building conversion to residential apartments. Compact environments usually have older disused buildings, constructed for other purposes than residential. In central, high-value areas, these buildings are appealing to developers due to lower construction costs. Policy incentives could bring in developers to extend the lifespan of disused buildings as well as requiring the regeneration project to adapt the surrounding urban spaces. Higher density and building extensions could also increase the budget for adaptation.

Each financing option transforms the urban form and space, shifting the spaces temperature vulnerability. This influences the chosen Adaptation goals, suggesting that adaptation budgets, created through spatial transformations, require to be considered, when planning urban adaptation.



Increasing ground floor commercial space and their dedicated outdoor spaces

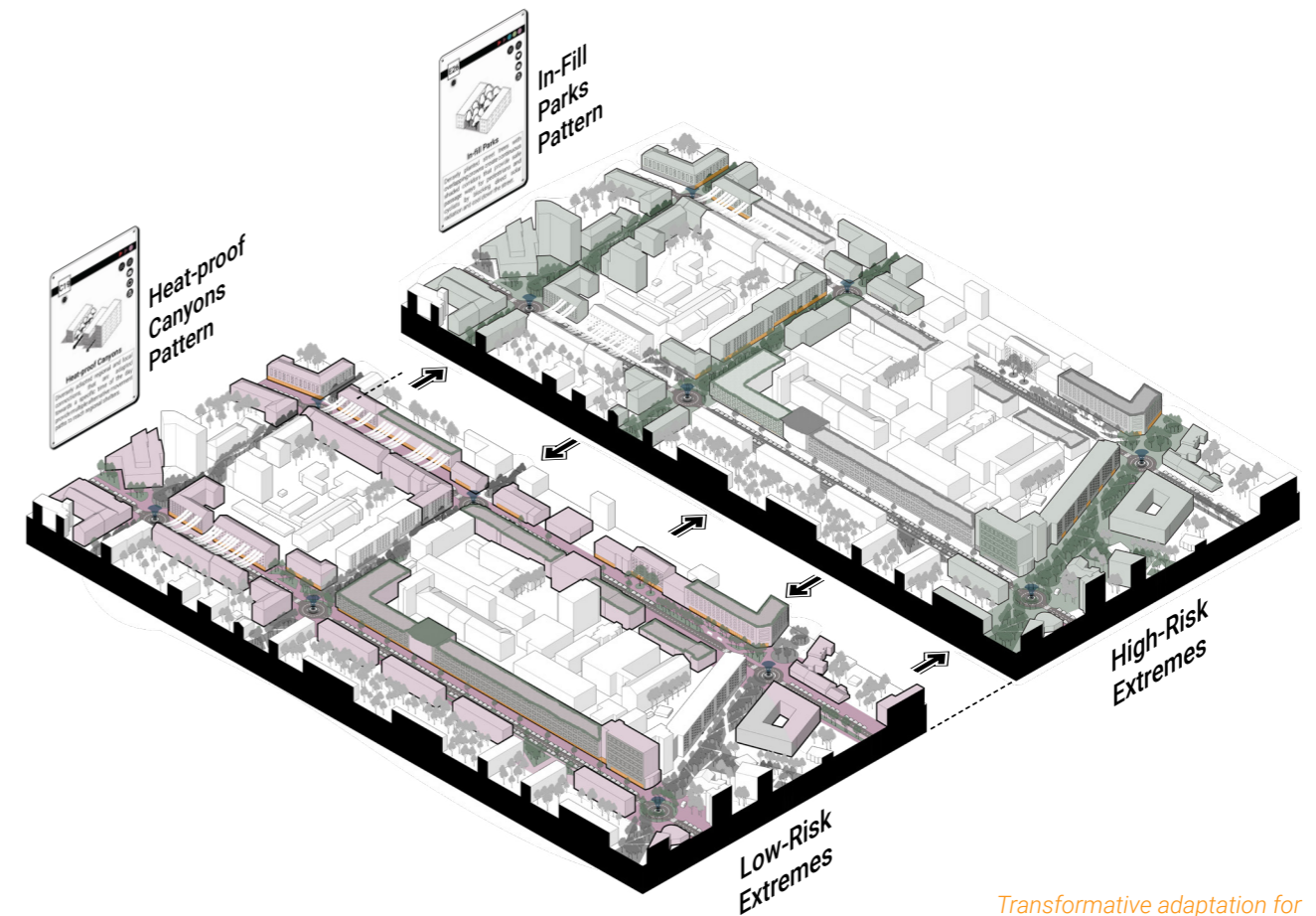
Increased pedestrian activity (higher sensitivity)  
Higher economic investment (higher adaptive capacity)



Increasing density of current urban fabric and converting former industrial buildings into residential housing

Urban regeneration projects (higher adaptive capacity)  
Higher population density (higher sensitivity)

Figure 151. Compact Mid-Rise LCZ climate adaptation financing options



### Incremental adaptation for Low-Risk Temperature Extremes

Heat-proof canyons designed for the Sanctuary Routes goal is an adaptation strategy that allows people to move through the urban environment and remain safe, especially during occasional heatwaves. This adaptation approach ensures high adaptive capacity, as a supporting strategy to alleviate low-risk temperature extremes. The adaptation is incremental, meaning that it would preserve the existing urban forms and spaces by introducing many technical interventions, that would provide immediate smaller scale benefits. To achieve long lasting adaptation, this approach requires to be simultaneously implemented as the transformative adaptation.

Figure 152. Compact Mid-Rise LCZ intervention phasing dependant on future risks

### Transformative adaptation for High-Risk Temperature Extremes

Infill parks designed for the Comfort Trails goal is an adaptation strategy that provides people with an outdoor shelter to cool down urban environment during frequent temperature extremes. This larger structure can influence the microclimate in high-risk temperature extremes. The adaptation is transformative, meaning that it would require a systemic change of the urban spatial functions by redirecting and removing the street designed for vehicles and replacing it with a dense vegetation strip spanning across the neighbourhood. This transformation would require social change as people would be reluctant to give up the current street structure. Additionally, the instant benefits would be minor and only increasing over the years, as the planted vegetation and trees would require time to fully mature. To safeguard sensitive residents from today's extremes, this approach requires to be simultaneously implemented as the incremental adaptation.

Figure 153. Open Mid-rise Neighbourhood (Bauras, n.d.)



## Site 02

Karoliniškės

## Karoliniškės Residential Micro-District

### Urban Context

Karoliniškės is one of the oldest Soviet Union residential “micro-district” project in Vilnius, located in the western part of the city. The development of these large-scale mass-produced residential neighbourhoods were set to answer the demand of housing within 10-12 years (Ruseckaitė, 2010). The concept was developed to create self-sufficient urban units with plenty of green spaces analogous to modernistic neighbourhood standards.

The area began to take shape from the 1970s and became an original urban form in Vilnius. It was built on a flat 200 ha plateau and to compensate the lack of natural topographical variation, architects designed the building skyline to have different heights and form hill structures (Ruseckaitė, 2010). Although the architecture in Karoliniškės follows typical Soviet-era designs, the buildings were arranged in an original way, forming cross-shaped clusters that created semi-enclosed courtyards.

Despite the effort to introduce originality, the district faced criticism for its dense construction and spatial monotony (Ruseckaitė, 2010). Large open spaces, while integrating nature, are often underused, poorly maintained or left as left-over grass fields. The separation of land-use functions created spaces that are of low vibrancy and increasing strain on movement infrastructure. While initially these neighbourhoods were design with low car-ownership, dependency on cars-oriented transit, has transformed these environments into informal carparks limiting walkability and diminishing the quality of these environments.

All of these essential problems are required to be addressed together with better adapting these spaces to temperature extremes. By redeveloping these areas with temperature in mind, the usability, vibrancy and quality can be highly improved.

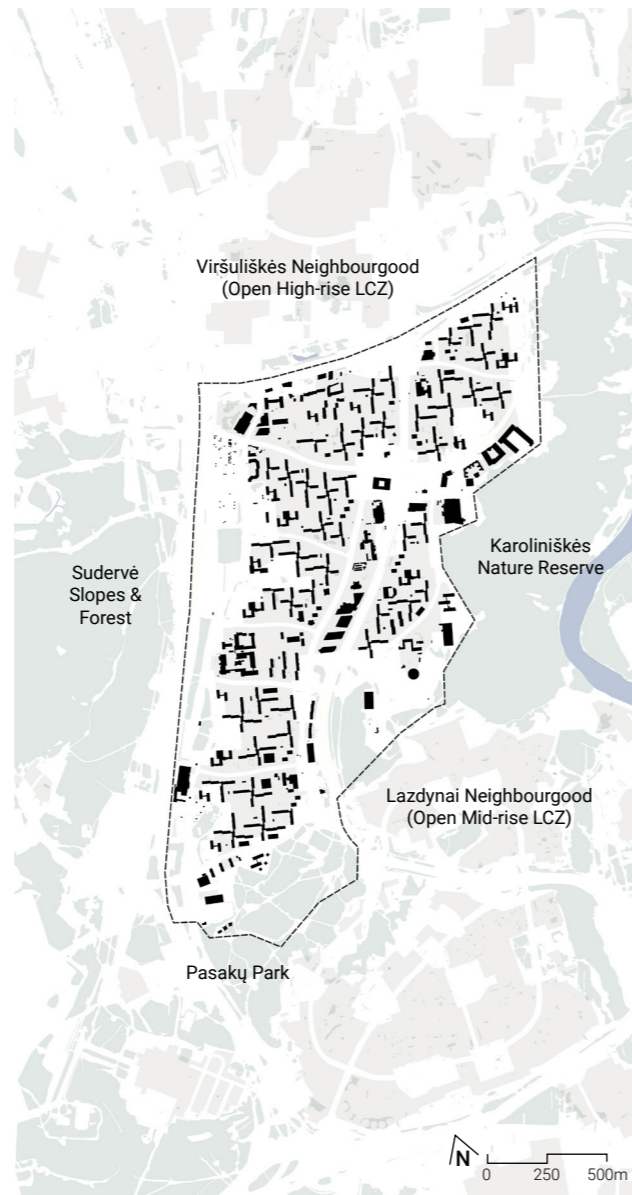


Figure 154. Karoliniškės Neighbourhood Plan



Figure 155. Karoliniškės Study Area

## Urban Structure Analysis

Examining the neighbourhood's topographical structure and its ecological systems, it illustrates that the urban context is situated between the Sudervė stream valley and the steep bank of Neris River. Both of these slopes are natural woodlands, while the urbanised area in-between is built upon a flat plateau, illustrated in the section below. This indicates that the area is prone to high wind speeds, which are channelled through the linear structure of the neighbourhood and its primary roads.

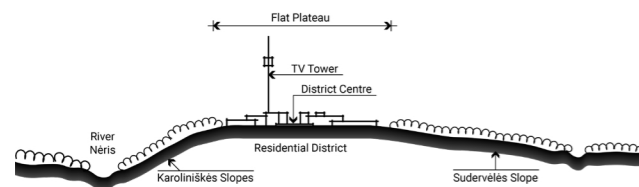


Figure 156. District Section (adapted from Balėnas 1970)

While the neighbourhood is situated near large natural elements, which do elevate the heat, the reach of these elements is limited by the ring road on the West side and the large primary road on the East side. The main artery of the district Laisvės avenue spanning from North to South, connects the residents with the rest of the city by providing the main bus public transportation lines. Due to the district's linear structure, most of the residential buildings can reach bus interchange stops in less than 300m. On the other hand, the main infrastructure line disconnects the neighbourhood into two parts as the transportation corridors width in its most compact areas stretches to 65m.

The land-use map illustrates that there have been little changes after the area's development from the 1970s, consisting of monofunctional high intensity residential areas with specialised complex zones, all of which were developed as education spaces, such as kindergartens or primary and secondary schools. However, the large amount and close proximity of these governmental institutions provides the area with an opportunity to integrate these buildings better into the environment and transforming them to shelters in temperature extreme situations.

- Natural areas / Forests
- Natural water bodies
- Buildings
- Contour line & Ground elevation

Figure 157. Environmental Analysis (Top Left Map)

- Forest and wooded area zone
- Agricultural area zone
- Water zone
- Conservation area zone
- Residential zones:
- Residential areas with extensive development
- Residential areas with low building intensity
- Residential areas with medium building intensity
- Residential areas with high building intensity
- Centre zones:
- Main Centre area
- City segment centre areas
- Specialised complex zone
- Service zone
- Collective garden zone
- Industrial and storage zone
- Infrastructure zones
- Infrastructure corridor zones
- Watershed zones
- Shared space, greenery zones
- Intensively used greenery zones
- Extensively used greenery zones

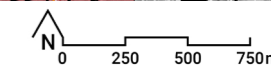
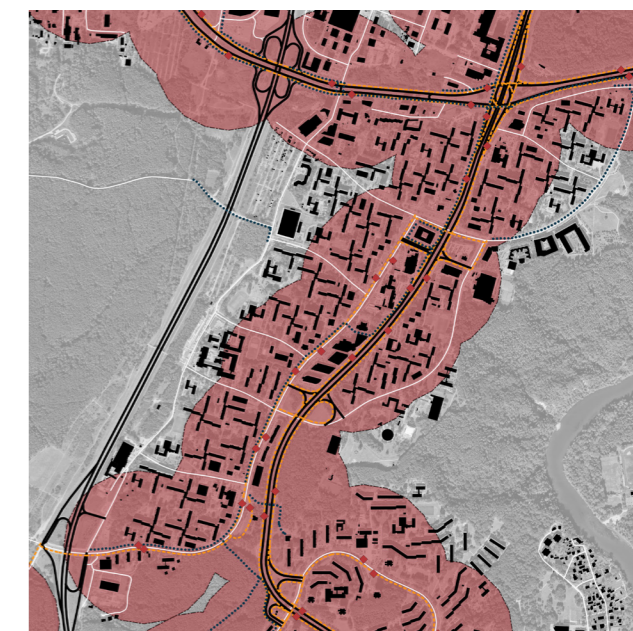
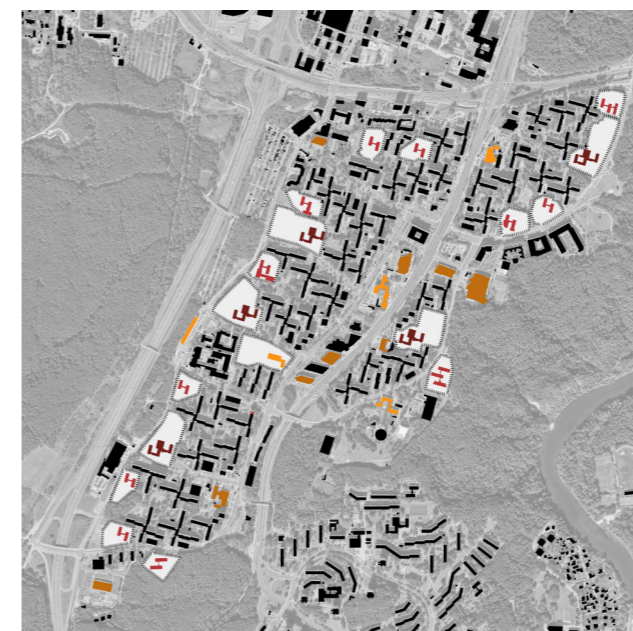
Figure 158. City Zoning Plan (Top Right Map)

- Buildings
- Public kindergarten (possible shelter)
- Public school (possible shelter)
- Retail services (possible shelter)
- Public buildings (shelters)
- Restricted education grounds

Figure 159. Public Service Analysis (Bottom Left Map)

- Primary roads / Arteries
- Secondary roads
- ⋯ Bicycle Paths
- - - Public transport lines
- ◆ Public transport stops
- Service area (300m.) of public transport stops

Figure 160. Circulation Analysis (Bottom Right)



## Temperature Vulnerability Analysis

When focusing specifically on temperature vulnerability, the exposure maps indicate that the area is prone to both extremes, although the positioning of problematic spaces for each extreme is different. The neighbourhood's linear spine next to Laisvès avenue and spaces surrounding larger buildings exhibits higher exposure level to heat. These can be explained as these spaces have paved surfaces and large low-rise buildings, acting as heat sinks and radiating temperature from the buildings themselves. During a cold spell, the problematic spaces are open green zones on the urbanised edge between buildings and forests, indicating that larger open spaces without dense trees or bushes does not retain heat, creating dangerous cold exposure spaces. On the other hand, the commercial spine becomes a cold mitigating space, providing an area of relief.

When examining sensitivity, the whole neighbourhood possesses old built-up blocks, that have one of the highest population densities in the city. Additionally, the mapped thermal performances of residential buildings show, that most of the buildings, that are old, are outdated and not up to standards, meaning that the already susceptible population does not have adequate shelters at home, drastically limiting their adaptive capacity and requiring to either develop alternative spaces or improve their homes. All of this creates a severe urgency, that requires adapting the public spaces meant and fit for elderly.

- Education buildings (shelters)
- High Heat Exposure / Stress
- Low Heat Exposure / Stress

**Figure 161.** LST recordings during a heatwave (Top Left Map)

- Education buildings (shelters)
- Low Cold Exposure / Stress
- High Cold Exposure / Stress

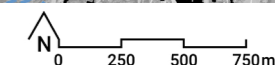
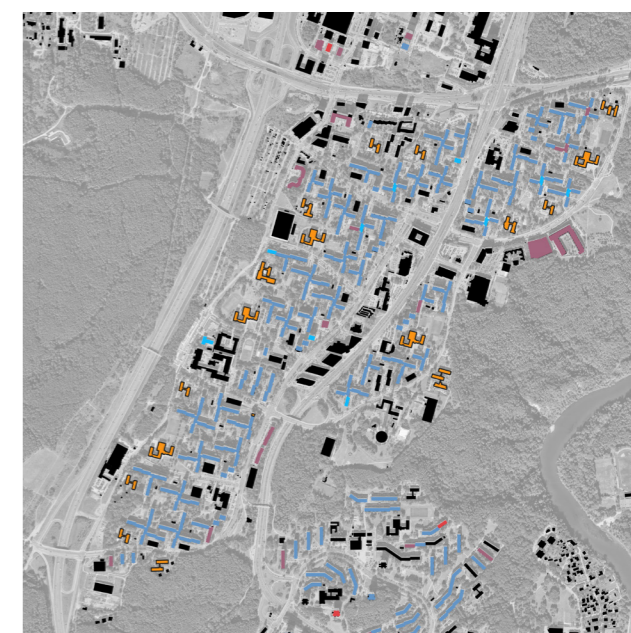
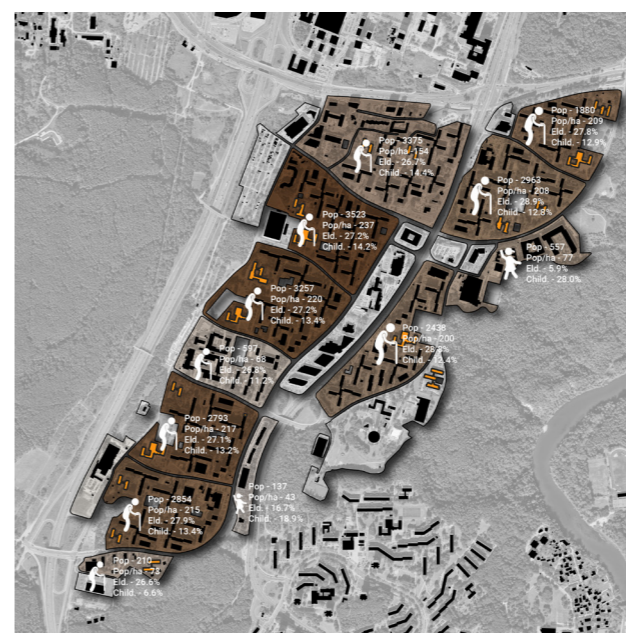
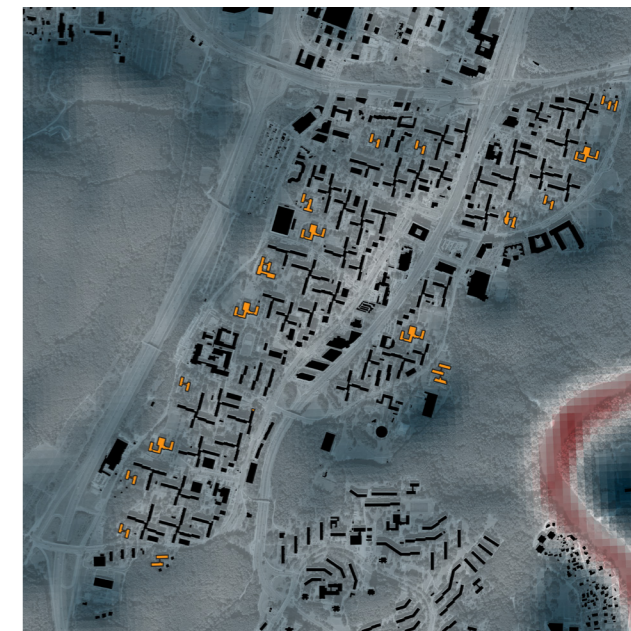
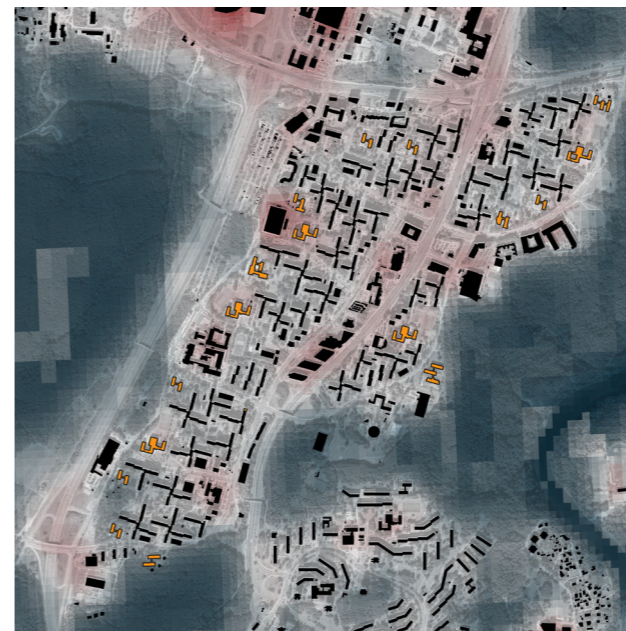
**Figure 162.** LST recordings during a coldwave (Top Right Map)

- Education buildings (shelters)
- 250 Residents/ha
- 0 Residents/ha

**Figure 163.** Neighbourhood sensitive demographics (Bottom Left Map)

- Education buildings (shelters)
- High Performance
- Medium Performance
- Low Performance
- Very Low Performance
- No Data

**Figure 164.** Thermal Performance of Buildings - adaptive capacity indicator (Bottom Right)






## Adaptation Potential Analysis




To understand the accessibility, mobility and shelter reach of this particular neighbourhood, a space syntax was utilised. By calculating the street networks angular integrations of 300m. by foot and 5km. by car, the essential local: L. Asanavičiūtės, D. Gerbutavičiaus, V. Druskio, I Šimulionio, A. J. Povilaičio and Sausio 13-tosios streets, as well as regional: Vilnius western bypass and Laisvės avenue, were mapped. This distinction informed that the local streets create continuous walking environments between different built-up areas, while the regional street cuts the neighbourhood in half, creating two separate west and east locales. Because of this the two sides requires stitching back together, to ensure accessibility. This is especially important for the easter side, as it is currently disconnected from the commercial space on the west side of the avenue.

As the whole neighbourhood was centrally planned, the area incorporated many education facilities in high proximity to one another (Ruseckaitė, 2010). These facilities, functioning as kindergartens, primary schools or secondary schools, were situated on the periphery of the neighbourhood, separating them from the residential functions and overall active spaces. While their high proximity covers almost all residential buildings within a 300m. walking shed, their isolating spatial placement and enclosed fencing, makes these buildings hardly accessible. A better integration to their surroundings could create an indoor shelter framework of nearby public buildings, that could be used not only by children but by the elderly during climate hazards.






Lastly, these types of residential micro-districts lack strong community ties and proper maintenance, as they do not have clear separation between private and public spaces (Pakalnis, 2016). As the buildings are constructed in a free plan arrangement, there are no private or semi-private courtyards, making the space fully public. A visibility analysis allows to identify, which spaces are less visible and could be transformed into more private resident land to develop small resident communities. These spaces between the buildings would foster stronger social ties, which would increase the adaptive capacity, as residents would tackle temperature extremes together.

-  Education buildings (shelters)
-  High integration - Active spaces
-  Low integration - Disconnected spaces




**Figure 165.** Local Streets (Angular Integration by Foot - 300m.) (Top Left Map)

-  Education buildings (shelters)
-  High integration - Active spaces
-  Low integration - Disconnected spaces

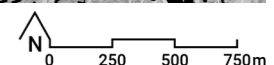
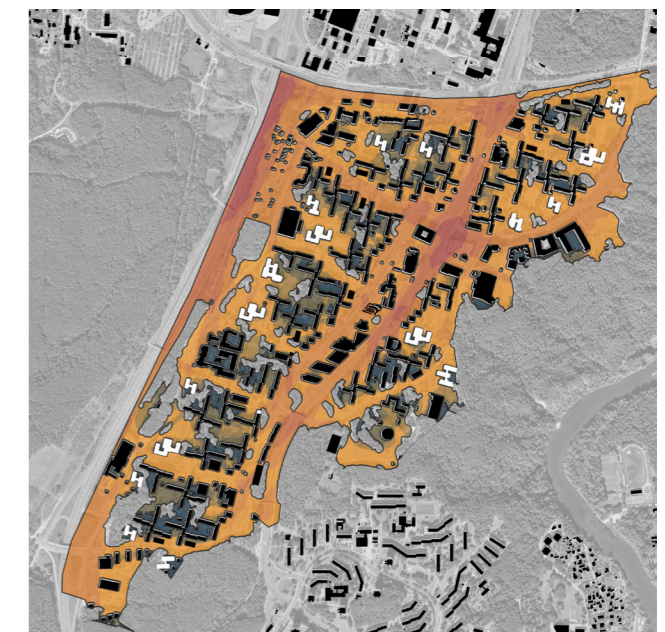
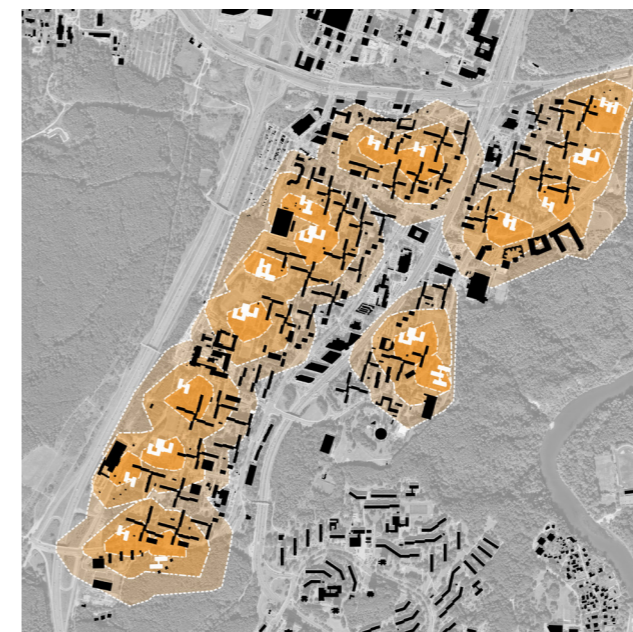
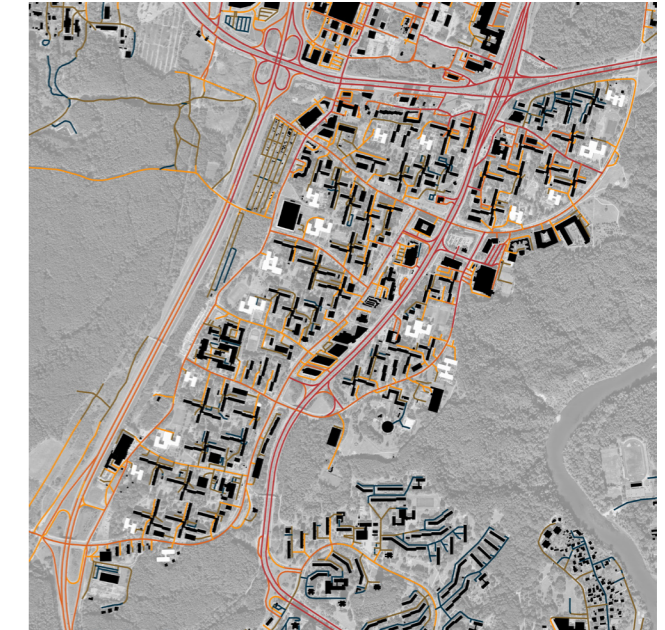
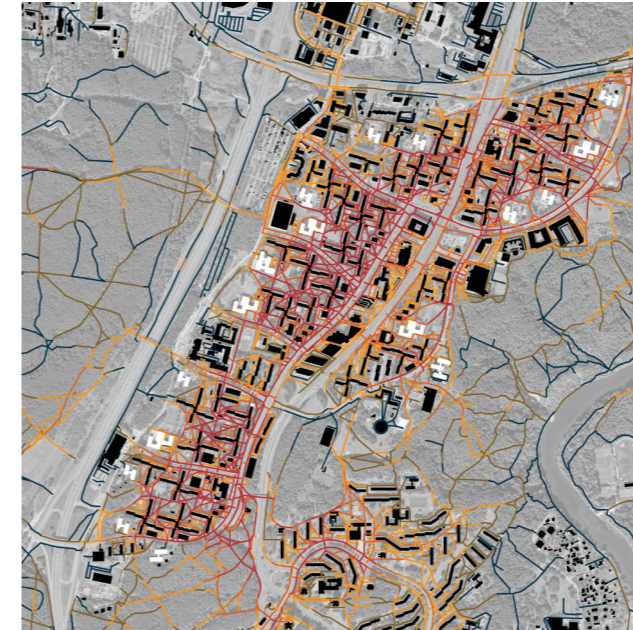
**Figure 166.** Regional Streets (Angular Integration by Car - 5000m.) (Top Right Map)

-  Buildings
-  Selected shelters (Education buildings)
-  Adjacent area (100m.)
-  High proximity area (200m.)
-  Medium proximity area (300m.)

**Figure 167.** Education buildings as temperature shelters (Bottom Left Map)

-  Education buildings (shelters)
-  High visibility - Open Public
-  Low visibility - Enclosed Private

**Figure 168.** Neighbourhood visibility analysis (Bottom Right)



## Site's Spatial Qualities

To understand the spatial qualities of Karoliniškės a limited lens of 400m. was placed around one education facility – Ryto secondary school. This lens allowed to better understand the impacts of temperature extremes on the area as well as to investigate the relationship between education grounds and the monofunctional residential spaces.

As the area was constructed following modernist district principles with large open and left-over spaces, the objective would be to introduce new functions that would include adaptation strategies for temperature extremes while simultaneously increasing adaptive capacity by strengthening community ties between residents living in the densely populated urban blocks.

Today the urban form is vulnerable to heat and cold exposure, as large open areas between buildings do not protect from either direct solar radiation nor from frigid winter winds, while building interface spaces are crowded with personal vehicles, taking away any quality space to socialise with neighbours. Both social and thermal qualities are further examined.

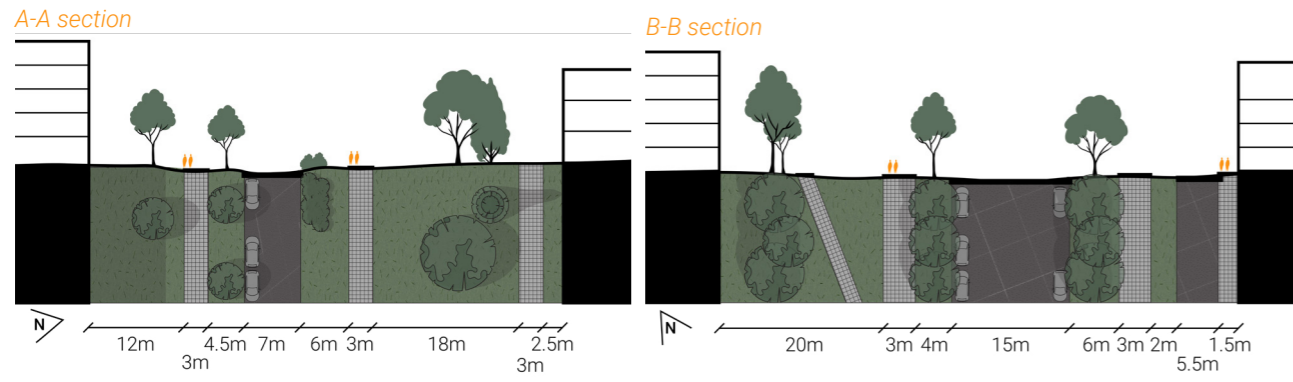


Figure 169. Karoliniškės residential street sections A-A & B-B



Figure 170. Karoliniškės residential space relation to education spaces

## Social Well-being Analysis








To understand the areas social well-being patterns, insights were documented by walking through and mapping spaces dedicated for specific uses, observing of how people use the space, and which spaces are most frequently used, during fieldwork on the 17th of April.

### Valued Social Spaces

The most active spaces with the most users were observed in two main spaces: the public shopping areas and more private user-selected spaces, such as children play areas and sport grounds. The participant age distribution showed that elderly people used further located spaces, such as a shopping centre, situated in the east, and especially the market, located in the south, where it also acted as a social space, while children were using spaces within the block, as playgrounds and their schools were located here. The streets surrounding each block were only used as transition spaces to reach their home or the commercial streets, as the closest public transport stops are located there. However, these streets should not be overlooked, especially for elderly, as only by using these paths they reach their preferred spaces.

As the given urgency for this neighbourhood is Risk-free Elderly, a search for alternative spaces, which could be used by elderly and located close-by, was undertaken. Glimpses of possible social spaces were scattered within the residential block, such as covered building entrances, small meeting and seating spaces, as well as front gardens.

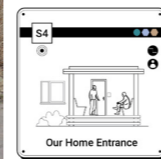
By improving and expanding the current residential social spaces and linking them together with further public gathering spaces, each urban block would provide a range of opportunities to strengthen social cohesion between its' residents and create stronger sense of place. The relevant Social Well-being patterns are Courtyard Gardening (S1), Quiet Nature (S2), Urban Hike (S3), Our Home Entrance (S4), Learning spaces (S5), Central Civic Spaces (S9), Community House (S14).

-  Walking
-  Smoking
-  Kids playing
-  Shopping
-  Dog walking
-  Sitting
-  Cycling

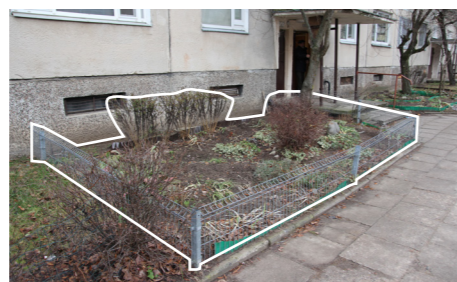
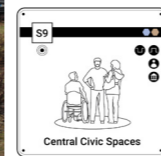
Actions observed illustrated in diagrams



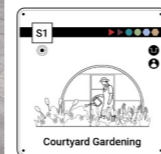
**Figure 171.**  
Entrance interface



**Figure 172.**  
Community seating



**Figure 173.**  
Apartment front gardens

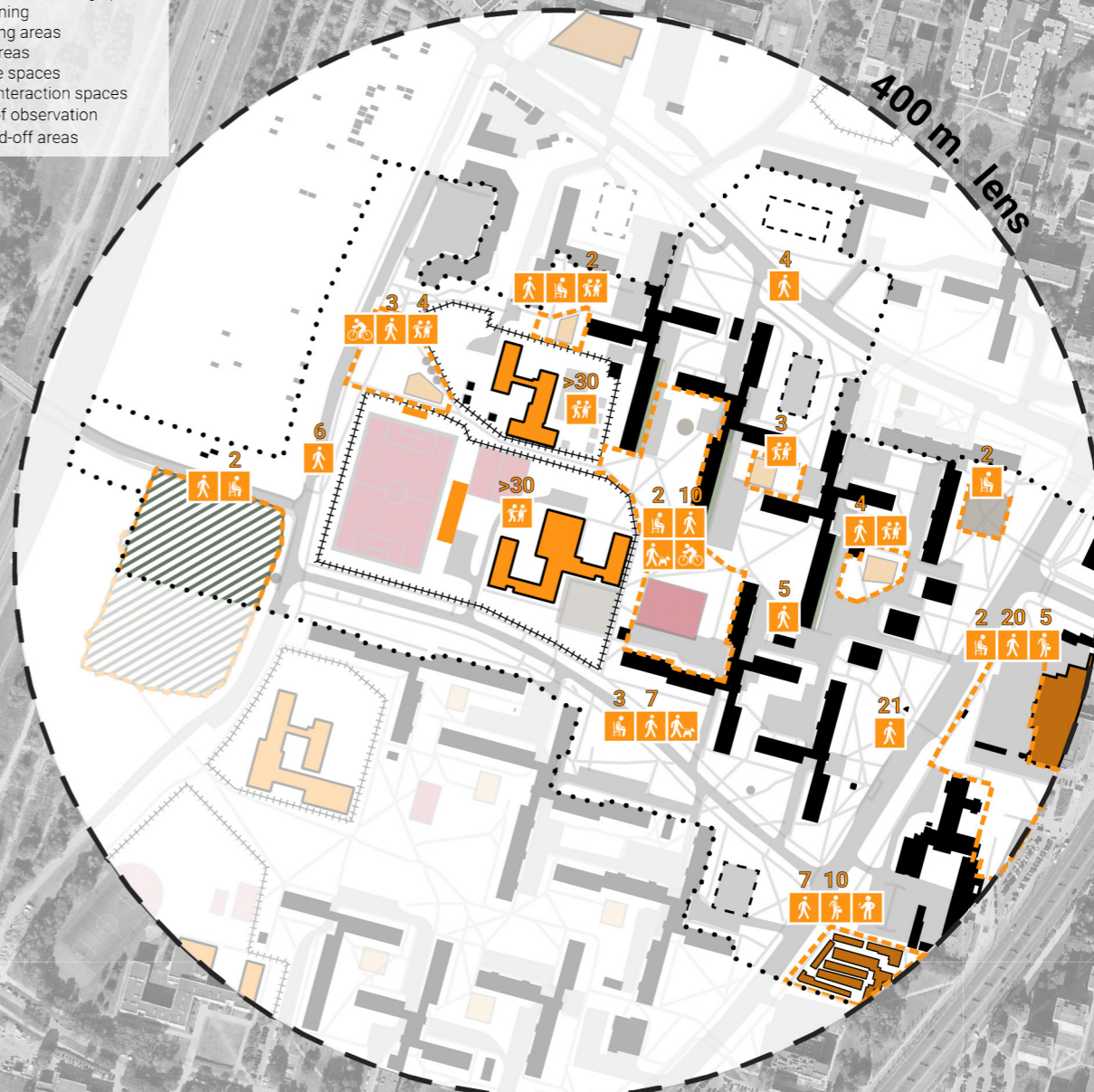


**Figure 174.**  
Schools & Kindergartens



Main Neighbourhood Social Well-being Spaces for Elderly linked to Patterns

-  Buildings
-  Education buildings
-  Shopping centres
-  Sitting and meeting spaces
-  Gardening
-  Sporting areas
-  Play areas
-  Nature spaces
-  High interaction spaces
-  Area of observation
-  Fenced-off areas



**Figure 175.** Public space distribution and valued social spaces

## Thermal Comfort Analysis

To understand the areas' thermal comfort, urban forms that influence its microclimate were observed as well as temperature data was collected with a Kestrel Heat Stress WBGT Tracker to compare thermal recordings between nearby spaces. As the site is focusing on heat and cold adaptations, two fieldworks recording sessions of outdoor temperature readings were conducted. The first was on the 12th of January from 14:00 to 15:00, during a colder day, and the second on the 17th of April from 15:30 to 16:30, during a comparably warm day.

The most prominent urban characteristics in the surrounding area, that exacerbate heat during a heatwave are paved plots intended for parking and southern facades of tall low-albedo building. These spaces are subject to direct solar radiation and retain the heat into the evening. A better dislocation of these heat prone areas would limit their exposure to direct sunlight as, the same tall buildings or old trees in the area do cast a significant shadow, creating spaces of relief from the sun. An additional thermal pattern would be to create dense vegetation in the current left-over lawns, significantly increasing the vegetation and shading of the area, as the warmer day recordings show, that even with no windspeed small, forested areas can reduce WBGT by 2°C, compared to nearby spaces with no vegetation.

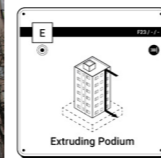
On the other hand, cold exposure in the environment, was mostly dependent on wind. Large open space or areas adjacent to individual tall buildings would feel colder due to increased windspeed, with wide and irregular street spaces recording the lowest windchill index of -1.3°C, around two-degree decrease compared to enclosed spaces.

In this environment, a compromise is required to limit high winds on the pedestrian level, even if it would be a negative design element during a heatwave. This decision was made, as it seems that there are alternative patterns that would limit heat exposure, while cold exposure is fully dependant on wind.

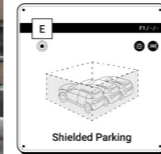
The relevant Exposure Reduction patterns that would improve the area are Broken Canyon (E8), Rain Garden (E10), Reflective Path (E13), Green Shades (E15), Green Windbreaks (E17), Extruding Podium (E19), Cool Envelope (E21), Second Envelope (E22), Shielded Parking (E24), Shielded Block (E25)



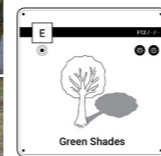
**Figure 176.**  
Tall building downdraft



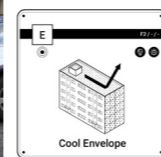
**Figure 177.**  
Vehicle dominated space



**Figure 178.**  
Unutilised old trees



**Figure 179.**  
Heat sink surfaces



Main Neighbourhood form qualities that influence space thermal properties

- Buildings
- High heat absorption walls
- Downdrafts from tall buildings
- Trees and vegetation
- Paved surfaces
- ➔ Wind corridors
- Natural cooling spaces
- Wind-chill index recordings on site
- WBGT recordings on site

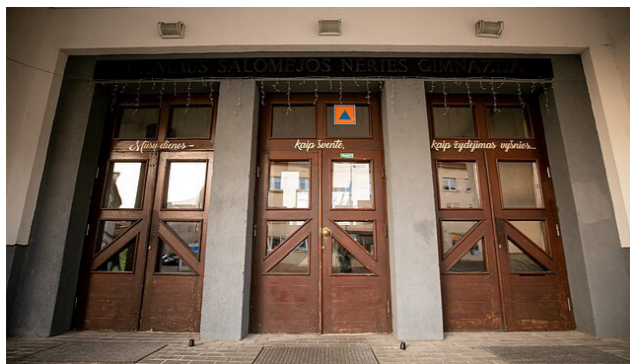


**Figure 180.** Form properties that influence space thermal quality

## Potential Spaces of Transformation

### Public Indoor Spaces as Integrated Shelters

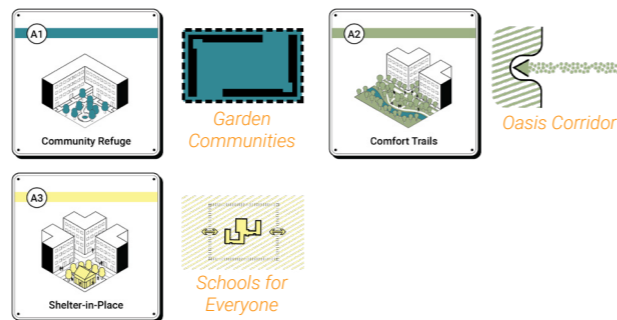
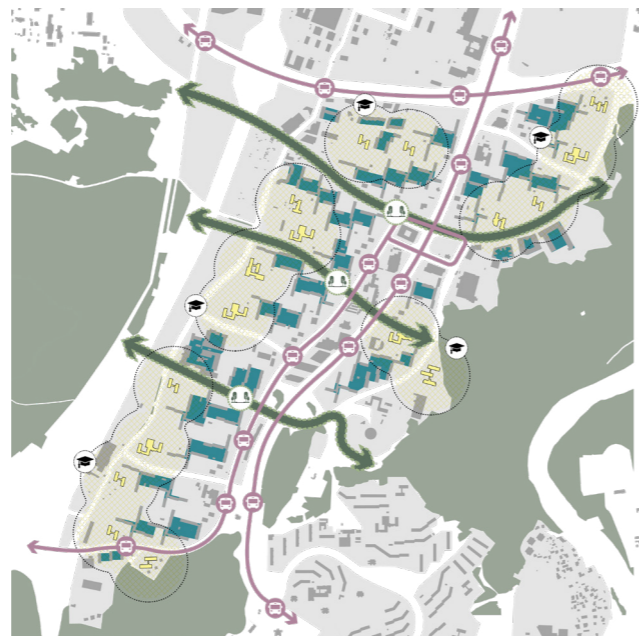
The analysis informed the selection of the 3 primary Adaptation Approach Goals for the area are Community Refuge (A1), Comfort Trails (A2) and Shelter-in-place (A3), while the four approach was not necessary in the neighbourhood as all possible shelters types are available within the neighbourhood, with education spaces, such as kindergartens and schools, being in high proximity to all residential spaces of the neighbourhood, acting for both Shelter-in-Place and Sanctuary Routes goals. These spaces currently act as civil collective protection structures to protect civilians in case a war conflict occurred. This prompted to rethink these to further incorporate their outdoor spaces to ensure they can become social spaces for the whole community, extend the knowledge that people can use these spaces, not limiting to warfare or climate disasters.



**Figure 182.** Schools as Collective protection structures in Vilnius (Umbrasas, 2022).

To adapt more day-to-day social spaces, that would provide safety to lower-risk temperature extremes, open plan district residences were examined, how the structure could be transformed to a more courtyard structure, emphasising the current gardening spaces. Lastly, the large forests, situated to the West and East, could be provided with a stronger movement link, that during extremes would also provide sheltering along the way.

To finance these adaptation developments, the centre commerce structure could be redeveloped with higher densities and mixed-used buildings, by public-private partnerships.



- Buildings, bordering the potential transformation spaces
- New construction buildings
- Community Refuge Goal (A1):**
- Residential courtyards to redevelop and introduce gardening
- Comfort Trails Goal (A2):**
- Local streets to create resting spots and plant continuous vegetation
- Shelter-in-Place Goal (A3):**
- Schools to connect with and integrate within the residential areas

**Figure 181.** Karoliniškės residential district with possible large-scale adaptations strategies



## Adaptation Design | Community Refuge Goal

### New Developed Pattern – Garden Communities

To develop Garden Communities, inner spaces between residential buildings, designated as more private spaces through a visibility analysis, were chosen to be transformed into gardening courtyards for their residents. This meant, that these spaces would exclude any car parking spaces and focus on revitalising nature and creating active social environments robust to endure any temperature extreme.

This new pattern emphasises two social spaces: the apartment front gardens and the covered building entrances and extend these across the inner courtyard. By giving land ownership to the resident collective, spaces around the courtyard can be used as fully garden spaces, offering residents an active lifestyle, possibility to grow their own food and a social activity to build stronger communities. Larger plantings, bushes and fruit trees increase humidity and provide more shadow opportunities mitigating exposure to heat extremes. The building entrances are extended to provide more seating options. Openable glass walls are designed to shelter entrance from wind as well as passively heat-up during cold sunny days. The parallel placement of covered entrances and large greenhouses, that can act as civic spaces, create safer outdoor spaces protected from wind, where play zones or seatings can be used even in cold weather.

The necessary parking spaces are relocated outside the courtyard, where long shadows casting from the buildings ensure that the spaces do not retain heat during a heatwave.

With this new solution pattern adaptation for both extremes are achieved, however the interactions of integrated patterns in the final design illustrates, that adaptation is reach within different spaces in the same courtyard, with outdoor gardens providing relief in extreme heat, while enclosed entrances and greenhouses active spaces in extreme cold.



Figure 183. Design Precedent - Community Garden in Seattle (Seattle Municipal Archives, 2004)

Figure 184. Inner courtyard transformation into “Garden Communities” illustrated in sections

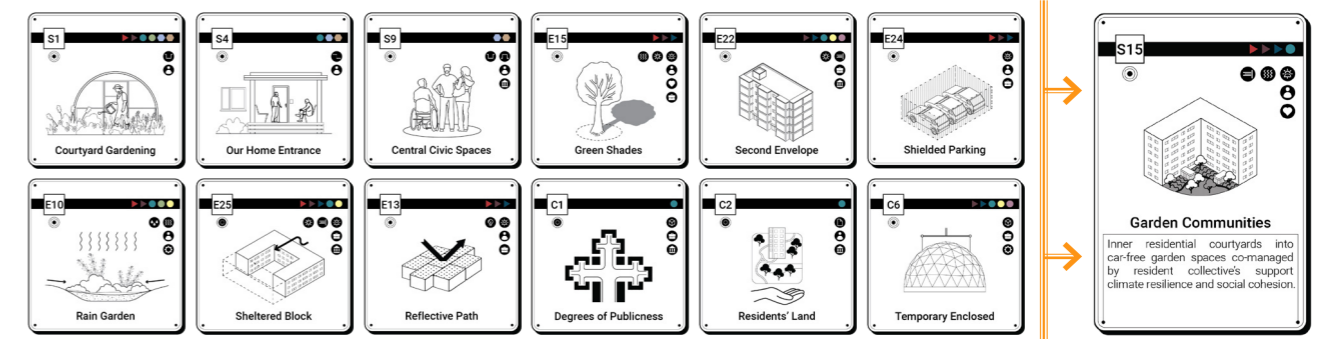
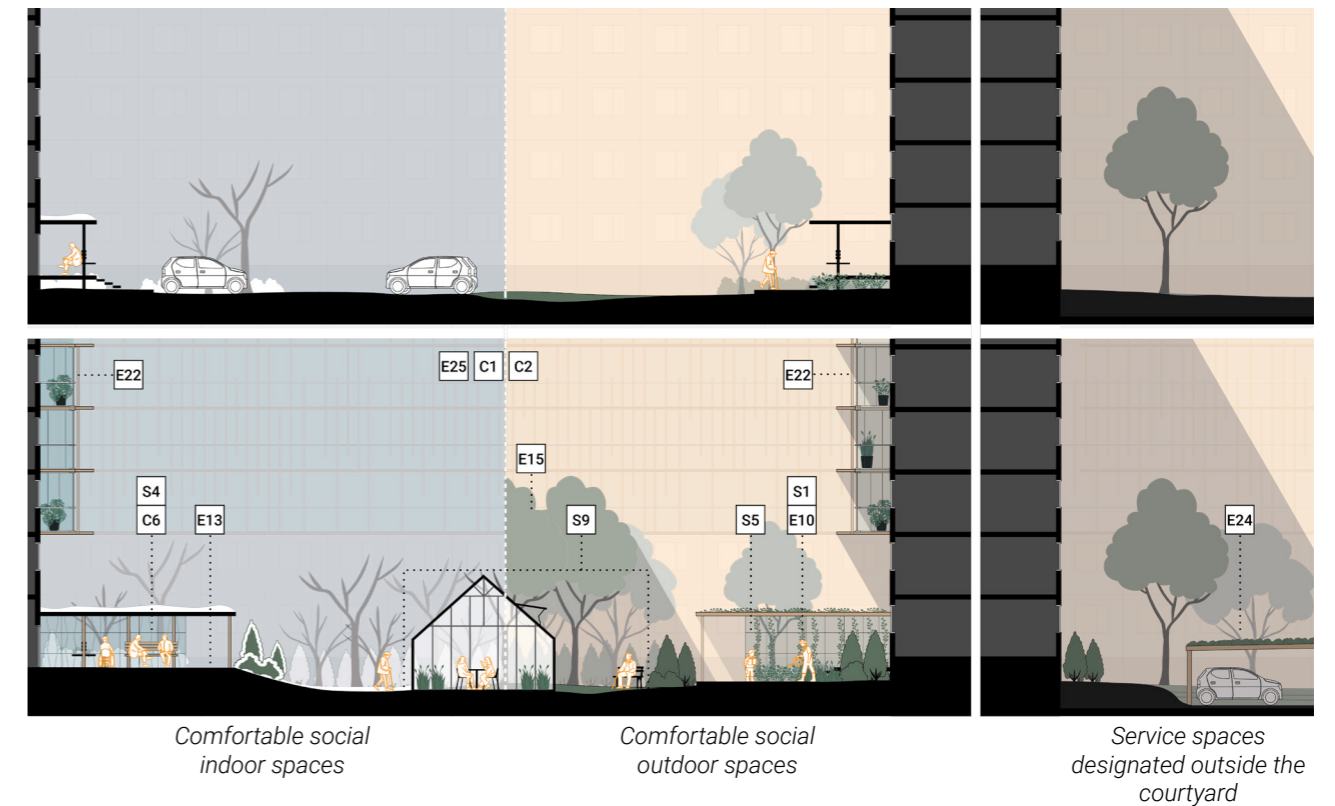


Figure 185. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Adaptation Design | Comfort Trails Goal

### New Developed Pattern – Oasis Corridors

To develop Oasis Corridors, local streets that connect residences to amenities and larger natural spaces, were chosen to be transformed into paths providing constant protection for pedestrians trying to reach further spaces. This meant, that these spaces would require a strategic vegetation planting guide and a development of linear space, that limits exposure to heat with shades, while providing resting spaces that protect them from frigid winds, creating safety bubbles. Large sections are dedicated to planting zones to ensure that trees can grow unobstructed, creating large canopies. These planting zones also act as snow collection areas, allowing maintenance workers to push the snow out of the path, requiring less salt to melt the snow, which damages the soil.

While currently these streets do have limited asphalt paving and large open spaces, an optimisation of these streets can provide even more benefits for people with limited mobility, that require traversing these spaces to reach shops, public transport or nature. These enhanced linking spaces also provide opportunities to strengthen the link between the neighbourhoods west and east side, and a comfortable walk might encourage people to reach a further required amenity, instead of taking their car. Equally distances resting spaces also ensure that elderly people can take a break and not be exposed to temperature extremes.

The redevelopment of these spaces puts emphasis on creating protected paths for pedestrians and cyclist, as shades and windbreaks are provided for sidewalks, which are separated from the main traffic line, while the street itself enforces slower vehicle movement allowing to replace asphalt with reflective brick paving and only keeping paved space for cyclists, who share the street with vehicles, creating a bicycle street. Street parking is essential to limit the need to park inside the urban blocks, complimenting the designed pattern of Garden Communities.

Even though the main design element for this new pattern is vegetation, essential maintenance workers are a very important part to ensure the patterns success. They are required not only to make sure that the connecting street is safe by removing snow and ice, but they also uphold the environment by trimming evergreen shrubs, such as Thujas, keeping the design if these spaces attractive.

With this new pattern, adaptation for both extremes is secured through different scales. Heat exposure reduction is achieved throughout the whole design, having a local scale influence, while cold exposure reduction is realised through small, scattered points across the design, having an impact on a micro scale level, although creating a structure that is translated into a local scale.

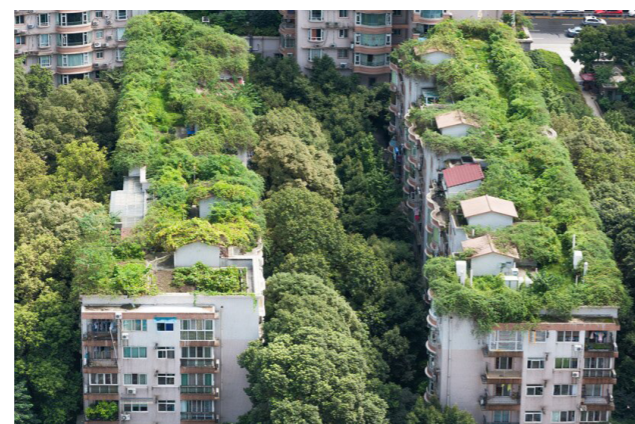


Figure 186. Design Precedent - Greening Polish Cities (Weber-Siwirska, 2023)

Figure 187. Irregular canyon transformation into an "Oasis Corridor" and optimisation for a heatwave and coldspell conditions at noon (H/W = <0.30)

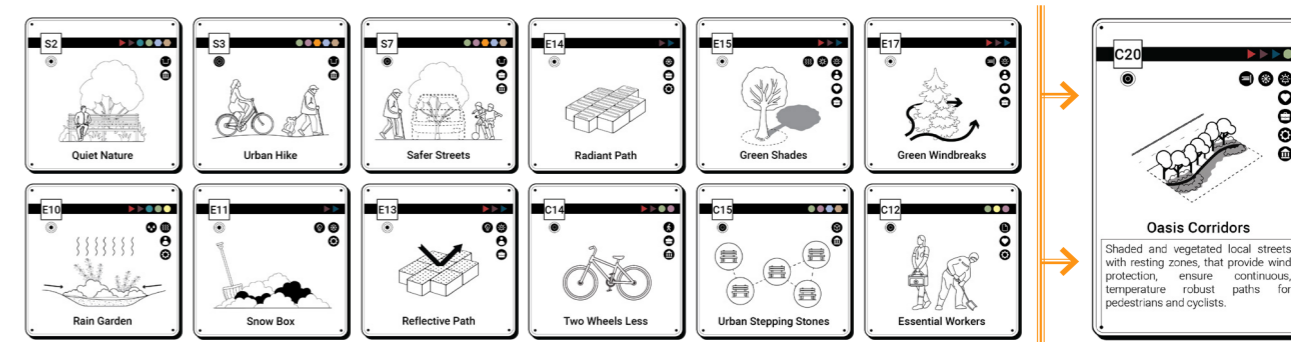
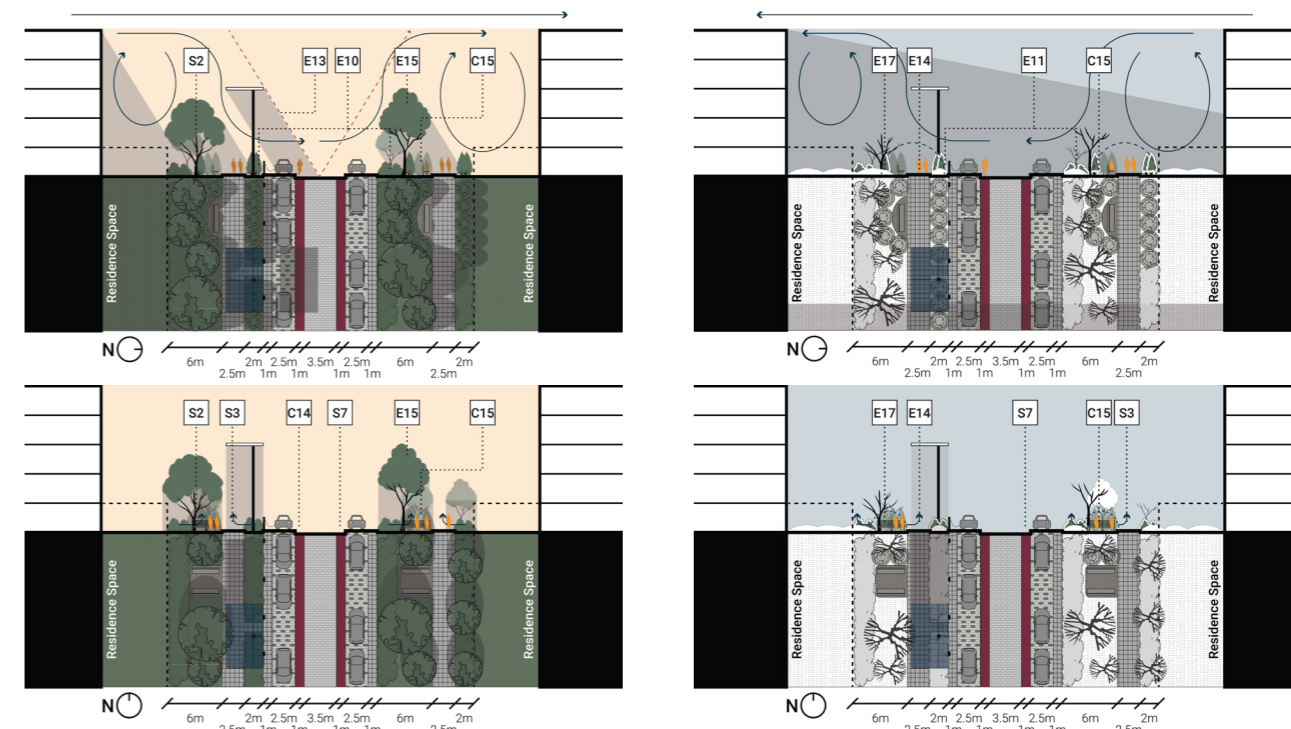


Figure 188. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Adaptation Design | Shelter-in-Place Goal

### New Developed Pattern – Schools for Everyone

To develop Schools for Everyone, the in-between spaces transitioning from residential function to education grounds, were chosen to develop a more integrated space between the two, by reshaping the building blocks and introducing new functions in the current left-over spaces. This meant, that more concentrated functions would disperse across the threshold guiding people from one side to another, encouraging residents to use the education facilities as shelters from temperature extremes.

To achieve a stronger link, the placement of education buildings was altered, as new extensions, which could include public libraries, gyms or general community spaces, were positioned towards the residential neighbourhood. There form imitates a perimeter structure, clearly defining private school grounds meant for children and shared spaces for children and the residents. Between the new extensions, a 25m. wide canyon like space was formed, to concentrate activities and provide a quick bridge between education facilities. The two open ends allow people to move through the space. Between the shared education space and residential inner courtyards, a park is created to mitigate temperature extremes, while also creating a step between intended public and private. With the removal of the fence on the western side of schools, it shifts the building to the edge, providing an opportunity for a more active and inclusive plinth, where many entrances could be integrated.

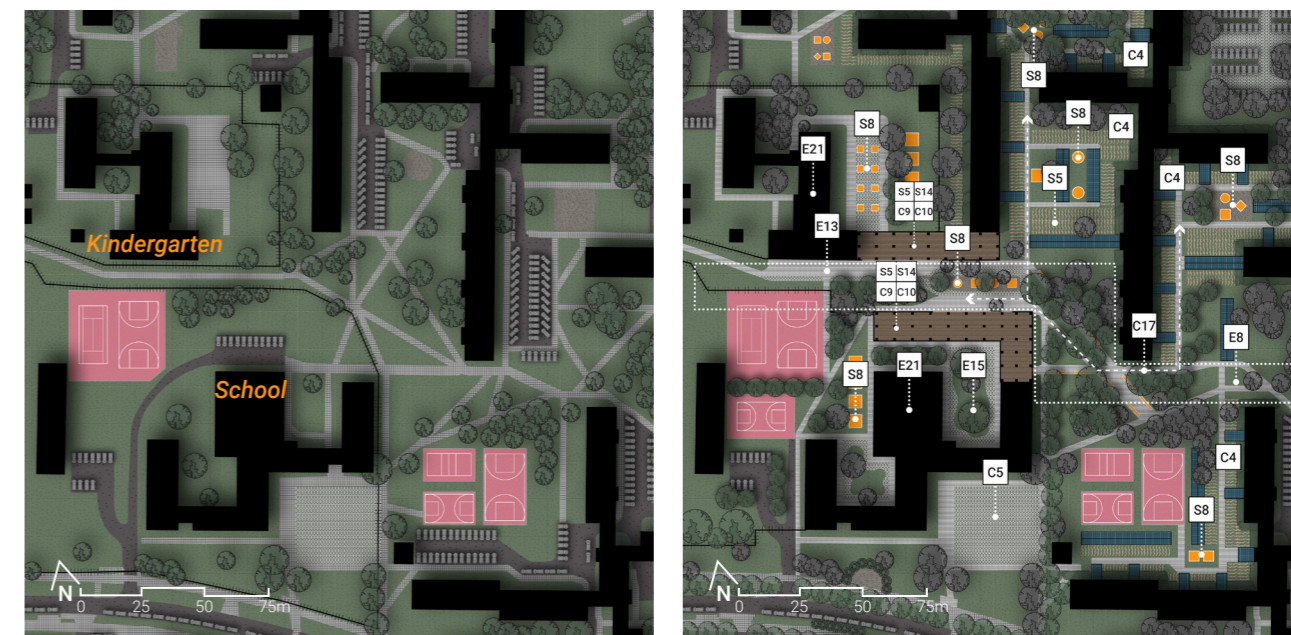
While this pattern does create a new indoor shelter for the residents, its cooperation with other patterns in the area provide immense benefits. Garden communities provide outdoor education spaces, where children together with residents could learn about biology, botany or garden planting. This increases interactions between elderly and children creating stronger community and as a result higher adaptive capacity, as neighbours are likely to help each other. Oasis gardens ensures that paths leading from the school to bus stops, shops or home protect children and teachers from possible heat or cold stress. A full transformation not only adapt the spaces for temperature extremes but also revitalises the old modernist residential micro-districts.

With the new pattern, adaptation for both extremes is reached, and in this case, the shelter space overlaps indoors. Additional considerations should be taken to minimise the required energy demand to cool and heat up the indoor space. A decentralised energy source to overcome any power outages, such as solar energy for cooling and geothermal for heating, should be explored.



Figure 189. Design Precedent - Climate Shelter Network in Barcelona (Barcelona for Climate, n.d.)

Figure 190. Education grounds transformation into "Schools for Everyone" illustrated in plan



Enclosed and fenced-off education grounds

Large open left-over spaces from modernist urban planning

Distinction between private education grounds and shared grounds between two schools and the residential block

Adding functions to the residence, such as a centre park and gardens rows.

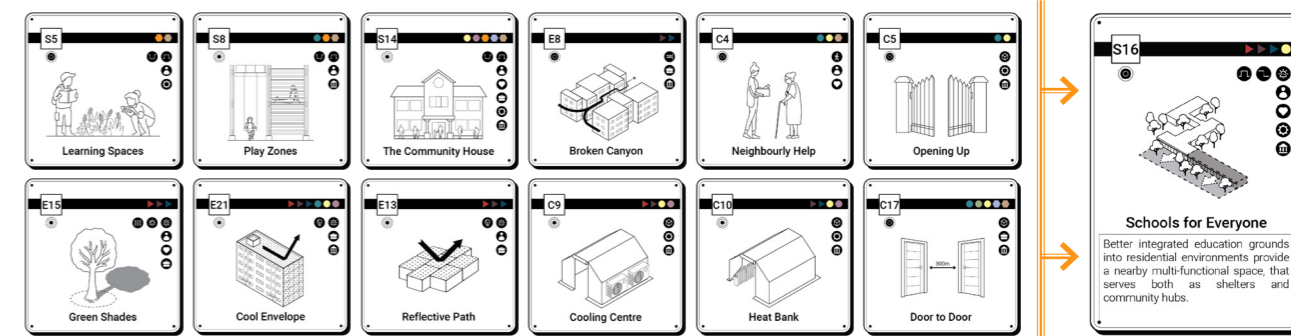


Figure 191. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

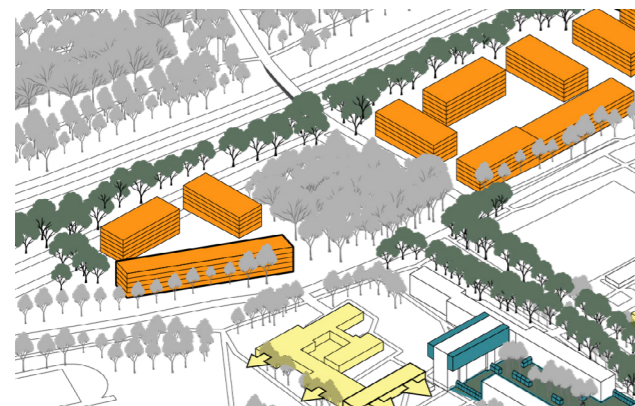
## Conclusion | Site 02

### Open Mid-rise Climate Adaptation

To conclude on the newly developed adaptation strategies for an open mid-rise LCZ, the newly developed adaptation patterns were compared to one another by their temperature extreme mitigation, implementation difficulties and were sequenced by the degree of future temperature risks and requirements, seen in the axonometric drawing on the right.

As all of these patterns are situated within an open mid-rise zone, which has lower built densities and quite a lot of open undeveloped space. The most feasible option for funding these adaptations are through public private relationships. These could include allowing private developers to build in currently open spaces or to increase the density of existing developments through redevelopment projects. Conditions could be set that would require private developers to also build the developed adaptations patterns for their surrounding project spaces or, alternatively, an adaptation tax could be introduced based on each square metre of new construction, to fund the adaptations designs.

Similarly to the previous case, financing options influence vulnerability, requiring additional Adaptation goals for these transformations.

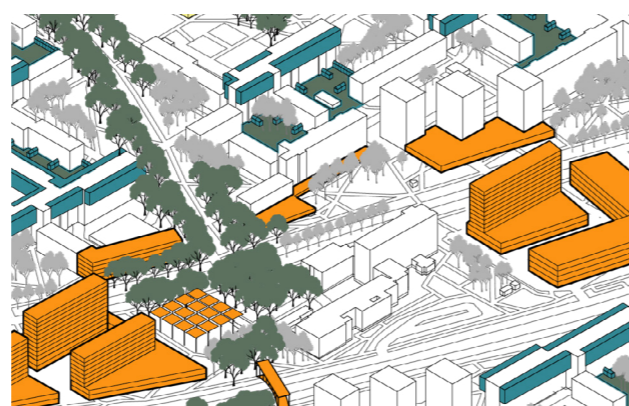


Increasing dedicated land for urban development

New developments  
Higher built-up proportion (*higher heat exposure*)  
Less natural spaces (*higher heat exposure*)



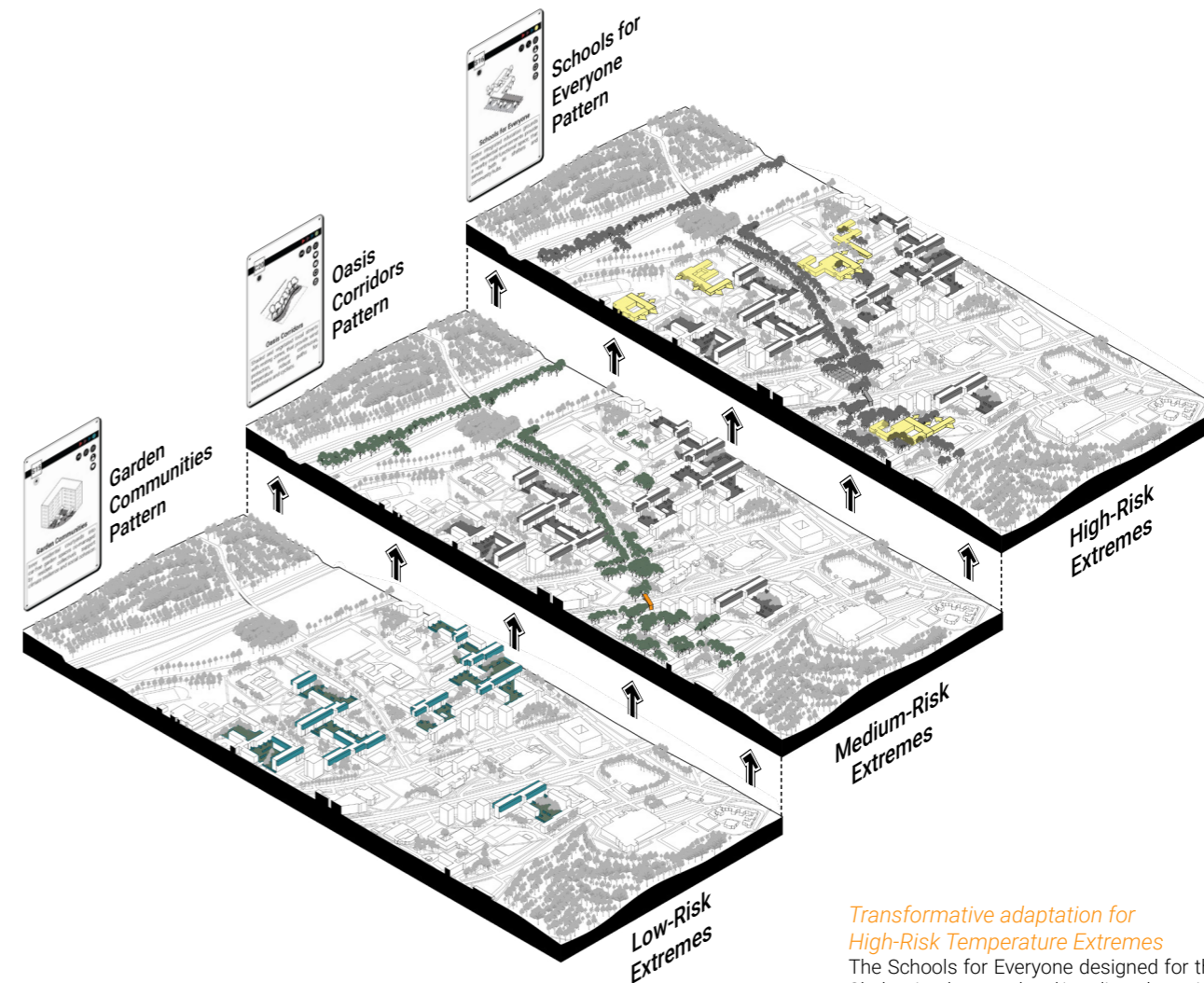
Figure 193. Urban qualities of a climate adaptive Open Mid-rise environment during a Heatwave and Cold spell



Increasing density of currently developed land

Redevelopment projects (*higher adaptive capacity*)  
Higher population density (*higher sensitivity*)  
Higher compactness (*higher heat exposure*)

Figure 192. Open mid-rise LCZ climate adaptation financing options



### Incremental adaptation for Low-Risk Temperature Extremes

Garden communities designed for the community refuge goal is a primary adaptation strategy that allows people to take control and creates leisure spaces to wait out *occasional temperature extremes*. As these are open spaces only low-risk temperature extremes would be mitigated.

### Medium-Risk Temperature Extremes

Oasis Corridors designed for the Comfort Trails' goal is a secondary adaptation strategy, which allows people to move through their neighbourhood and remain self-sufficient without being isolated indoors in *unpredictable temperature extremes*. This approach ensures high adaptive capacity but only as a supporting strategy for medium-risk temperature extremes with limited social improvements.

### Transformative adaptation for High-Risk Temperature Extremes

The Schools for Everyone designed for the Shelter-in-place goal and is a dire adaptation strategy, which provide residents with an alternative shared indoor shelter to protect themselves during *frequent temperature extremes*. These spaces would provide a collective meeting space and a strong protection from high-risk extremes. This transformation is only necessary in worse case scenario, as it would require a dedicated public engagement effort to change the current persistent views on schools and their openness.

Figure 194. Open Mid-Rise LCZ intervention phasing dependant on future risks

Figure 195. Open Low-rise Neighbourhoods (Aero Fotografija, 2015)



## Site 03

Northern Verkiai territory

## Northern Verkiai territory

### Urban Context

The northern territory of Verkiai, in this intervention case, is constrained to three parts of the city: Naujaneriai, Balsiai and Kryžiokai, situated on fringe of Vilnius. Established during the Soviet period, these urbanised spaces were not developed for permanent residence but rather intended for summer gardening and recreation outside the city, named kolektyviniai sodai (collective gardens). Alternatively, to residential micro-districts, such as the intervention site 2, the planning of these spaces was minimal and their development mostly informal, as only small plots of individual land were drawn, while buildings, paths, and infrastructure were shaped spontaneously by the gardeners themselves (Šiupšinskas, 2021).

A suburbanisation shift began in the early 2000s, when legislation made it possible to construct residential homes in these collective gardens (SINUŠAITĖ-PETREIKIENĖ & NAIMAVIČIENĖ, 2020). As housing prices in the city rose, people, especially young families and retired citizens, have begun converting garden plots into permanent homes. This transformation has put pressure on the area's limited infrastructure, transportation access and other required amenities. Today Northern Verkiai territory is shaped by a mix of collective garden and residential open low-density environments, disconnected from the larger city.

All of these challenges are required to be addressed together as a new development strategy for these rural fragments, to adapt them to temperature extremes and integrate within Vilnius planning framework.

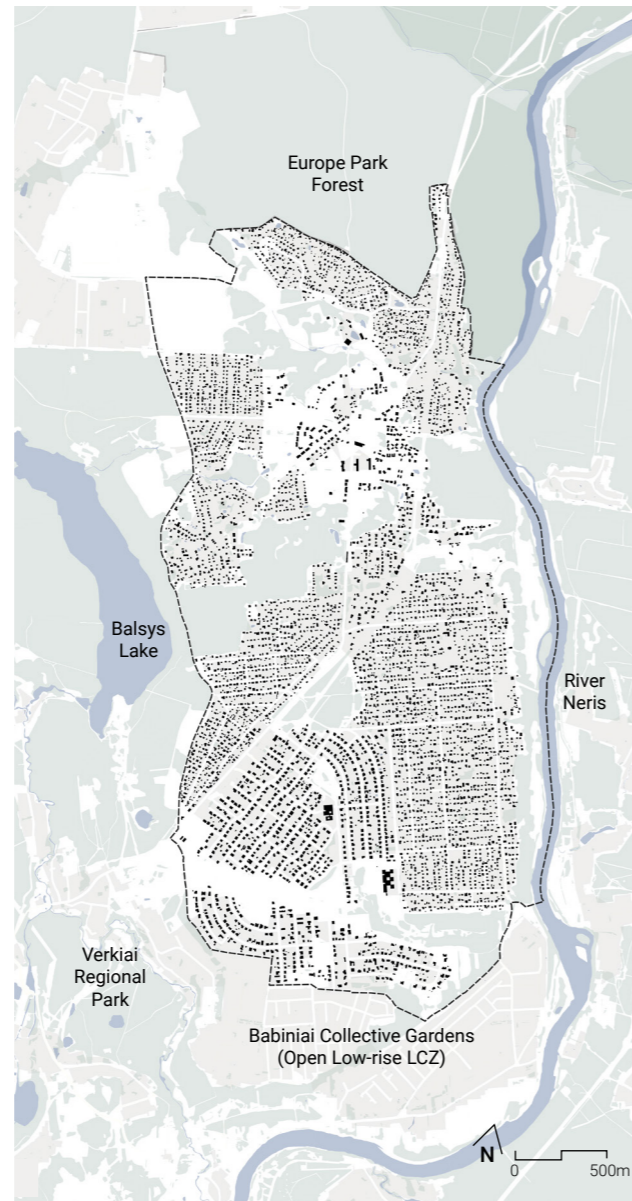


Figure 196. Northern Verkiai Neighbourhood Plan



Figure 197. Northern Verkiai Territory Study Area

## Urban Structure Analysis

Examining the territory's topographical structure and its ecological systems, it illustrates that the urbanised space is situated between the Verkiai regional park and Neris river valley. Both of these ecological corridors are large water systems, one being the Žaliejų Ežerai glacier formed lakes, the other river floodplains, and an urbanised area in-between, illustrated in the section below. The proximity of large natural elements reduces the exposure of the areas around the built environment; however stronger links are required to reach those spaces.

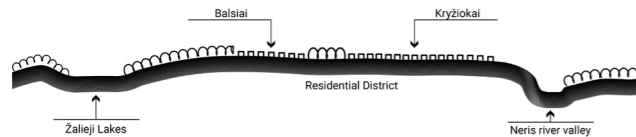


Figure 202. District Section

The zoning plan for the area shows that almost everything developed is low intensity and low-rise residential single-family homes. The public amenities in the area are two grocery stores and a shopping mall in the south towards the city. There is one kindergarten and one newly built school, with a new cultural centre being planned, next to the education facilities and a new sports centre in the north. The retail services are situated on the main connecting artery, while educational facilities are situated further deep in the residential spaces, requiring taking a public minibus to reach those spaces.

The accessibility of the area is limited. The majority of infrastructure was developed with car dependency in mind. Service (secondary roads) to reach residential homes, especially in collective gardens are only dirt roads. However, the main artery has been renovated to include a shared pedestrian and cycling paths separate from the street that goes through the territory.

- Natural areas / Forests
- Natural water bodies
- Buildings
- Contour line & Ground elevation

Figure 198. Environmental Analysis (Top Left Map)

- Forest and wooded area zone
- Agricultural area zone
- Water zone
- Conservation area zone
- Residential zones:
- Residential areas with extensive development
- Residential areas with low building intensity
- Residential areas with medium building intensity
- Residential areas with high building intensity
- Centre zones:
- Main Centre area
- City segment centre areas
- Specialised complex zone
- Service zone
- Collective garden zone
- Industrial and storage zone
- Infrastructure zones
- Infrastructure corridor zones
- Watershed zones
- Shared space, greenery zones
- Intensively used greenery zones
- Extensively used greenery zones

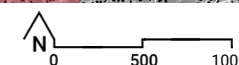
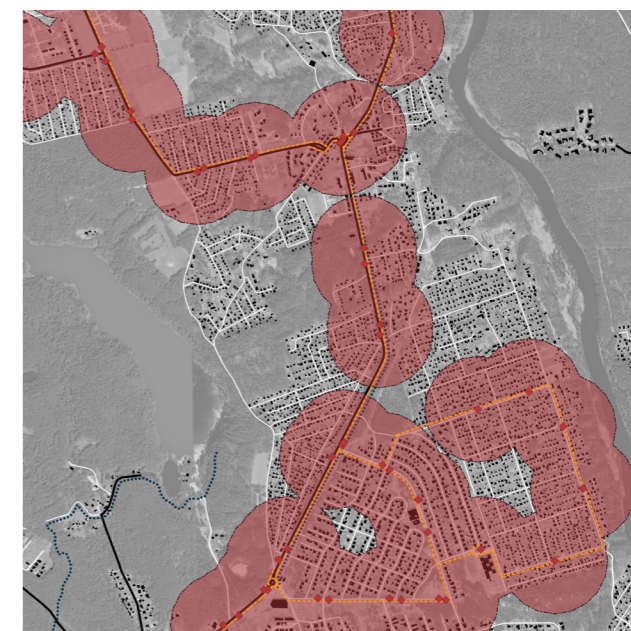
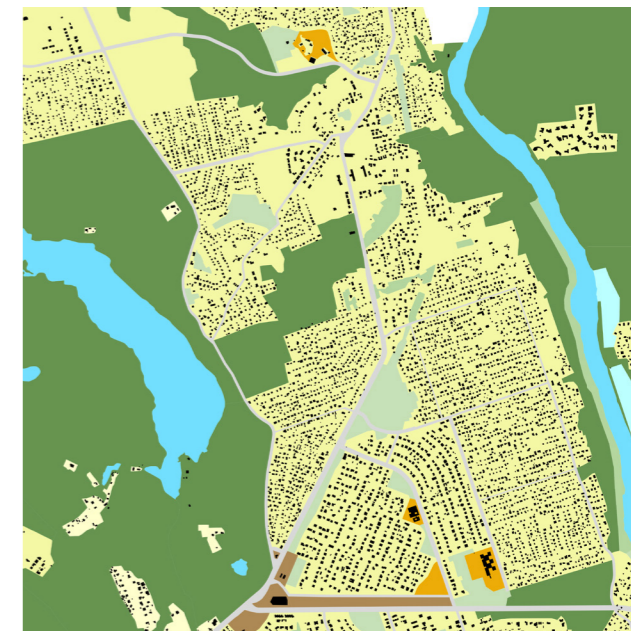
Figure 199. City Zoning Plan (Top Right Map)

- Buildings
- Retail services (possible shelter)
- Children Playgrounds
- Public education buildings (possible shelters)
- Planned public buildings (possible future shelters)
- Private Land - Parcels

Figure 200. Public Service Analysis (Bottom Left Map)

- Primary roads / Arteries
- Secondary roads
- Bicycle Paths
- Public transport lines
- ◆ Public transport stops
- Service area (300m.) of public transport stops

Figure 201. Circulation Analysis (Bottom Right)



## Temperature Vulnerability Analysis

When focusing specifically on temperature vulnerability, the exposure maps indicate that the area is severely prone to extreme cold. LST map during a heatwave indicates that the only areas that can store heat are urbanised suburbs with larger houses and compact parcels retaining higher temperature due to higher density of paved or unvegetated surfaces as well as larger amount of building materials exposed to solar radiation. During a cold spell the same suburbs are fully exposed to cold as surface temperatures plummet. The only temperature regulating spaces are around water, with the size of the waterbody determining the amount of cold mitigation. These can be explained through higher temperatures than the surrounding surfaces, as well as increased radiation reflectance due to ice.

When examining sensitivity, the whole neighbourhood possesses high proportions of sensitive demographics, with built-up spaces, developed for permanent residential functions, housed more elderly, while collective gardens, which historically provided seasonal residences, houses proportionally more children. This can be theorised that more young families are moving into these gardens and transforming their parcel from a garden to a full detached house. All of this creates two simultaneous urgencies, that require providing more close-by amenities for elderly, as well as areas for collective play and safe passages to reach schools, as kids try to find activities in these environments.

Currently the most essential amenities are in the area, by providing groceries, pharmacies and education. These are also outside of collective gardens, requiring people to walk or drive to reach them, even though these amenities are linked by public transport.

- Education buildings (shelters)
- Retail buildings (shelters)
- High Heat Exposure / Stress
- Low Heat Exposure / Stress

**Figure 203.** LST recordings during a heatwave (Top Left Map)

- Education buildings (shelters)
- Retail buildings (shelters)
- Low Cold Exposure / Stress
- High Cold Exposure / Stress

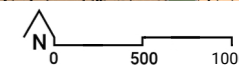
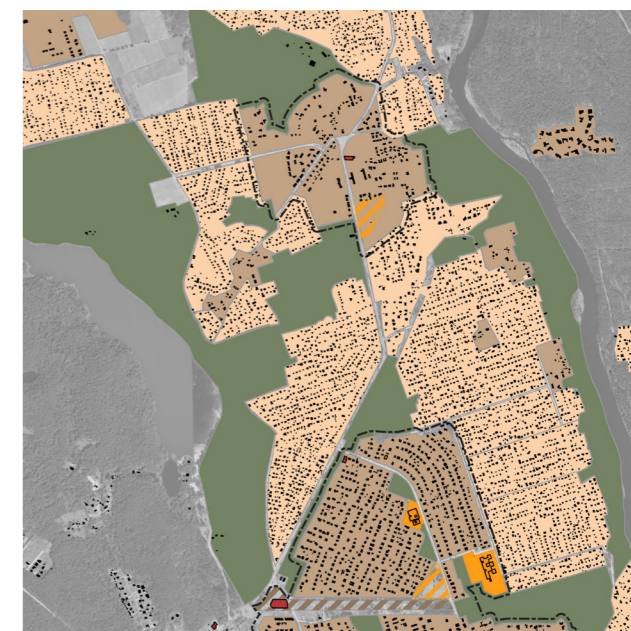
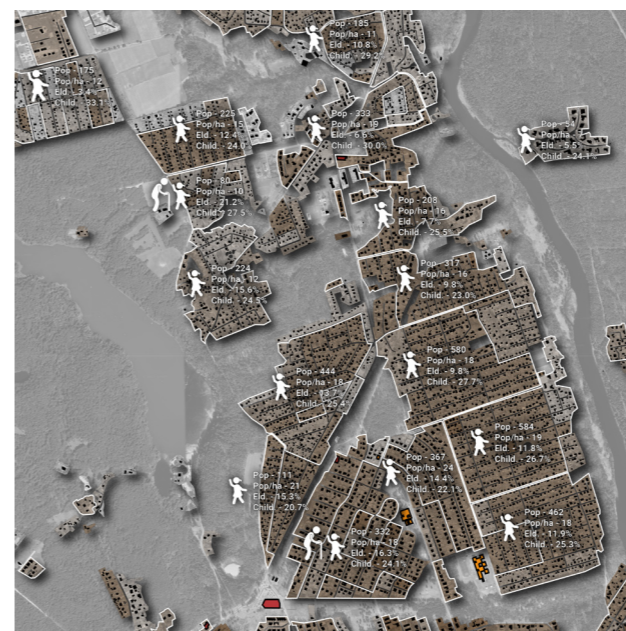
**Figure 204.** LST recordings during a coldwave (Top Right Map)

- Education buildings (shelters)
- Retail buildings (shelters)
- 50 Residents/ha
- 0 Residents/ha

**Figure 205.** Neighbourhood sensitive demographics (Bottom Left Map)

- Buildings
- Retail services (possible shelter)
- Public education buildings (possible shelters)
- Neighbourhood cluster
- Planned Urban Peripheral centre (1.2 Intensity)
- Villa structure (0.4 Intensity) - Full residence
- Collective Gardens (0.4 Intensity) - Seasonal residence
- Forests or dense vegetation (Dense trees LCZ)
- Specialised complex
- Planned specialised complex




**Figure 206.** Land-use distribution - exposure & adaptive capacity indicator (Bottom Right)






## Adaptation Potential Analysis

To understand the accessibility, mobility and shelter reach of this territory, a space syntax was utilised. By calculating the street network angular integration of 300m. by foot and 5km. by car, the essential local: Ragučio, Balsių, Kryžiokų Sodų 2-oji, Sakališkių and section of Krakiškių street, as well as regional: Žaliųjų Ežerų and Krakiškių streets were mapped. This distinction informed that the local streets create spaces accessible by pedestrians, where new amenities, small workplaces and shops could be integrated to create a self-sufficient node, while regional streets show an alternative high mobility corridor to the current primary artery, creating an opportunity to expand the accessibility of the area. This goes together with the placement and public transport routes, as the territory is spread out, public transport is essential to cover the homes. When examining the reach of 300m. of bus stops (interchange spaces), the area barely covered, while mapping the reach of the current public buildings in the area with the reach of 800m. shows servicing half of the homes, requiring to consider safe path in relation to temperature extremes or integrating bicycle paths.








Lastly, visibility analysis was mapped to find open areas, where community spaces or new development could occur in the built-up territory, excluding dense vegetation and forest, as these spaces are essential for temperature adaptation and should not be intervened

-  Indoor public buildings (shelters)
-  High integration - Active spaces
-  Low integration - Disconnected spaces




**Figure 207.** Local Streets (Angular Integration by Foot - 300m.) (Top Left Map)

-  Indoor public buildings (shelters)
-  High integration - Active spaces
-  Low integration - Disconnected spaces

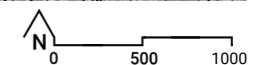
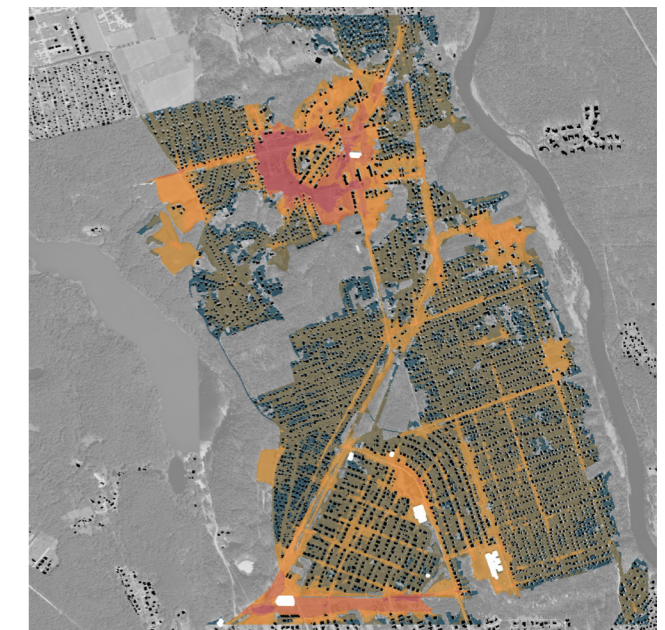
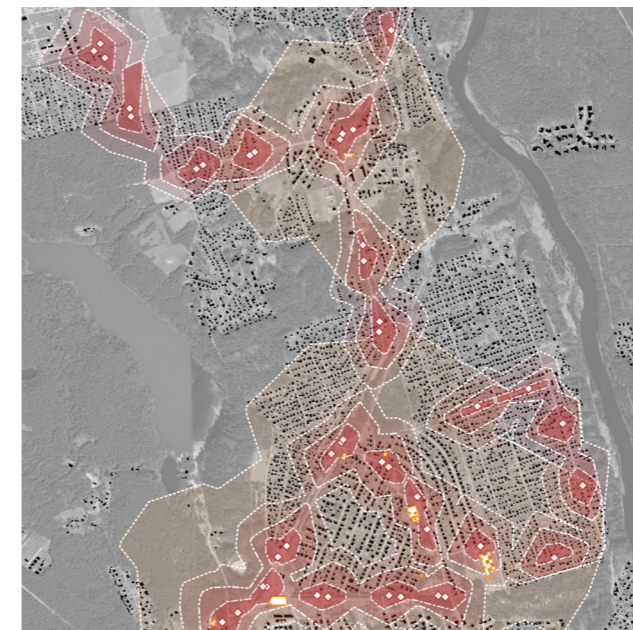
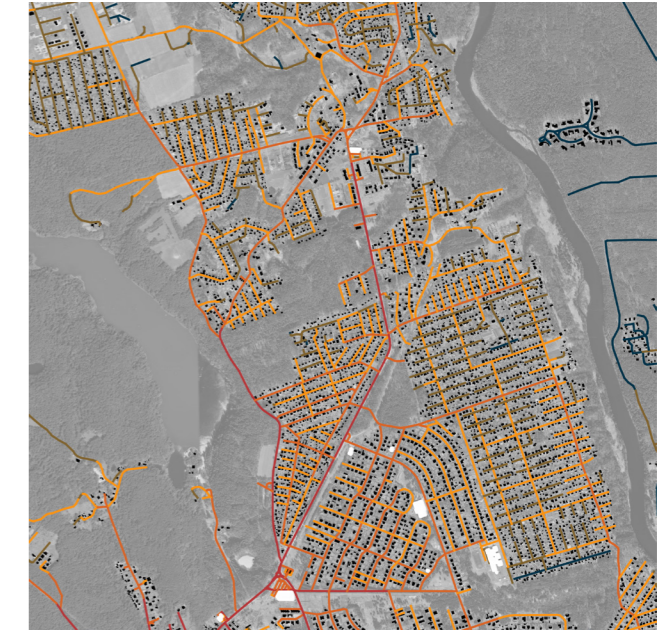
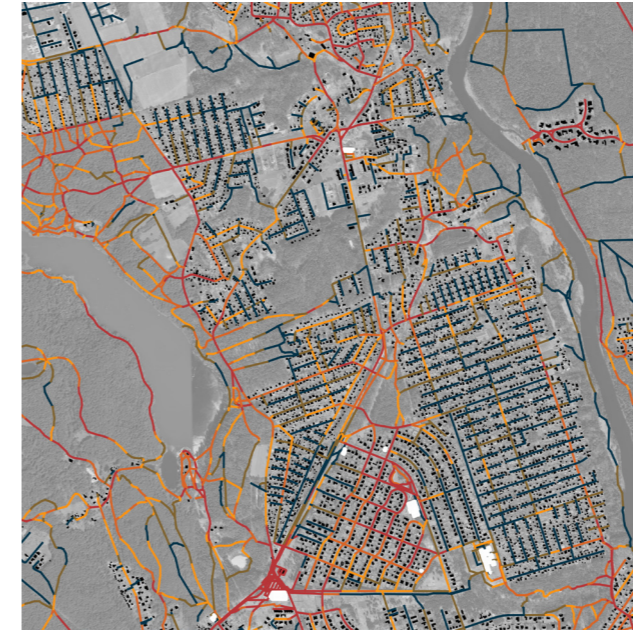
**Figure 208.** Regional Streets (Angular Integration by Car - 5000m.) (Top Right Map)

-  Buildings
-  Education & Retail building shelters
-  Walkable servicable area (800m.)
-  Bus stop shelters
-  Adjacent servicable area (100m.)
-  High proximity servicable area (200m.)
-  Medium proximity servicable area (300m.)

**Figure 209.** Education buildings as temperature shelters (Bottom Left Map)

-  Indoor public buildings (shelters)
-  High visibility - Open Public
-  Low visibility - Enclosed Private

**Figure 210.** Neighbourhood visibility analysis (Bottom Right)



## Site's Spatial Qualities

To understand the spatial qualities of the Norther Verkiai territory, a limited lens of 400m. was placed around a final bus stop in Naujaneriai. This lens allowed to better understand the impacts of temperature extreme on this particular area as well as investigate the spatial relationship between residences, collective gardens, grocery shop, empty spaces and the interlinking interchange space – Naujaneriai bus stop.

As the area is developed through small parcels of land only usable as a single-family home, as planning document are limiting the intensity and possible density. New investments in shops or workspaces are limited as the area encompasses very low population density, around 10 people per hectare, as well as no dedicated amenity zoning. To solve these challenges, the objective would be to densify the area, while retaining the desired social qualities of open low-rise environments and remove the qualities that are vulnerable to temperature extremes.

Today, the urban form is especially vulnerable to cold exposure, as separate and unrelated buildings does not influence the wind, creating constant frigid winds between buildings. However, the low height buildings do provide an alternative approach of dealing with cold exposure by maximising solar radiation, as low sun angles still penetrate into the pedestrian level, improving thermal comfort of south facing spaces.

A-A section

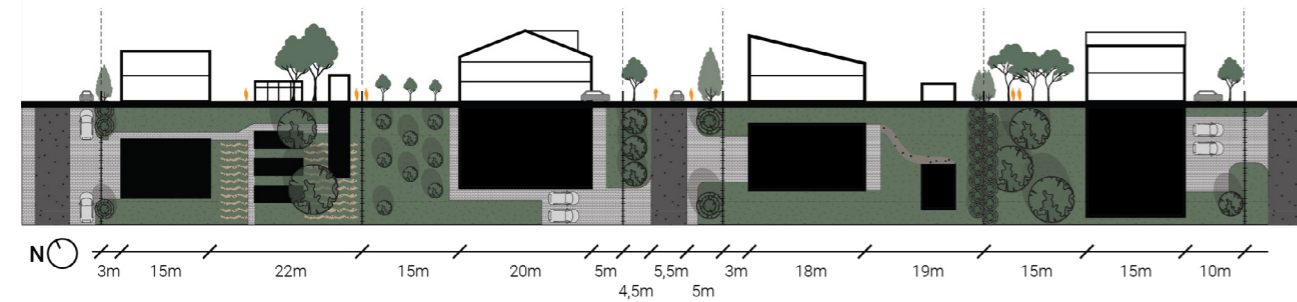


Figure 211. Naujaneriai neighbourhood section



Figure 212. Naujaneriai residential space relation to interchange spaces






## Social Well-being Analysis

To understand the areas social well-being patterns, insights were documented by walking through and mapping spaces dedicated for specific uses, observing of how people use the space, and which spaces are most frequently used, during fieldwork on the 18th of April. It was set during a warmer period within the marginal season, to see which activities persist in non-ideal temperature settings that can be further encouraged by providing even better thermal comfort factors.

### Valued Social Spaces

Compared to other intervention sites, this particular environment showed very little activities, as the examined area does not have dedicated space for leisure, nor a high number of people passing by the area. The only activities spotted were mostly necessary, such as walking or cycling home, waiting for a bus, going shopping. However, some of these activities were supplemented with social interactions, as people waiting for a bus sat down and make conversation, while some met nearby the entrance to the shop and positioned themselves nearby to talk for a few minutes. This showed that in open low-rise environments, where there is no dedicated public space to spend one's time, main social spaces emerge as areas nearby interchanges or amenity interfaces, where higher foot traffic occurs.

By establishing more clustered public functions, situated between public transport routes and residences, these spaces would become nodes social interaction, as higher number of people moving through the spaces would meet each other. The relevant social well-being patterns are Quiet Nature (S2), Urban Hike (S3), Safer streets (S7), Waiting to Go (S11), Social Shopping (S13).

-  Walking
-  Shopping
-  Cycling
-  Waiting
-  Sitting

Actions observed illustrated in diagrams



**Figure 213.**  
Interchange spaces



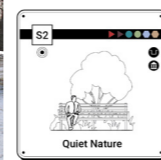
**Figure 214.**  
Walking, cycling trails









**Figure 215.**  
Shops for interactions



**Figure 216.**  
Large natural spaces



Main Neighbourhood Social Well-being Spaces linked to Patterns

-  Buildings
-  Shopping centres
-  Important Nature spaces
-  High interaction spaces
-  Area of observation
-  Fenced-off areas



**Figure 217.** Public space distribution and valued social spaces

## Thermal Comfort Analysis

To understand the territory's thermal comfort, urban forms that influence its microclimate were observed as well as temperature data was collected with a Kestrel Heat Stress WBGT Tracker to compare thermal recordings between nearby spaces. As the site is focusing primarily on cold adaptation, the fieldwork recording outdoor temperature readings was conducted on the 13th of January from 13:00 to 14:00, during a cold winter day.

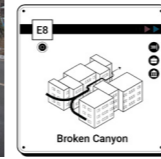
The most prominent urban characteristics in the surrounding area, that are exposed to cold are wide open straight streets, open spaces due to undeveloped land, unmaintained snow-covered paths. These spaces are subject to high windspeeds, that require adequate wind blocking measures. Some of these measures were seen during the visit, as narrow streets with high evergreen vegetation provided shelter from wind, although still limited one's movement due to slippery paths. These findings can also be observed in the windchill index recordings, as spaces that were oriented to channel the wind during that particular day, reached temperatures as low as  $-5.05^{\circ}\text{C}$ ,  $4.5^{\circ}\text{C}$  lower than the standing in the bus stops cover, where the index was calculated to be  $-0.55^{\circ}\text{C}$ .

On the other hand, while it was not observed in fieldwork, temperature simulations of this particular environment showed, that during sunny winter days, PET levels could differ up to  $6^{\circ}\text{C}$  when comparing space with direct solar radiation and spaces in shadow. This illustrates that any public spaces meant for winter use require to be facing the south and not blocked from the sun by vegetation or other buildings.

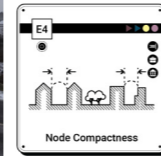
The relevant exposure reduction patterns that would improve the area are Nearby Regulating Water (E1), Under the Wind (E3), Node Compactness (E4), Broken Canyon (E8), Snow Box (E11), Radiant Path (E14), Green Shades (E15), Green Windbreaks (E17), Sheltered Block (E25).



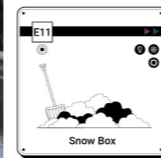
**Figure 218.** Wind changing roads



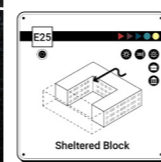
**Figure 219.** Unprotected open spaces



**Figure 220.** Snow covered paths

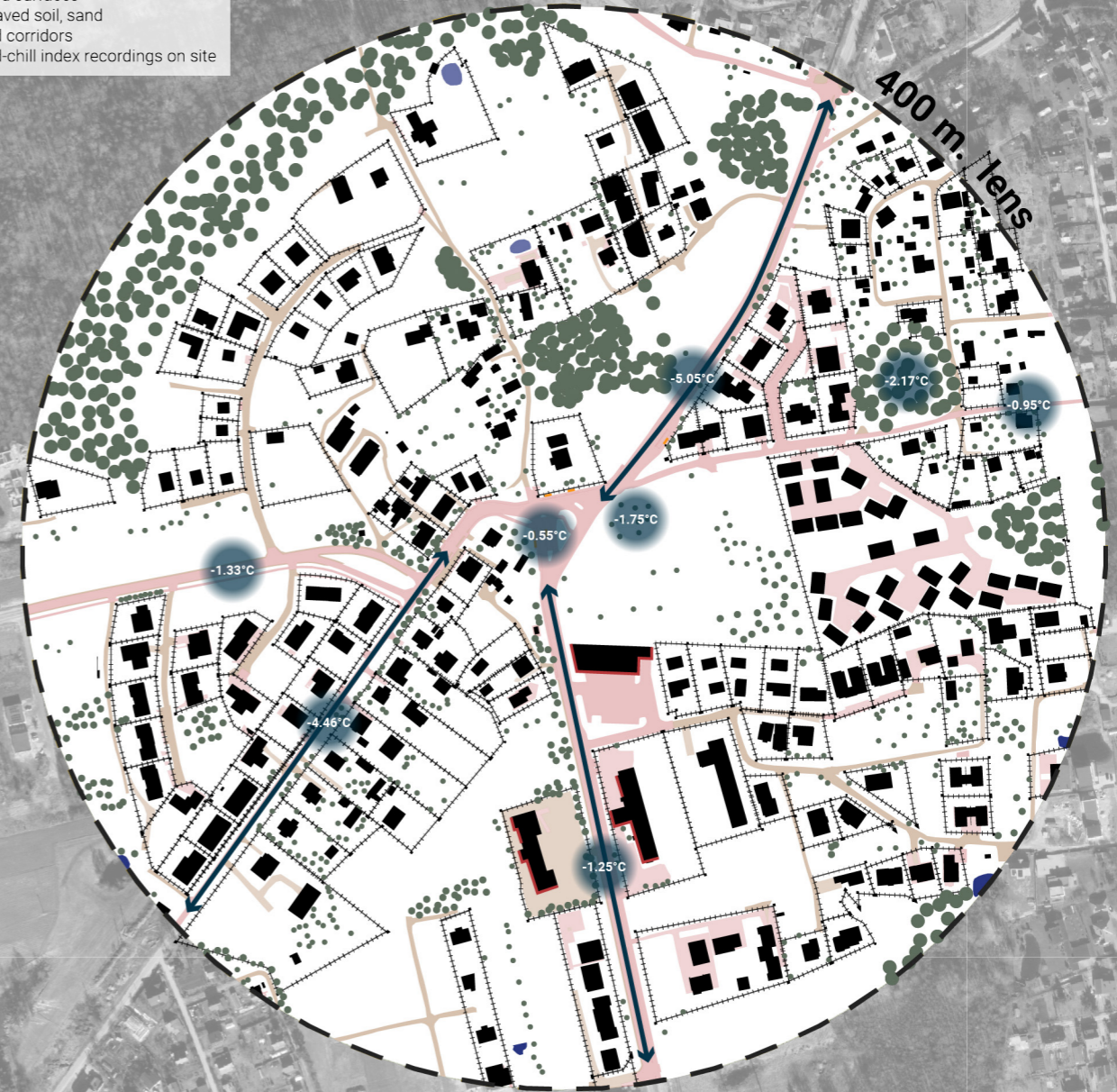


**Figure 221.** Sheltered passage ways

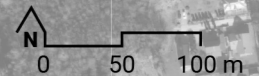


Main Neighbourhood form qualities that influence space thermal properties

- Buildings
- High heat absorption walls
- Trees and vegetation
- Paved surfaces
- Unpaved soil, sand
- ➔ Wind corridors
- Wind-chill index recordings on site



**Figure 222.** Form properties that influence space thermal quality



## Potential Spaces of Transformation

### Interventions to increase Adaptive Capacity

The analysis informed the selection of all 4 Adaptation Approach Goals for the territory, as the area is lacking in every possible Adaptation Approach.

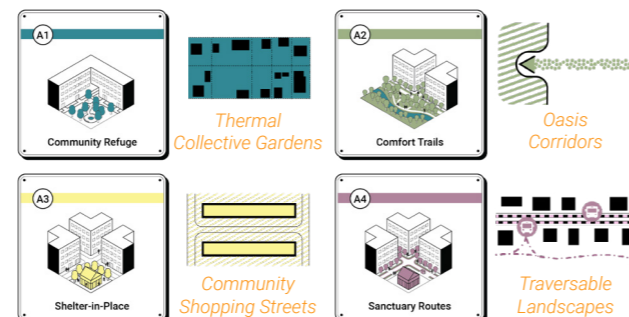
As the area's urban form is completely exposed to extreme cold, and does not contain any space, within the collective gardens, that would provide relief during a hot day, the Community Refuge goal (A1) optimises the current urban design to provide spaces for both extremes. With this transformation collective gardens become Thermal Collective Gardens.

Comfort Trails goal (A2) requires that the residents can safely reach the vast forest and waterfronts surrounding the territory. Here an already developed pattern Oasis Corridors, can easily solve this issue by providing connecting larger natural spaces with rows of trees and bushes in streets that provide protection from extreme heat and cold.

As the area is lacking in amenities and public spaces for people to gather, Shelter-in-place goal (A3) emphasises the need to construct these spaces across the territory. To fulfil this goal, Community Shopping Streets are integrated alongside main transportation routes, to allow residents and people from further away to use these active streets.

And lastly, the most crucial goal is Sanctuary Routes (A4), that would ensure fast movement through the environment to reach regional shelters, such as the territory's only school. Traversable landscapes pattern develops new cycling and walking paths along nature to limit the exposure during heatwaves, while a more expansive public transport network shortens the distances required to walk, limiting exposure to cold.

Oasis Corridors and Traversable Landscapes in some cases do overlap on the same connecting spaces complementing adaptation. While Thermal Collective Gardens and Community Shopping Streets are focusing on different spaces in the area, they do benefit from each other, as both increase built and population densities, ensuring a more justified economic reasoning to add amenities in the area and attracting people to live here.



- Buildings, bordering the potential transformation spaces
- New construction buildings, that can substitute shelters
- Current indoor shelters - education buildings and shops
- Community Refuge Goal (A1):**
- Collective gardens to redevelop to optimize outdoor thermal comfort
- Shelter-in-Place Goal (A3):**
- Spaces adjacent to public transport to develop as retail hubs
- Sanctuary Goal (A4):**
- To expand walkability and public transport in regional and local roads

**Figure 223.** Northern Verkiai territory with possible large-scale adaptations strategies



## Adaptation Design | Community Refuge Goal

### New Developed Pattern – Thermal collective gardens

To develop Thermal collective gardens, the residential parcels themselves were chosen to be transformed into residential spaces, that balanced both a garden and a desirable family home. This meant that the building layouts of the collective gardens would require to be changed and strictly regulated, to optimise solar gains and manage wind patterns.

The new pattern emphasises two private outdoor spaces, the north side garden and the sun catching south terrace. By focusing on mitigating both extremes, the land has to be divided into two sides, each optimising either to reduce heat or to collect heat. The northern side covered in vegetation provides a green and shaded from both trees and the building family space. In winter this space is fully in shadow, requiring moving to the other side, where vegetation is limited to maximise solar radiation. The different building height restrictions and slanting roof guidelines ensure that shadows are not impacting the neighbours building nor their garden. The building heights are regulated with buildings in the south limited to two storeys, while the ones in the north limited to three. This creates a wave-like movement in the urban design, breaking up the monotony. The roofs, additionally, guide frigid winds from the north over the buildings, while cool air coming from the south is downwashed inside the parcels, ventilating the space.

With this new solution pattern, adaptation for both extremes is achieved by opposite spaces in the same private land, with the garden side providing relief in extreme heat, while the sunny south side creates more comfortable spaces in cold weather.



Figure 224. Project Precedent - Green Collective Gardens in Vilnius by PUPA (Jonasauskis et al., 2014)

Figure 225. Parcel transformation into “Thermal collective gardens” illustrated in sections and plans

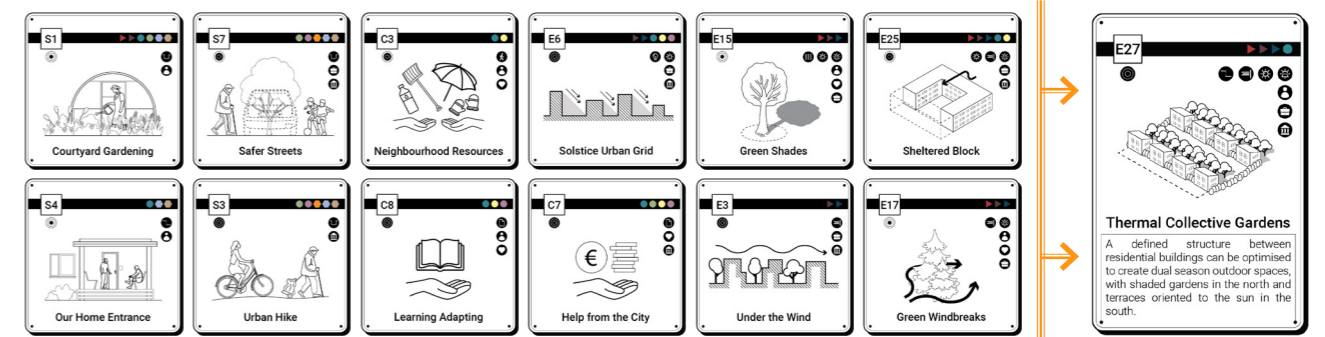
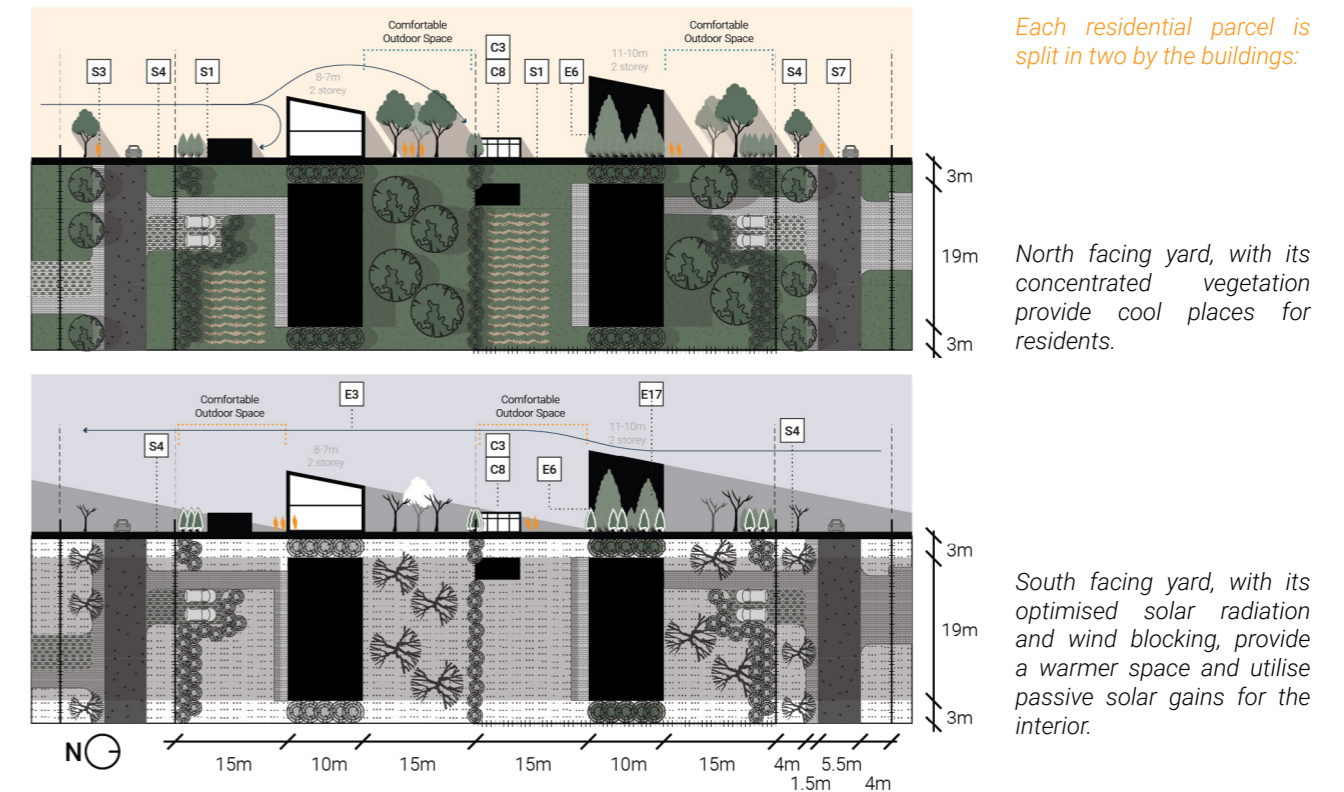


Figure 226. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Adaptation Design | Shelter-in-Place Goal

### New Developed Pattern – Community Shopping Streets

To develop the Community Shopping Streets pattern, areas that are highly integrated within a low-rise low density residential districts require a transformation of the built form. Higher density development in these areas would allow incorporating amenities, such as stores, cafes, workshops or small offices, that would be designed as indoor shelters during temperature extremes. To ensure these areas are developed and successful in creating lively district hubs, they require concentrated mixed-use buildings, situated near public transport lines. Due to the limited established and developed public space together with dispersed parcel landownership in this particular built environment, the pattern emphasises the importance of streets as the neighbourhood’s public space.

The public space is established within a street canyon with both sides developed as connected apartments similar to rowhouses. The ground floor facing the active streets are designated for amenities and commercial purposes, while higher floors as well as the outer sides of the buildings include residential apartments. The street width is designed as a shallow canyon ( $H/W > 0.25$ ) to maximise solar gain in winter and add deciduous trees to shade in summer. To ensure a lively street, the pedestrian sections are expanded to allow commercial spaces to extend their activities into the street or allow open-air community pop-ups, creating a lively plinth. The space is covered with a glass roof to protect it from weather and entrap heat inside. The roof is constructed to allow public transport to pass, while car parking inside the streets is restricted to limit vehicle (exhaust) pollution concentration.

To disperse this heat during heatwaves, buildings situated on the south side are divided to include small parks within this structure. This greenery would not only cool the spaces and clean the air, but the prevailing winds from the south would also circulate the air within the canyon allowing hot air to rise through the roof structure’s openings, bringing in the cold air into the canyon. On the other hand, the continuous northern buildings are developed with an additional floor to block and redirect frigid winter wind.

With this new solution pattern, adaptation for both extremes is achieved within the indoor shelters as well as the outdoor transition spaces are constructed to be more comfortable during heatwaves and cold seasons, as the street allows for solar infiltration as well as adjustable shading options during summer.

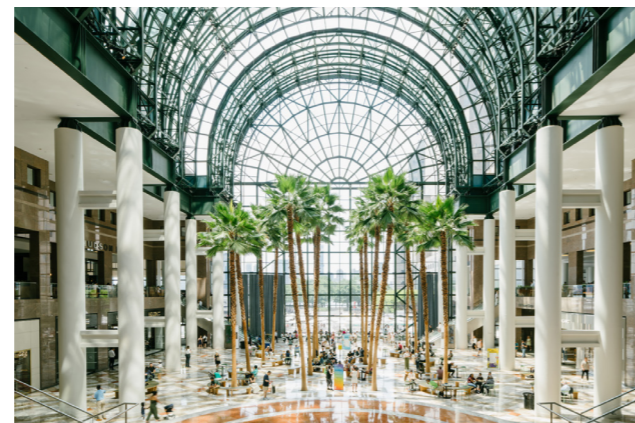


Figure 227. Design Precedent - Winter Garden at Brookfield Place in Toronto (Brookfield Place, 2025)

Figure 228. Street transformation into “Community Shopping Streets” illustrated in sections and plans

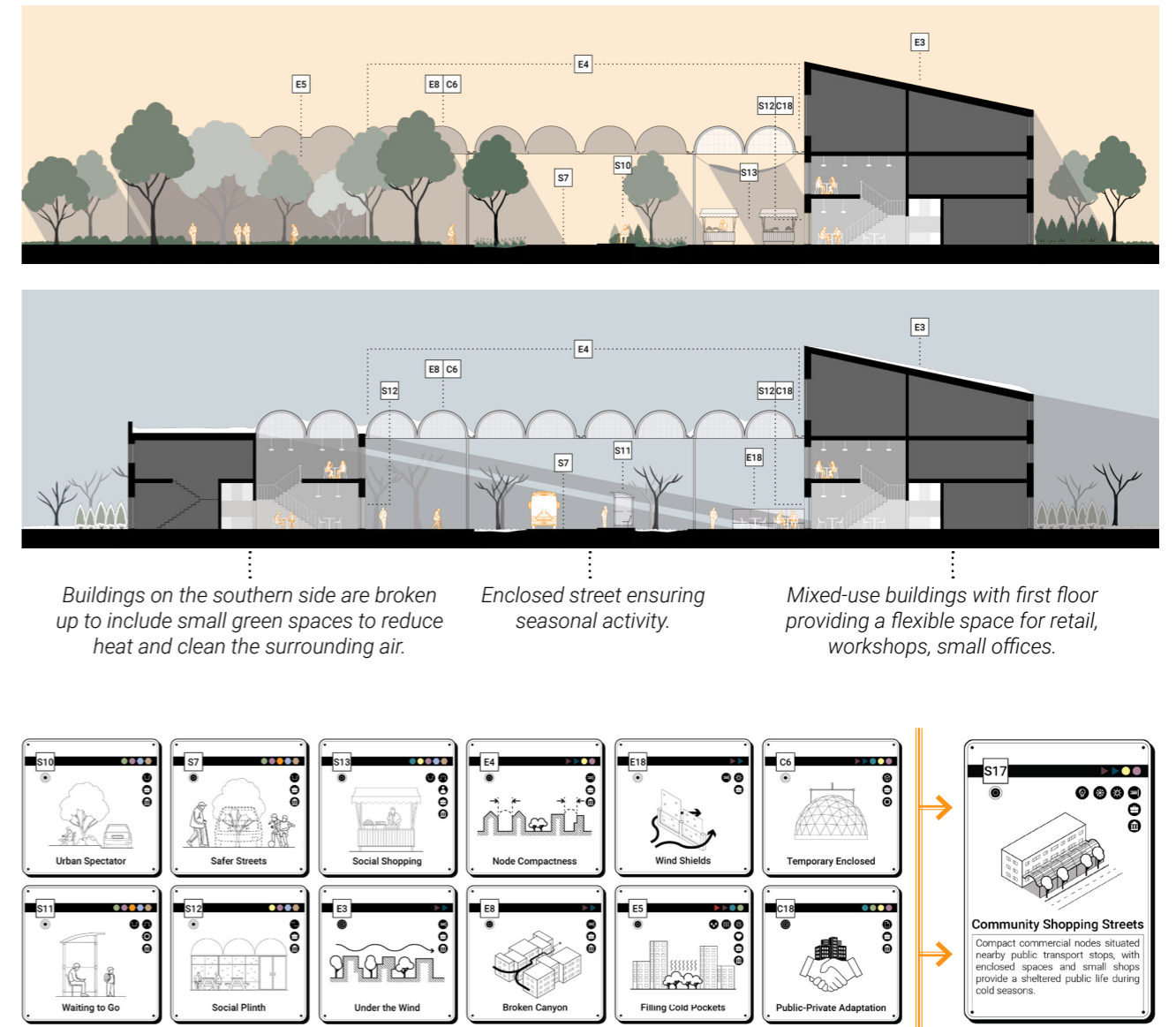


Figure 229. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Adaptation Design | Sanctuary Routes Goal

### New Developed Pattern – Traversable Landscapes

To develop the Traversable landscapes pattern, the major infrastructure and movement corridors as well as large nature structures were chosen to be adapted to include alternative mobility options to ensure higher accessibility and safer mobility during heatwaves, while improving and expanding the current public transport systems to be more robust during extreme cold.

The new pattern emphasises varying adaptation approaches to movement according to temperature extremes. To ensure mobility in winter, public transport is expanded not only in primary neighbourhood arteries but also secondary roads traversing the residential communities. The currently paved two lane corridors are transformed into a shared one-way cycling and public transport lane with dedicated elevated walking paths, that cover underground infrastructure lines and possible future district heating pipes that could be used to heat the pavement. The one-way street is partially paved for cyclists while the left section for vehicles is permeable and gradually transitions into dedicated space for greenery. This space not only infiltrates rainwater maintaining pedestrian movement during pluvial flooding, but it also provides a space to push and store snow. The residential streets become more prepared for all climate extremes. However, as these corridors lack enough space for large trees and low-rise building do not provide adequate shading during heatwaves, alternative paths should be used. Spaces adjacent or within larger natural elements, such as rivers and forests, can be used for slow mobility. Ensuring the least interference to ecological systems, pedestrian and cycling routes can be planned traversing through natural spaces. By designing paths following the edge of a lake or through a forest clearing, it not only provides cooler movement corridors for their users but also a more pleasant environment to reach one's destination. Larger openings between residential spaces and nature are designed as collective public spaces by including leisure, sport and recreation spaces, strengthening the integration of nature paths into the mobility system as well as providing more public functions into a limited neighbourhood.

With this new solution pattern, adaptation for both extremes is achieved by balancing and designating movement corridors across the district, that prioritise addressing one extreme or the other, to create intersecting seasonal movement structures.



Figure 230. Project Precedent - Covered stairs in Trails, Canada (Bertrand, 2020)

Figure 231. Natural space and narrow corridor transformation into "Traversable landscapes" illustrated in sections and plans

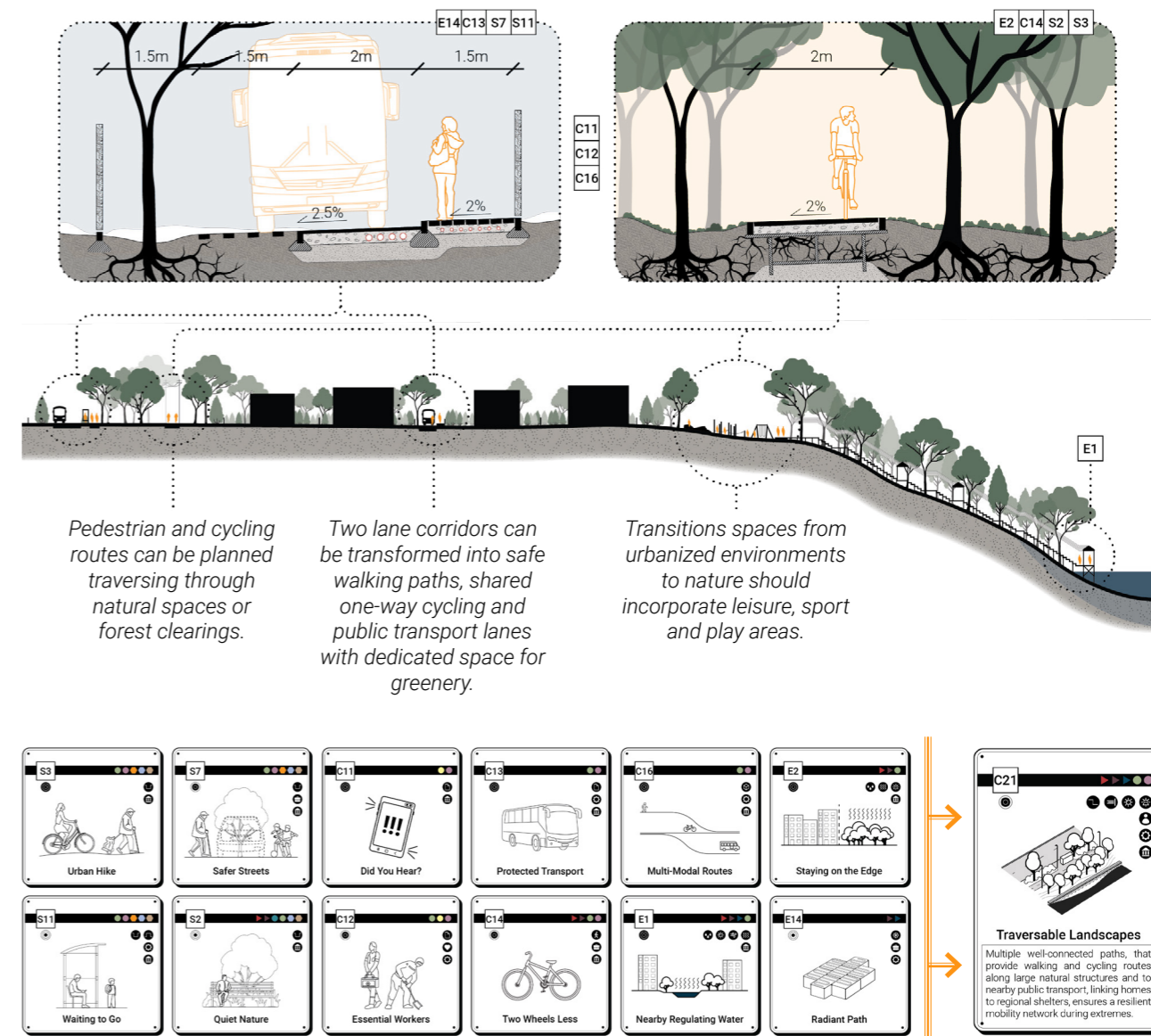


Figure 232. New developed Pattern, by integrating previous patterns within the Adaptation Strategy

## Conclusion | Site 03

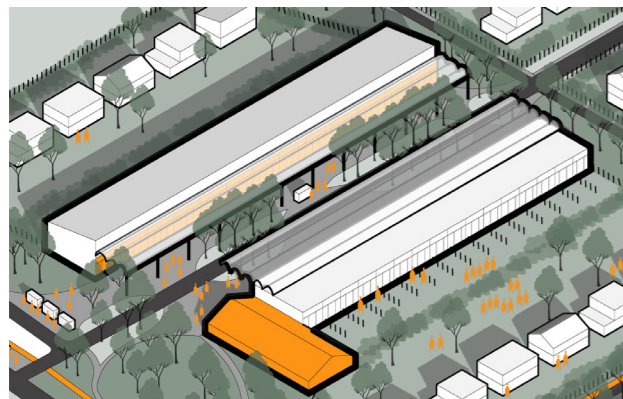
### Open Low-rise Climate Adaptation

To conclude on the newly developed adaptation strategies for an open low-rise LCZ, the newly developed adaptation patterns were compared to one another by their temperature extreme mitigation, implementation difficulties and were sequenced and designated to an adaptation type related to a specific temperature extreme and their risk degree and requirements, seen in the axonometric drawing on the right.

As all these patterns are situated within an open low-rise zone, which has very low built density and large open undeveloped spaces. This means that usual financing options are difficult to apply, as developers have little economic incentive to develop public amenities in low population density neighbourhoods, while large sprawling spaces are difficult to strategically adapt with a limited city budget. One feasible option would be a top-down densification and creation of small, dense urban hubs with concentrated retail activity, developed through private-public partnerships. By strategically clustering mixed-use developments, these hubs can attract private investment, while also offering residential units. With this financing option, the responsibility is on private actors and the city to create and maintain climate resilient spaces.

Alternatively, a more decentralised approach could include organizing resident participation and co-financing models, particularly in low-density or single-family home neighbourhoods. With the city's support in the form of subsidies or incentive programs, residents could collaborate together to fund and maintain more resilient surrounding spaces. This community-based adaptation path highlights social cohesion and enables effective small-scale transformation. Additionally, new single-family home construction, that is expanding the urban sprawl, would be strictly regulated to follow passive design principles and dedicate space for collective use to integrate adaptation strategies into the construction sector.

Private sector financing option transforms the urban form and space, shifting the space's temperature vulnerability, while local participatory funding fosters community bonds and shared responsibility. These influences the chosen Adaptation goals for better or worse, suggesting that adaptation budgets, created through spatial transformations or by community-led engagement, require to be considered, when planning urban adaptation.



Increasing density and allowing mixed-use buildings in low-rise urban environments

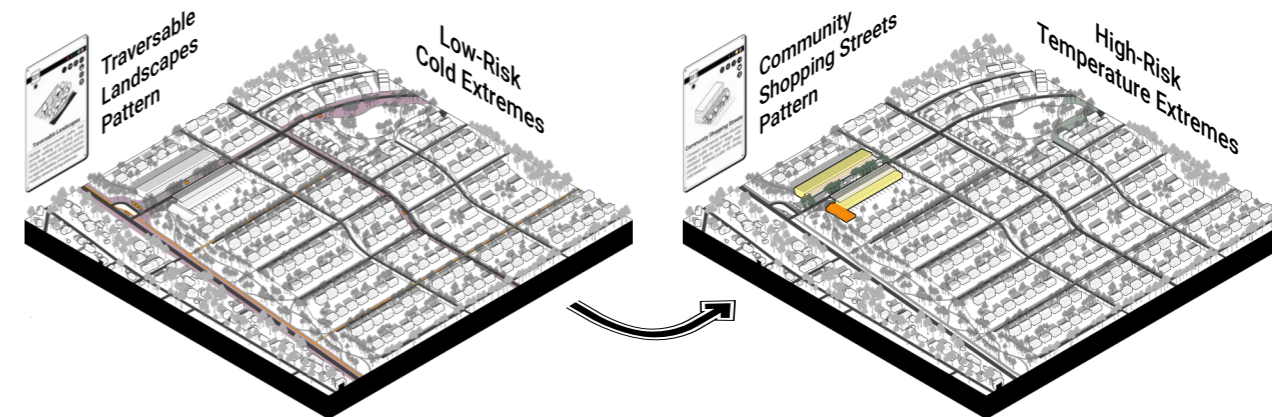
Accessible amenities (*higher adaptive capacity*)  
Higher built-up proportion (*higher heat exposure*)



Engaging local residents in participatory funding schemes and regulating development area requirements

Higher community engagement (*higher adaptive capacity*)  
Improved energy efficiency (*lower sensitivity*)

Figure 233. Open Low-rise LCZ climate adaptation financing options

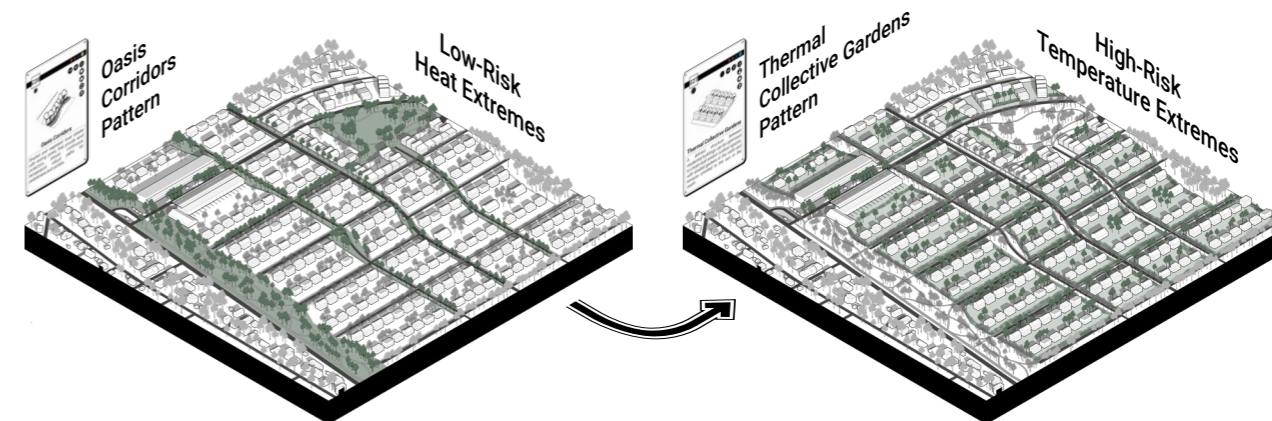


Incremental adaptation for Low-Risk Cold Extremes

Traversable landscapes designed for the Sanctuary Routes Goal is an incremental adaptation strategy that allows people to safely move through their neighbourhood and reach regional shelters in **occasional cold extremes**. This adaptation approach increases the current adaptive capacity as a supporting strategy for low-risk extremes, by expanding the public transport network into the residential streets, which are occasionally operated by minibuses in these LCZs.

Transformative adaptation for High-Risk Cold Extremes

Community shopping streets designed for the Shelter-in-Place Goal is a transformative adaptation strategy, which provides residents with a shared indoor shelter to protect themselves during **frequent extremes**. This adaptation approach transforms the current development tendencies to address high-risk temperature extremes, by integrating dense developments to create amenity, shelter and public space hubs, currently not present in these LCZs.



Incremental adaptation for Low-Risk Heat Extremes

The Oasis Corridors designed for the Comfort Trails goal is an incremental adaptation strategy, which allows people to move through their neighbourhood without being isolated indoors in **occasional heat extremes**. This adaptation approach increases the current adaptive capacity as a supporting strategy for low-risk temperature extremes, by expanding greenery and connecting the large natural elements already present in these LCZs.

Transformative adaptation for High-Risk Heat Extremes

Thermal Collective Gardens designed for the Community Refuge Goal is a transformative adaptation strategy, which requires individual homes to follow strict development area constraints to reduce the impact of **frequent extremes**. This adaptation approach transforms the current development tendencies to address high-risk temperature extremes, by structuring the development of residential houses to create courtyards from private parcels, currently not present in these LCZs.

Figure 234. Open Mid-Rise LCZ interventions dependant on future risks

## Adaptation Implementation

### City Adaptation Timeline

A broader perspective, including the whole urban context as well as a dedicated timeframe, is necessary, to plan and implement the integrated site-specific adaptation strategies across the city. The combined patterns used to create these adaptation strategies, can be broken down again into their separate design elements, that simplify the complex spatial structures and allow to plan the implementation timeline strategy, which outlines the adaptation pattern sequence, their smaller interlinked clusters and their influence across the different integrated patterns. For the three examined Local Climate Zones, an implementation strategy was developed up until 2100. A large portion of the patterns were extended further than 2050, especially patterns containing designs with greenery, as adaptation is a continual endeavour to the changing environment, even after reaching net-zero emission goals set by the Paris Agreement (UNFCCC, 2015). The timeline also, shows that some patterns stimulate and boost the implementation of other pattern, making it an interconnected system that provides an easier execution, when applying many different adaptation strategies.

### City Adaptation Plan

The Local Climate Zone specific adaptation strategies were upscaled and applied to other similar urban climate contexts, illustrating a possible approach to developing a city-wide adaptation plan, from smaller concrete design solutions.

#### Legend

- Public space transformations in Compact Mid-rise LCZs:
  - In-fill Parks adaptation pattern spatial structure
  - Heat-proof Canyons adaptation pattern spatial structure
- Public space transformations in Open Mid-rise LCZs:
  - Garden Communities adaptation pattern spatial structure
  - Oasis Corridors adaptation pattern spatial structure
  - Schools for Everyone adaptation pattern spatial structure
- Public space transformations in Open Low-rise LCZs:
  - Thermal Collective Gardens adaptation pattern spatial structure
  - Community Shopping Streets adaptation pattern spatial structure
  - Traversable Landscapes adaptation pattern spatial structure
- Low-Intensity Built-up areas
- High-Intensity Built-up areas
- Infrastructure Corridors
- Water Bodies
- Green Spaces

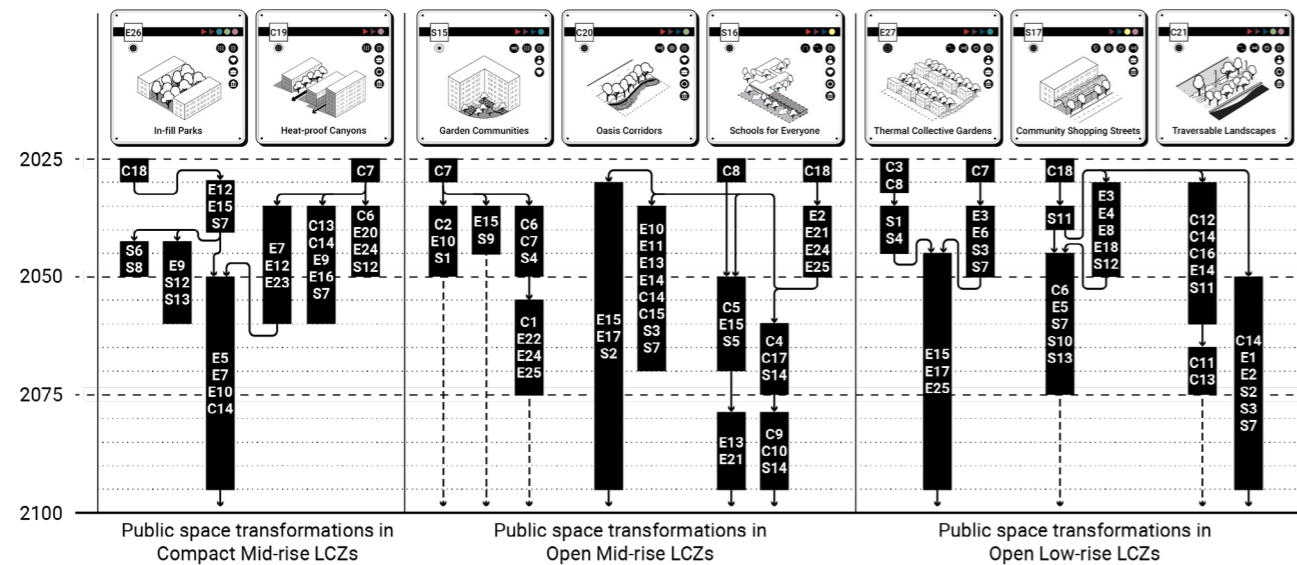


Figure 235. Pattern implementation timeline strategy, illustrating the implementation order of patterns to achieve the integrated site-specific adaptation strategies.

Figure 236. Vilnius temperature adaptation plan, spatialising the integrated adaptation patterns.



## Pattern Implementation

After developing adaptation designs for different sites and expanding on the patterns Atlas set, two pattern fields were created to understand how these transformations can be implemented.

### Pattern Stakeholders

Clustering adaptation pattern categories to stakeholders, that are responsible to introduce and maintain these designs, demonstrates that adaptation strategies range from resident led bottom-up strategies to municipality regulated top-down transformations. All adaptation groups slanted towards top-down strategies illustrate, that, while residents can provide local changes, these projects require help, supervision and could be strategically reproduced in other similar cases by regulating bodies. Other clusters reveal, that to implement Exposure Reduction patterns, which transforms urban form elements, they rely on private-public partnerships to generate funding, to establish Social Well-being patterns, which maintain the most social collective spaces, requires community involvement, and lastly, Coping Network patterns, that ensures adaptive capacity, mobility and functioning temperature shelters, are dependant on public services. This distribution signals, that pattern implementation requires various stakeholders and their cooperation to achieve urban temperature adaptation.

### Network of Patterns

Throughout the process of designing public space adaptations and integrating various patterns into space, four possible relations between patterns were established. These relations link patterns that are complementary, conflicting, can be considered as alternatives to one another or embedded within another. Complementary links illustrate that adaptation patterns provide benefits across the different pattern categories and informs the users of the Atlas, which patterns synergies. Most of the conflicting and alternative links were found between Exposure Reduction patterns, focusing on opposite extremes. Here the links show, which patterns diminish each other's effect and provide alternatives to deal with a specific temperature extreme. And lastly, Coping Network patterns were found to be more likely embedded within other pattern categories, showing the required initial pattern to achieve the desired adaptation design.

The full pattern field and all pattern links can be examined on the KUMU website, accessible by the QR code.



Explore the full Pattern Field Here

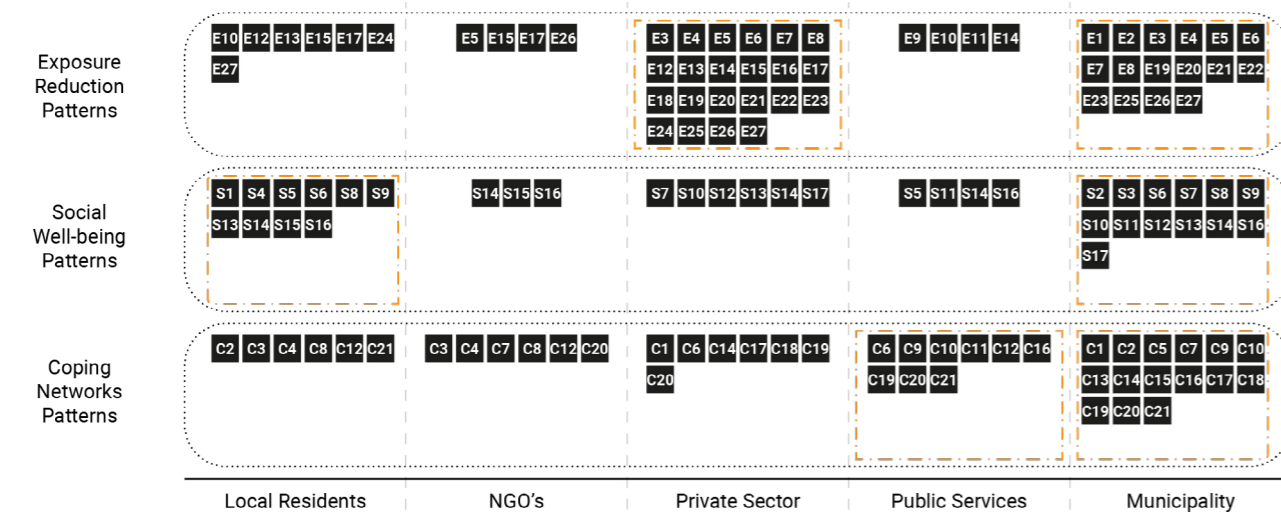
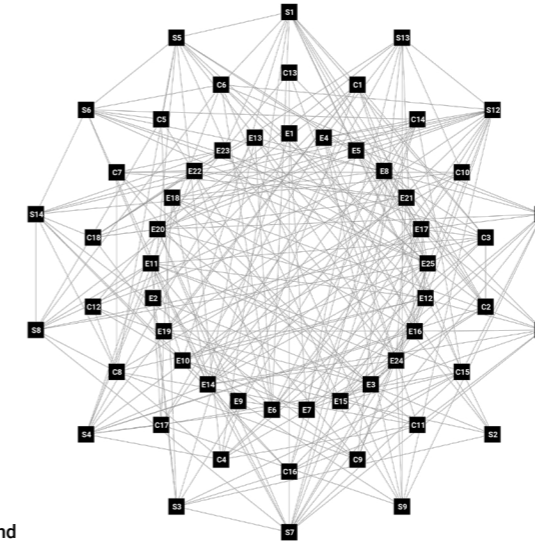


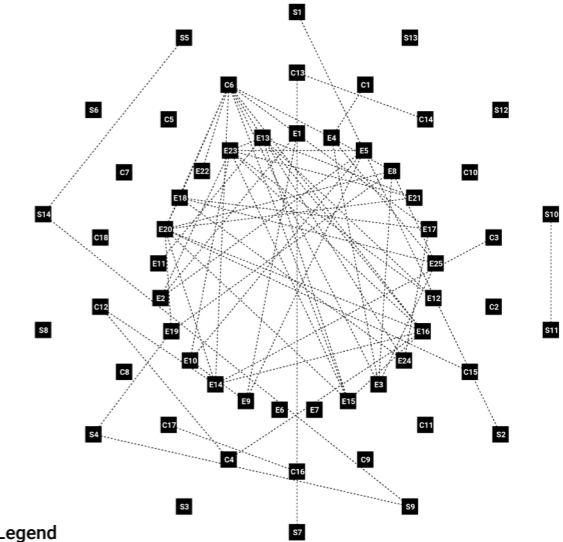
Figure 237. Pattern field, plotting the patterns to their respective responsible implementation stakeholders

### Complementary Patterns



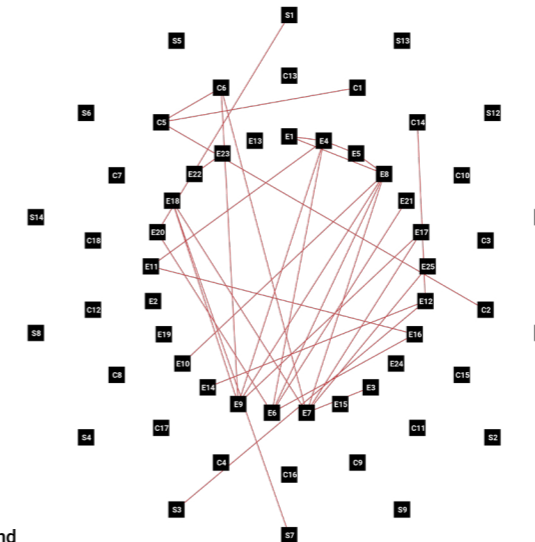
Legend  
 ■ Adaptation Patterns  
 — Complementary Patterns

### Alternative Patterns



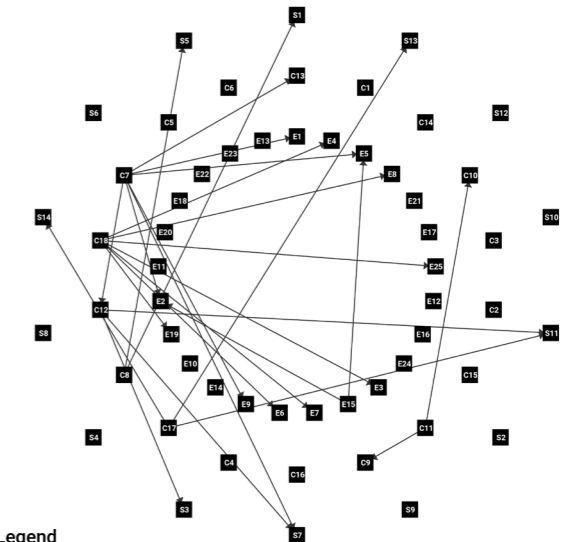
Legend  
 ■ Adaptation Patterns  
 - - - Alternative Patterns

### Conflicting Patterns



Legend  
 ■ Adaptation Patterns  
 — Conflicting Patterns

### Embedded Patterns



Legend  
 ■ Adaptation Patterns  
 → Embedded Patterns

Figure 238. Network of Patterns pattern fields, illustrating the four relationships between patterns

# 07

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## Evaluation

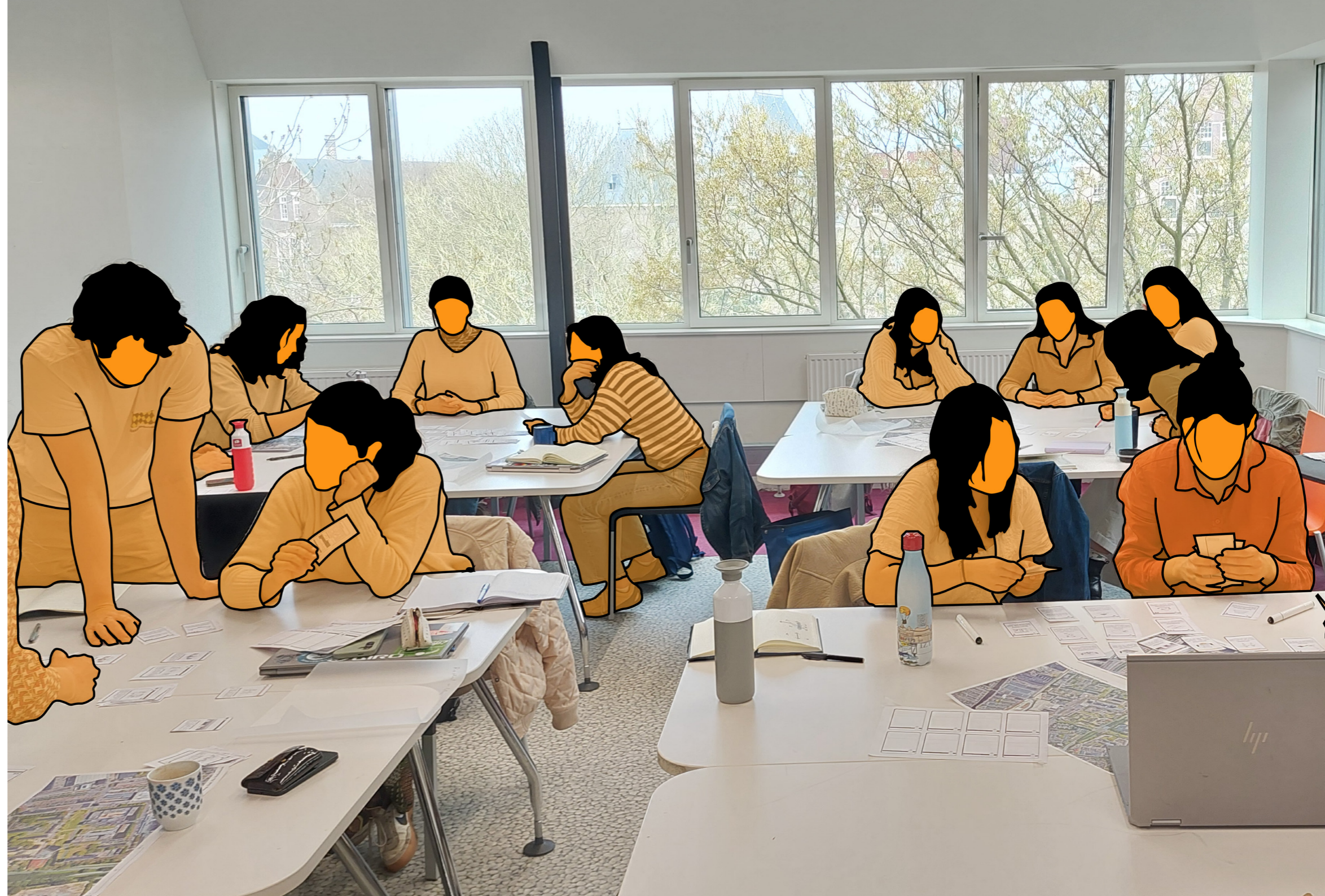
Pattern Language Workshop

ENVI-met Simulations

## Pattern Language Workshop

To evaluate the developed pattern language set and its functionality, a design workshop with urbanist master students was set. The workshop was used not to analyse their designs but examine how is the developed pattern set used to generate ideas, understand concepts, as well as how it can be used as a communication tool. By allowing other people, in this case students with a design background, to use, explore, analyse and design with the patterns, new insights can be realised as well as current weaknesses spotted.

14 students participated in the workshop on the 25th of March 2025, which was part of the Pattern Language teaching intensive course.



**Figure 239.** Photo of students participating in the Pattern Language workshop, conducted on 25th of March 2025.

### The Workshop Set up

As the workshop was set on limited time, there was a balance required to maintain between explaining the intended usage of the patterns to quickly get the participants up to speed, while also leaving some design aspects for them to explore.

For this reason, before the workshop a small presentation was delivered, explaining the graduation thesis, the theme of the patterns, and the general design framework steps beginning with adaptation goals that lead to specific solution patterns, their use for analysing the current situation and their application to improve the spaces. After the presentation, the participants were given some time to familiarise with the developed solution patterns. The thesis designs were not presented for the participants to not lead them to any specific design paths. This was also tested to see if similar methods of pattern interactions and conflicts would be seen and applied.

From here the participants were divided into four groups that all shared one location but varying adaptation goals.

### The Site and Objective

A specific neighbourhood, Poptahof, was chosen in Delft, to ensure that the participants, students of the TU Delft, were knowledgeable of the space and would allow them to analyse and redesign the space quickly and more confidently. The neighbourhood was also chosen for its similar characteristics to the Vilnius's micro-districts, as it is a high population density, 1960s modernist housing district (Urban Green Blue Grids, 2004).

To test the adaptation goal connection variety to solution patterns, the adaptation goals were chosen for each group, shown on the next page. Specific goal sets were chosen to provide a wide range of required adaptations. While an initial temperature vulnerability analysis would be required, the participants were instructed to consider the goals as their main temperature problem of the areas.

All of this set the workshop in motion, as the participants were not exploring the Poptahof neighbourhood with patterns through the lens of their given adaptation goals.

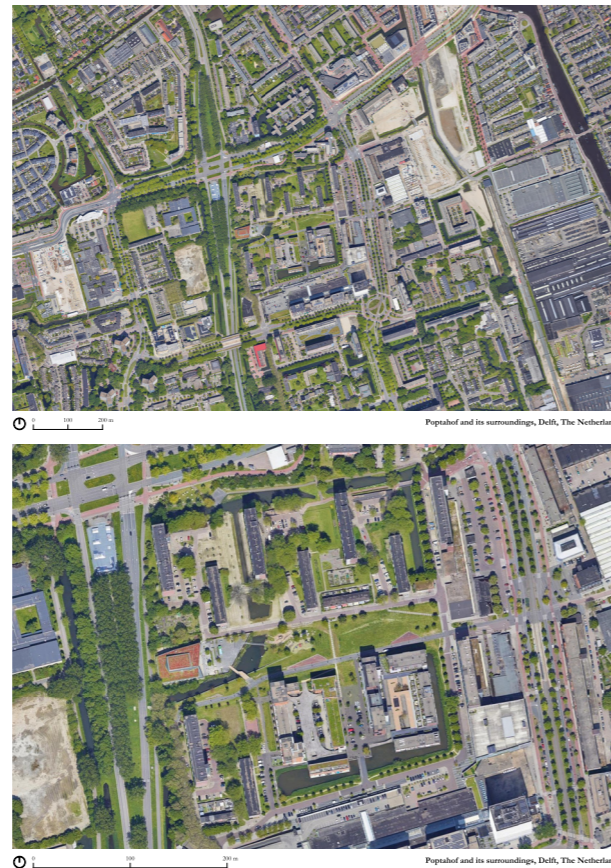


Figure 240. The given location to explore and test the pattern language - Poptahof, Delft, The Netherlands.

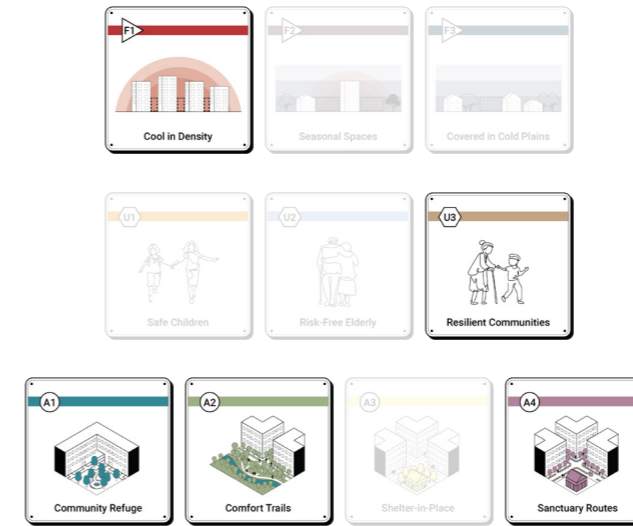


Figure 243. Group 01 – Designated goals to test the patterns

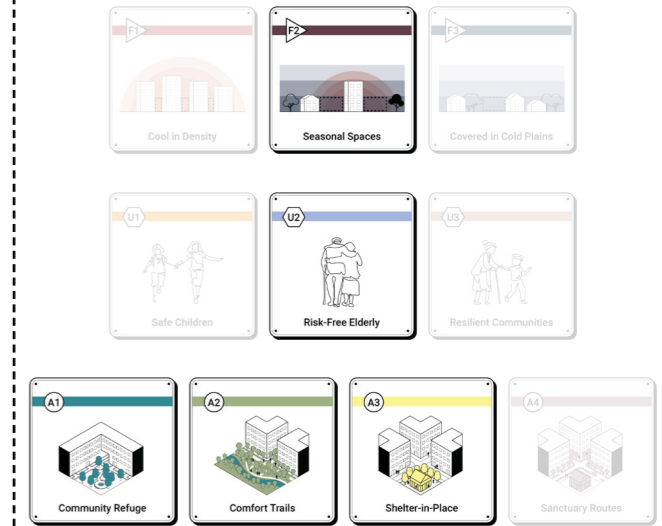


Figure 244. Group 02 – Designated goals to test the patterns



Figure 241. Group 03 – Designated goals to test the patterns

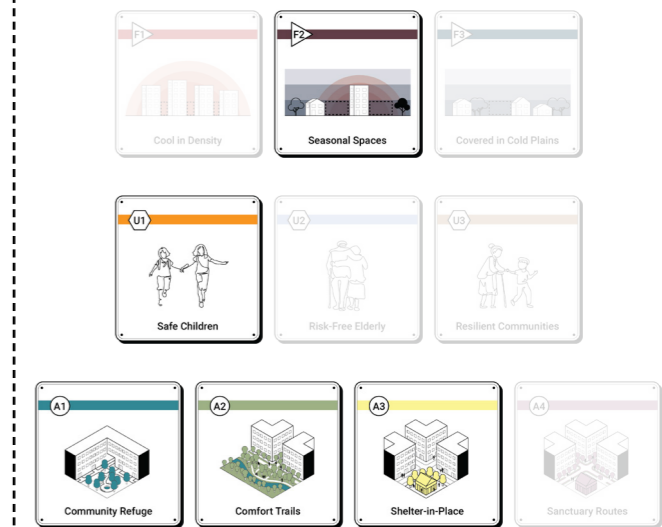


Figure 242. Group 04 – Designated goals to test the patterns

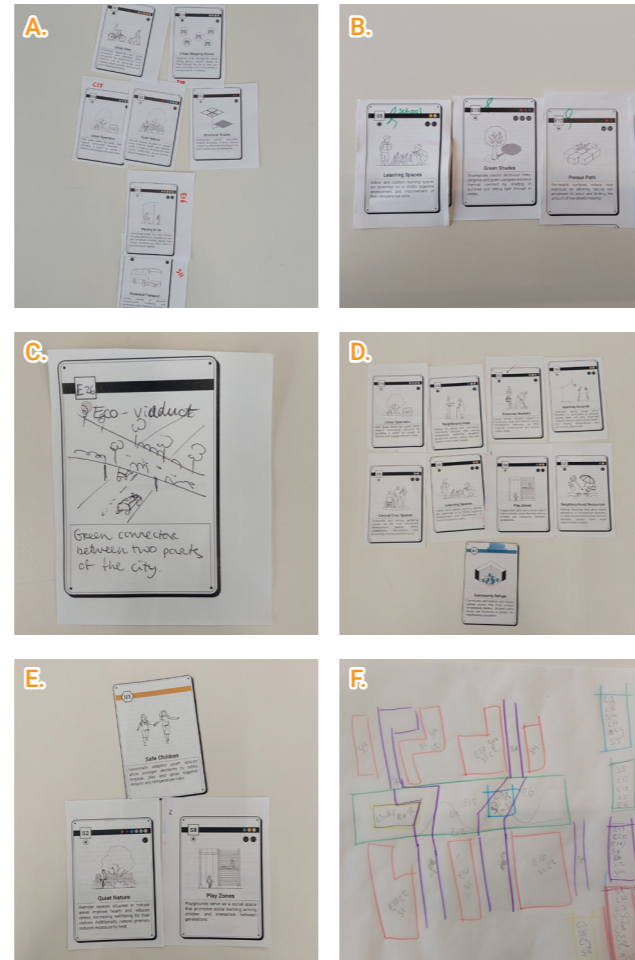
### The Pattern Usage

The participants were given an hour and 15 minutes to analyse and adapt the given neighbourhood to their goals. After this allocated time, there was a 15-minute reflection period, where the participants presented their designs, explained their pattern usage process and reflected on general questions on how to design with patterns. After their brainstorming sessions, their workspaces were photographed to see how the arrangement and placement of patterns were used in their designs, shown on the next page.

Their workspaces showed four main types of clusters, that can be considered as connections between the patterns. All four groups had a designated pile of discarded patterns that were “unapplicable” to their site or were not needed for their adaptation goals. Every group had clusters of patterns that were similar or provided synergies to one another, although some groups found the patterns to be compatible in larger groups, while others saw smaller separate interventions. In each case, there were a few individual patterns, that lacked spatial implementations, were more of a stakeholder engagement pattern or were considered as an all-encompassing pattern, that could not be applied to one or the other cluster. These individual patterns, require an additional consideration and a possible redesign to strengthen their practical and spatial implications. And lastly, one group improved on the clustering of pattern by placing them into a hierarchy structure, as they saw that some patterns were more important or could be considered as the main “non-negotiable” pattern for others to work and improve the highest ones.

With further examination of their pattern clustering, 6 type of pattern usages were seen illustrated on the right. Only two new patterns were created by the participants: Eco-viaduct and Woonerf, as the pattern set was quite extensive. All of these patterns use methods were reflected and required changes brought back into the pattern set, with some patterns requiring a redesign, while others an alternative name or a clearer explanation.

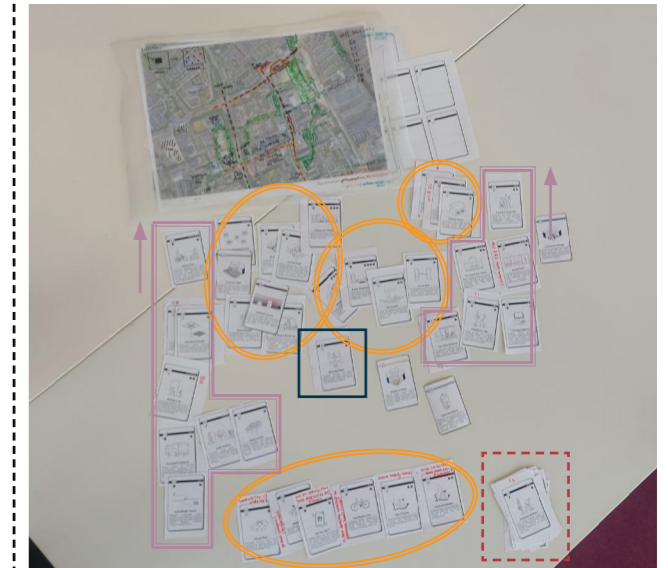
- Discarded pattern pile
- Clustering of similar or beneficial patterns
- Isolated individual patterns
- Ordering the importance and steps between the patterns



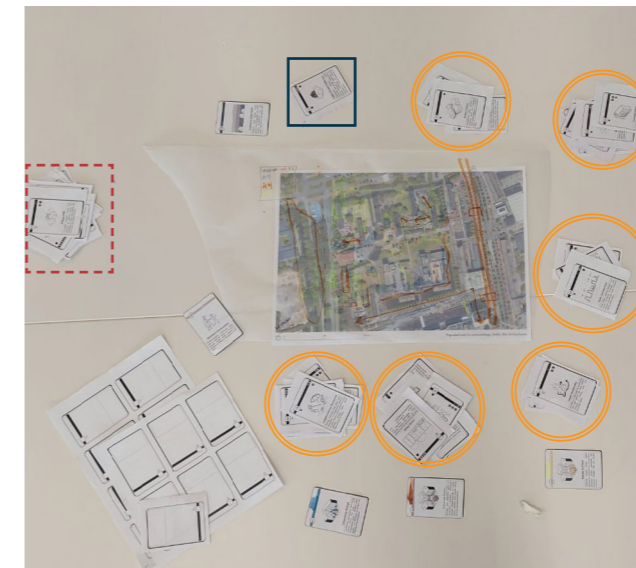
**Figure 245.** Various uses of the patterns during the workshop:  
 A – Creating hierarchies between patterns;  
 B – Linking synergies between patterns;  
 C – Developing new patterns;  
 D – Selecting patterns that answer a specified goal;  
 E – Finding compatible patterns;  
 F – Zoning the patterns to spaces.



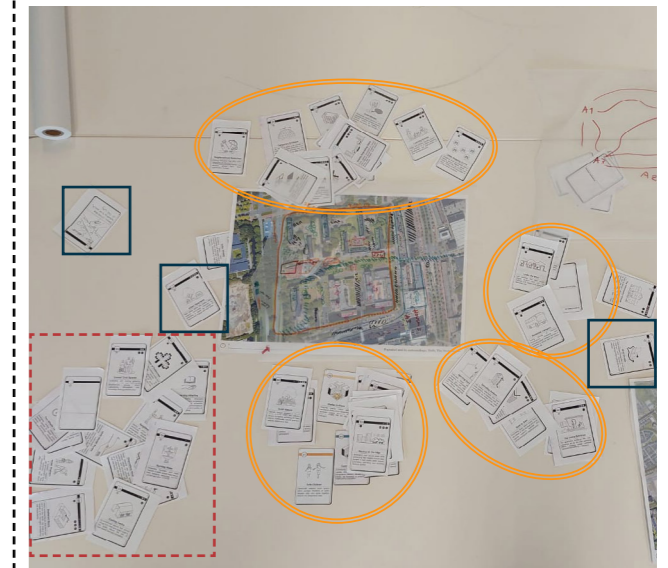
**Figure 247.** Group 01 – Workshop workspace and the use of patterns and their connections



**Figure 249.** Group 02 – Workshop workspace and the use of patterns and their connections



**Figure 246.** Group 03 – Workshop workspace and the use of patterns and their connections



**Figure 248.** Group 04 – Workshop workspace and the use of patterns and their connections

### Workshop Conclusions

With the various pattern design methods, the four groups created space adaptation designs, by following the given adaptation goals.

The final results, shown in the next page, illustrate a wide range of scale utilisation, with 2 groups working primarily on the micro-scale adaptation, one group preferred designing on the local-scale, by implementing patterns, that expanded further then their given space. The last group worked through the scales, beginning with the larger adaptation framework, in which they created a walking path, connecting the neighbourhood to its surroundings, and then zoomed into the given space to better illustrate a part of the path.

While the given adaptation goals were chosen to be different, the participating groups were all led by similar pattern themes and implications. All group designs, even the third group's, which had adaptation to extreme cold, included greenery. By increasing the current green zones, planting new vegetation or ensuring a direct route to these spaces, patterns relating to greenery were the most dominant. For the patterns' sensitivity aspect, the groups analysed the neighbourhood by marking social spaces related to their adaptation goals. Two main design options were undertaken: strengthening the current social spaces by reducing their exposure, and placing new social and physical well-being areas, such as community house or children and young adult running path, encircling the neighbourhood.

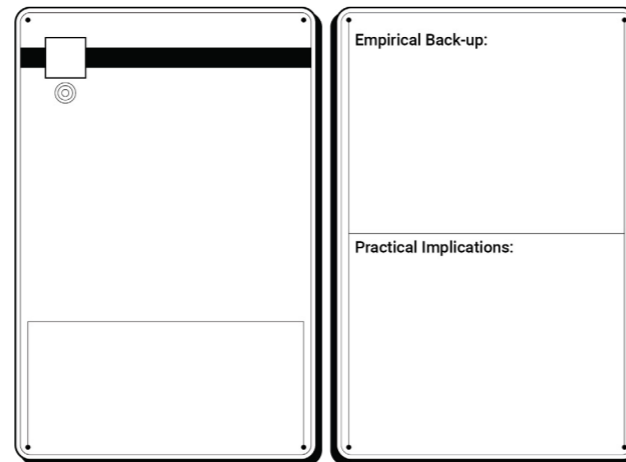
All of these results indicate that the developed pattern language provides designers with rules to design a wide range of possible temperature adaptation choices, which are justified by literature or observations.

### Feedback Reflections

The final part of the workshop was a small reflection, not only on their designs but on the patterns themselves. The biggest take aways were the links between the patterns. In the design process, each group found it necessary to not only understand, what the pattern implies, but also if the pattern could work together. This allowed the participants to deepen their understanding of a particular pattern by comparing it to others. However, a more abstract pattern, such as Temporary Enclosed (C6), was difficult to link to other patterns, which if

it was linked before, it would provide a better understanding of a complex pattern. Similar findings were observed with conflicting patterns.

These comments led to improving the pattern language atlas by including 4 pattern linking option. The first one states complementary patterns, which provide different patterns that enhance each other's functioning. The second link provides alternatives, that have similar adaptation results and can be chosen instead of the others. The third one highlights conflicting patterns, which diminish one another and requires careful implementation to not reduce their effectiveness or avoid using them together. The last one indicates, which patterns are necessary to fulfil the particular pattern. These linking options are shown in the pattern booklet and not on the pattern cards, to allow planners and experts to use the cards as a communication tool and find alternative links.



**Figure 250.** Pattern language improvement, by including pattern fields and links to other patterns concerning their similarity, conflicts and necessities, creating stronger the interrelationships between patterns.



**Figure 252.** Group 01 – Final spatial adaptation design



**Figure 254.** Group 02 – Final spatial adaptation design



**Figure 251.** Group 03 – Final spatial adaptation design

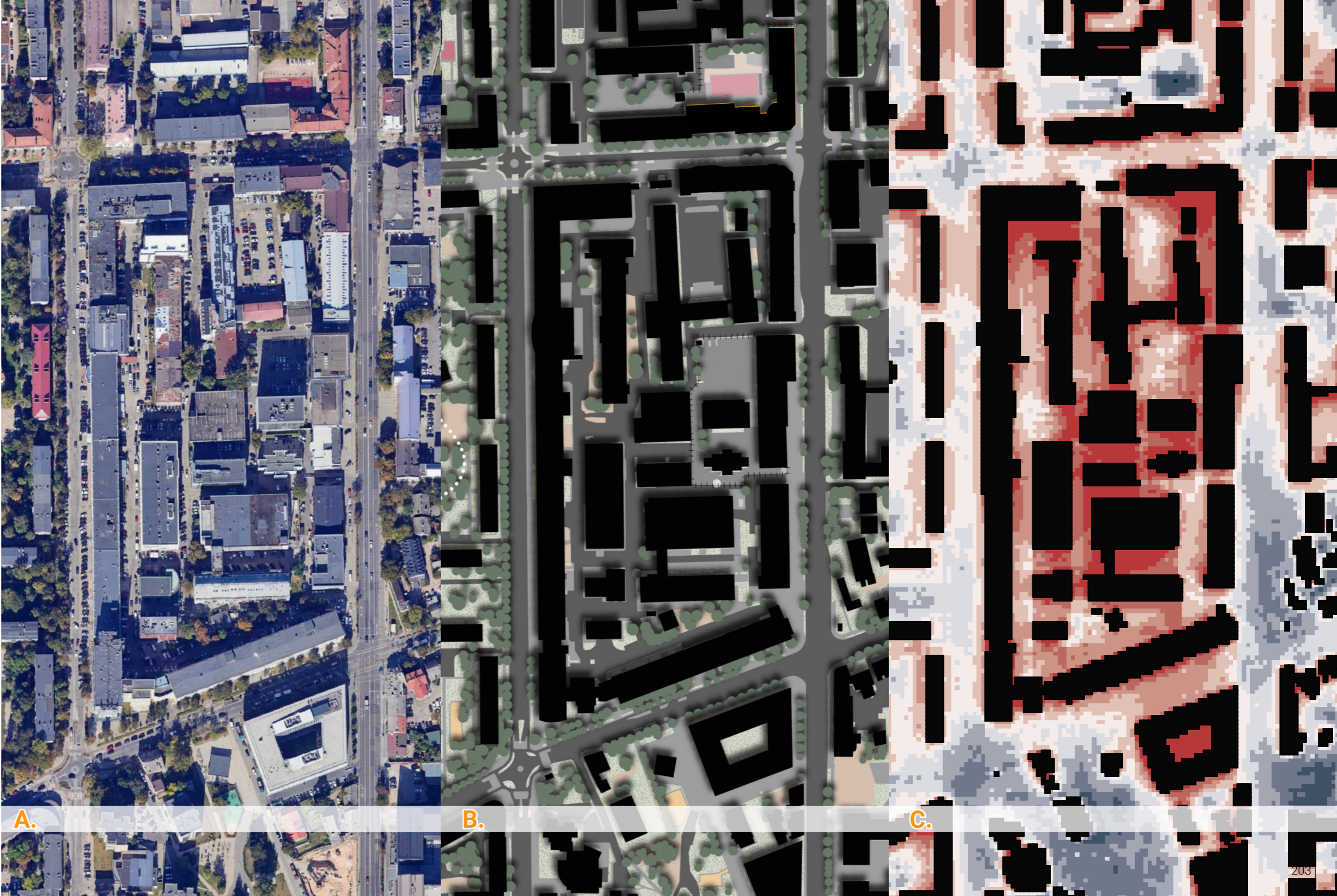


**Figure 253.** Group 04 – Final spatial adaptation design

## ENVI-met Simulations

### Climate simulations as an evaluation method

ENVI-met outdoor thermal comfort simulations were utilised to evaluate the design interventions on their ability to reduce exposure and increase adaptive capacity by creating protected paths to temperature shelters. The evaluation is done by comparing the status quo microclimate of the current built environment to the adapted environment's altered microclimate. By examining the designs reduction or increase of physiological equivalent temperature (PET) to a more comfortable range, the designs could be considered successful.



**Figure 255.** Transferring the Existing Situation into the temperature modelling software ENVI-met

## ENVI-met Simulations

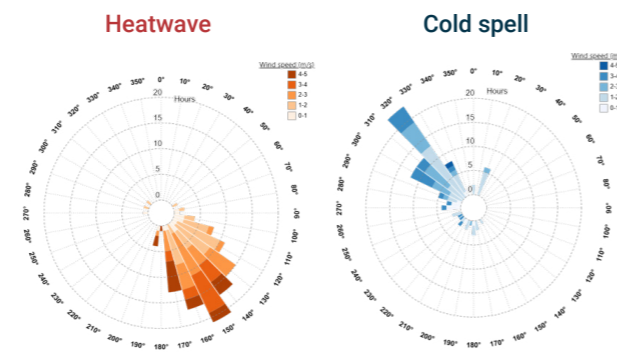
To evaluate the adaptation designs, it requires to model the spaces, input the required heatwave or cold spell climate data and lastly to extract the most relevant findings – a specific timeframe and spatial section through the simulated model.

To compare the PET value changes, each site and situation (heatwave or cold spell) had to be modelled and simulated for the status quo condition and as one possible design intervention, created in the previous chapter. Each site model was generated from in QGIS software, with data collected from Vilnius municipality data collection organisation (ID Vilnius, 2025). For sites No. 01 and 02, the resolution of the models was set to 5m x 5m x 5m grid, which allowed to simulation larger spaces, that informed how the temperature transfers through their surroundings. For the last site No. 3, as this site consists of single detached houses, the resolution was increased to 3m x 3m x 3m grid to be able to see how temperature transfers around the building.

For the climate data, which was required to input to the ENVI-met simulation, typical heatwave and cold spell scenarios were calculated, by averaging 5 extreme temperature days in the past 5 years in Vilnius, to fix an hourly temperature change across 24 hours. Hourly wind direction and speed were averaged as vectors to achieve a consistent wind direction and speed.

The final PET, wind speed, humidity, turbulent kinetic energy, which indicates areas that have high cold stress, potential air temperature and mean radiant temperature maps are shown in 1.5 m. height – pedestrian level. 2 timeframes were chosen: 14:00h, as in summer during this time heat exposure is the highest, while in winter cold exposure is the most mitigated, and 22:00h, as the UHI effect is strongest during the night (Azevedo et al., 2016).

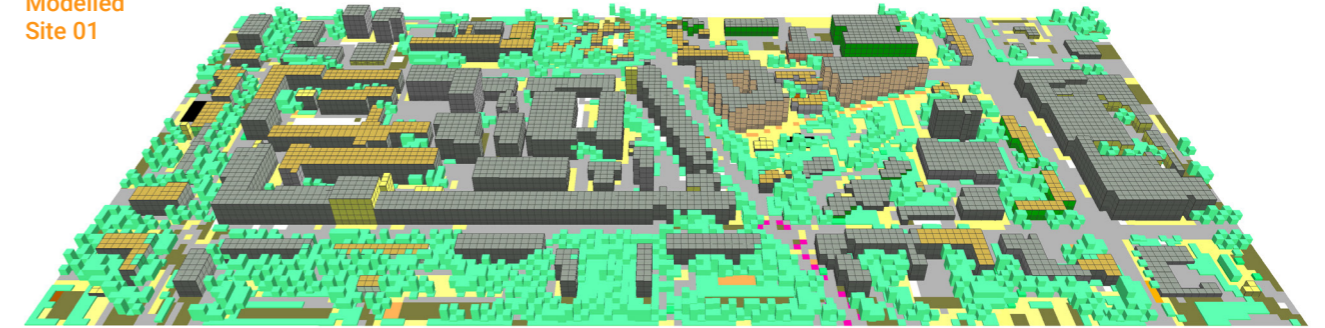
The typical heatwave and cold spell day calculations in Vilnius and all the simulation maps can be seen in the appendix.



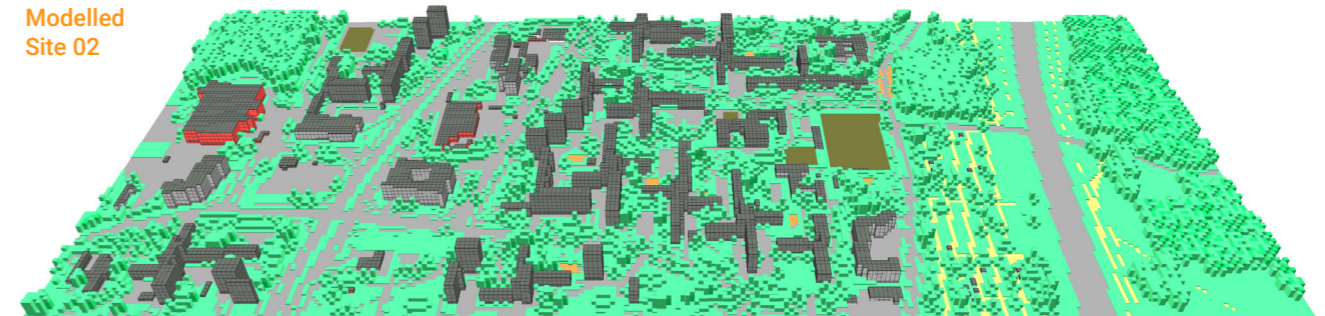
Daily Hour	Average Hourly Air Temp. (°C)	Average Relative Humidity (%)	Daily Hour	Average Hourly Air Temp. (°C)	Average Relative Humidity (%)
00:00	21.02	75	00:00	-17.12	81.2
01:00	20.34	77.2	01:00	-17.4	81.6
02:00	19.96	79.2	02:00	-18.08	82.8
03:00	19.92	79.6	03:00	-18.42	83
04:00	21.18	75.2	04:00	-18.58	83.4
05:00	22.82	71.4	05:00	-18.52	83.6
06:00	24.74	64.8	06:00	-18.52	83.2
07:00	26.84	55.8	07:00	-18.42	83
08:00	28.42	50	08:00	-18.1	82.8
09:00	29.82	44.4	09:00	-16.88	82
10:00	30.34	41.6	10:00	-15.5	80.2
11:00	30.9	39.8	11:00	-14.44	79.2
12:00	31.44	38.4	12:00	-13.68	76.6
13:00	31.42	39	13:00	-13.2	76.8
14:00	31.38	38.2	14:00	-13.62	79.4
15:00	31.22	39.6	15:00	-14.3	82.2
16:00	30.8	40.8	16:00	-15.36	84
17:00	29.46	44.6	17:00	-15.84	85.4
18:00	27.72	50.6	18:00	-16.42	85.6
19:00	25.74	58.8	19:00	-16.48	85.6
20:00	24.4	63.8	20:00	-16.82	85.4
21:00	23.62	68.4	21:00	-17.04	85
22:00	22.64	72.2	22:00	-17.58	84.8
23:00	21.94	75	23:00	-17.66	84.8
Average Wind Speed (m/s)			Average Wind Speed (m/s)		
2.20			1.60		
Average Wind Direction (°)			Average Wind Direction (°)		
150			305		

Figure 256. Climate data (hourly temperature and wind rose) used for a typical heatwave or cold spell simulation

Modelled Site 01



Modelled Site 02



Modelled Site 03

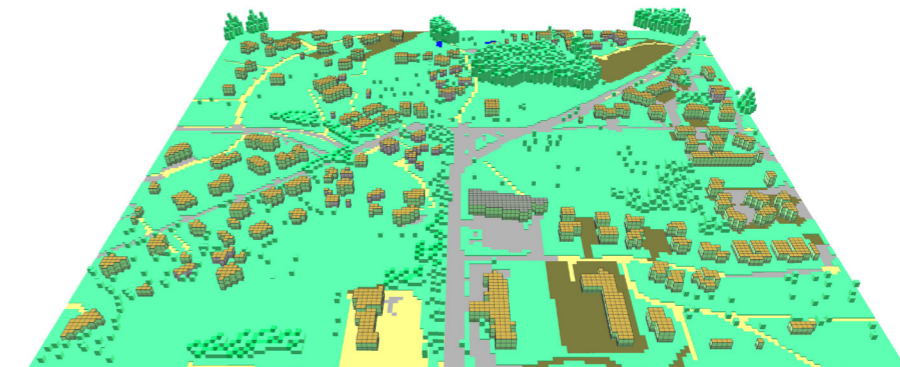


Figure 257. Modelled environments of the 3 examined sites in ENVI-met

### Evaluation of the Status Quo

From the simulations, the most relevant calculations, that explain how a person is feeling in the space, are physiological equivalent temperature (PET) values. To link this back to sensitivity, two sets of values were created, that examines how children and elderly experience temperature. As these groups' acclimatisation differs, the body metabolism parameters were taken from the ENVI-met presets, while clothing parameters, which increases or decrease heat transfer from the body and increases adaptive capacity, were set to 0.5 clo. in a heatwave and 2.0 clo. in a cold spell (Ács et al., 2024). The comparison of these findings between sites and timeframes also evaluates the undertaken analysis and further informs the general LCZ temperature vulnerabilities.

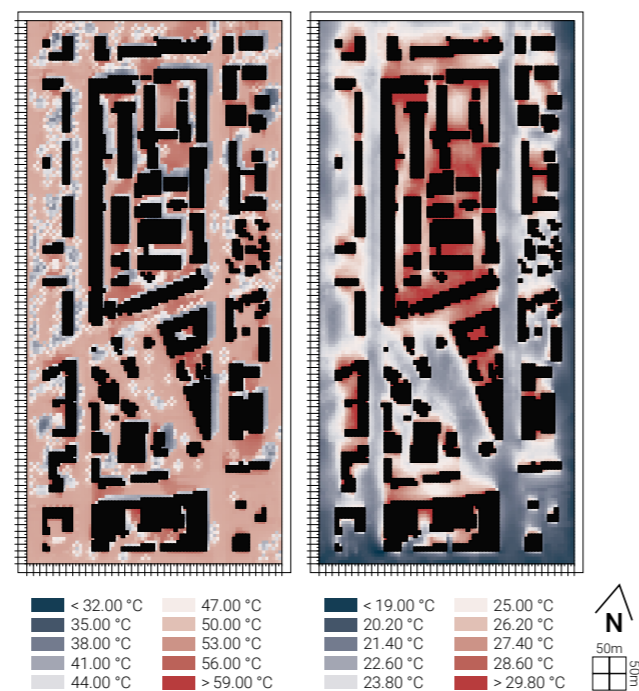
The LST indicators illustrated that compactly built environments are the most exposed to heat, open low rises are the least and open mid-rise are in-between. These simulations support, that when comparing the whole day, dense environments store heat, making the next day even worse, while open low-rise environment quickly dissipate the heat in the evening, with only spaces resembling enclosed courtyards in open mid-rise environments, which are protected from wind, entraps heat. Cold spell simulations provided more nuances to the LCZs. The meso-scale cold exposure conclusions, which stated that cold exposure is negatively correlated to heat exposure is supported in cases, when there is no solar radiation, in the evening or during a cloudy day, when the most prominent thermal factor is protection from wind. Although on sunny winter days, the complete opposite can be seen, as direct solar radiation improves thermal comfort significantly, providing open low and mid-rise environments with potential heat storing spaces.

An additional finding across the different sites was that PET values for elderly were worse than children's in the middle of the day during a heatwave, while at night and in every cold spell situation the opposite was seen. This could be theorised that elderly are more vulnerable to direct solar radiation, while children are less adapted to residual heat, although further studies are required to test these hypotheses.

Further on, each LCZ is more detailed examined to their temperature Focus and Urgency Goals, compact mid-rise compares PET values for children in a heatwave, open mid-rise compares PET values for elderly in different extremes, and lastly open low-rise compares PET values for children in a cold spell.

### Status Quo Site 01 – Naujamiestis

In compact mid-rise Vilnius environments, the high angled sun and comparably low building heights do not provide adequate shading, which could reduce heat exposure during the day (Y. Li et al., 2020). In these environments only vegetation shading provides sheltered spaces, requiring finding space for greenery. In the evening, more open spaces and straight canyons with higher winds dissipate heat more

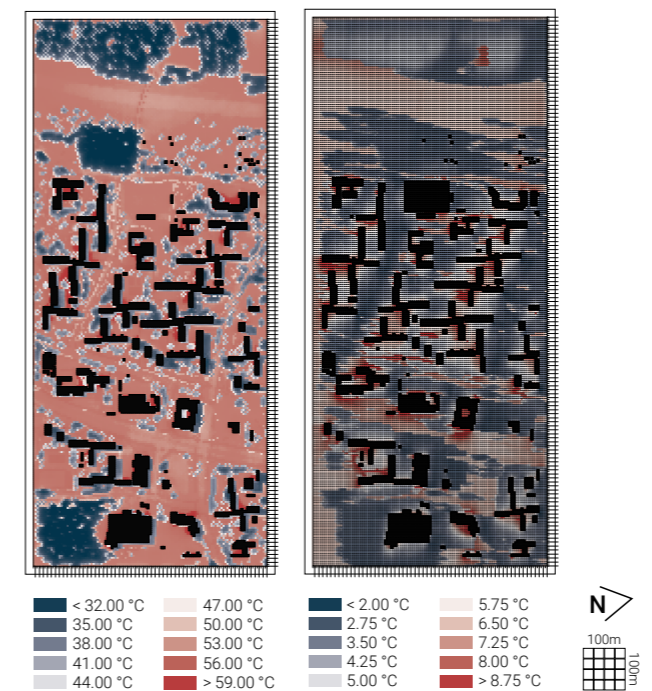


**Figure 258.** PET calculations of a typical heatwave scenario, during 14.00h (left) and 22.00h (right) for Children (8y.)

quickly than spaces with stagnant air, requiring ventilating these spaces. Limited green-blue spaces provide little humidity, resulting in dry hot spaces.

### Status Quo Site 02 – Karoliniškės

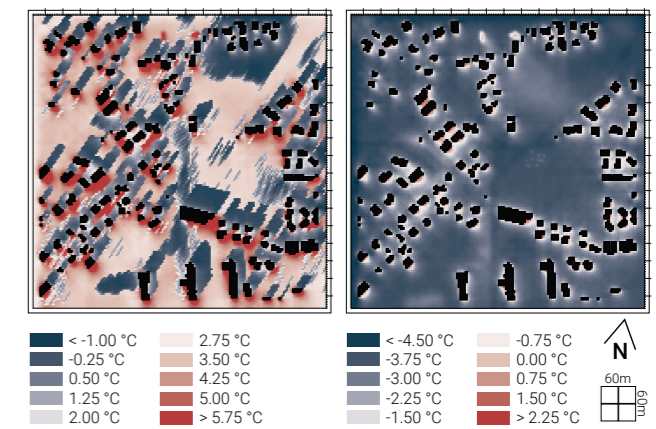
In Vilnius open mid-rise environments, while being susceptible to both temperature extremes, also provide opportunities for shelters concerning either extreme. During heatwaves larger natural spaces, such as forests, and high building heights provide shaded spaces for people to spend their time, although southern sides of buildings become dangerous overheated spaces. On the other hand, the same half enclosed southern building spaces become temperature shelters during cold spells. A balanced approach has to be taken to optimise these potential shelters and create safe passages between them.



**Figure 259.** PET calculations of a typical heatwave scenario, during 14.00h (above), and a cold spell scenario, during 14.00h (below), for Elderly (80y.)

### Status Quo Site 03 – Northern Verkiai territory

Open low-rise LCZs experience the highest diurnal change with high exposure to heat in the day and full dissipation during the night. This duality is present during heatwaves and cold spell, resulting in difficulty to manage mitigating and storing heat in the same spaces. Critical decisions have to be made in each case, to decide which spaces are categorised as shelters from heat and unusable in winter, and which could reduce cold although be too hot to use in summer. As all outdoor temperatures are dangerously low during cold spells for people to spend time outdoors, nearby indoor shelters or safe direct paths, that attempt to reduce extreme cold, to further shelters should be considered.



**Figure 260.** PET calculations of a typical cold spell scenario, during 08.00h (left) and during 14.00h (right) for Children (8y.)

## Adaptation Evaluation

### Transformed Site 01 – Naujamiestis

To evaluate how successful are the pattern spatial designs in regulating temperature extremes, a small transect, where the two patterns, developed for an compact-midrise environment, was modelled and simulated. The previous and transformed environments were compared by PET values, calculated for children, shown in the evaluation maps. The outlines mark spaces implemented with pattern designs: In-fill Parks, marked as P1, while Heat-proof Canyons were examined through the different measures applied, which were a street fountain, marked P2A, ventilated inner courtyard path, marked P2B, and two areas covered, one with sunshades, marked as P2C, and the other shaded by the extension of the building, marked as P2D. All design strategies were successful, apart the sunshades, in reducing the areas exposure to heat during the day and the night, compared to the current situation.

Beginning with In-fill parks, during a heatwave the public street previously showed PET values up to 56°C during the day and around 28°C during the night in spaces enclosed by buildings. After the transformation, the increased vegetation reduced the PET values by 23°C, significantly reducing exposure during the day. However, this transformation had very little influence for the street during the night, as the wider street was already able to dissipate heat throughout the night. The spread-out Heat-proof canyon strategies showed that, not only vegetation can reduce temperature

within an urbanised area, although these were more concentrated within smaller spaces and had a comparably smaller reduction of exposure. The established fountain, within the roundabout, showed a 7°C PET decrease above the fountain during the day and a 2.4°C PET decrease in the adjacent spaces during the night. The increased humidity provided a more comfortable space during the day and faster dissipation of heat during the night. The strategically opened up inner courtyard, provided ventilation channels, that ensured the overheating compact spaces could be provided with colder air, reducing the PET by 3-4°C during the day and night. The pushed in plinth, created an outdoor path following the building with a continuous roof and shade, that reduced PET values by 15°C during the day. This particular design element provided benefits only during the day, as it only blocks direct solar radiation. The only element, that had no influence on temperature was the fabric sunshades, however this can be reasoned as an inaccurate result from the evaluation program. The program is limited in creating a thin fabric substance that could block solar radiation, while allowing wind to move through, which in precedent studies have shown to have clear benefits for heat stress mitigation.

The evaluation proves, that vegetation and built element can reduce heat exposure. By analysing the heatwave during the day and night, it illustrates the importance to have both these adaptation strategies implemented, as they synergies their effects in reducing temperature extremes.

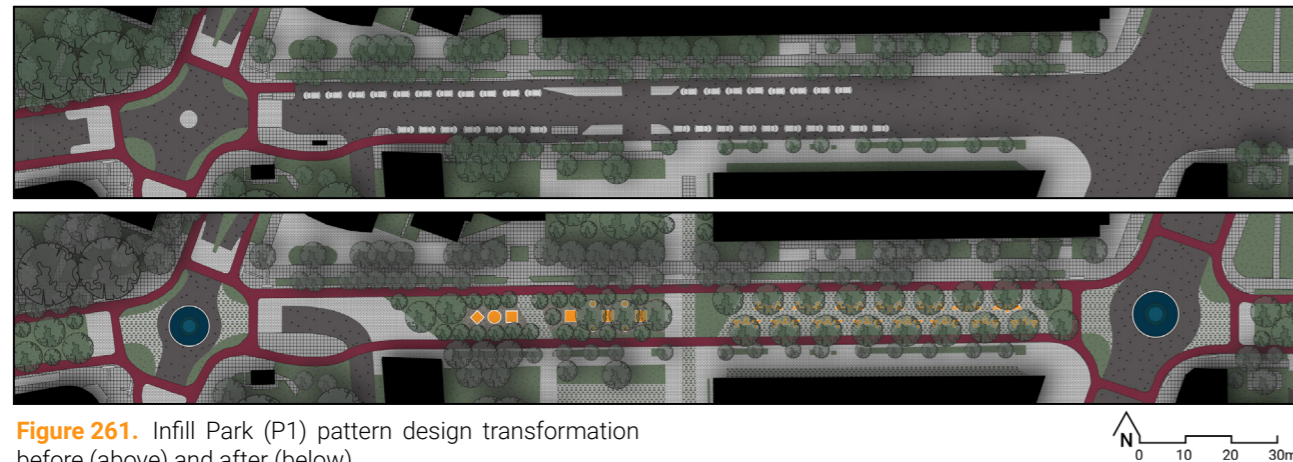


Figure 261. Infill Park (P1) pattern design transformation before (above) and after (below).

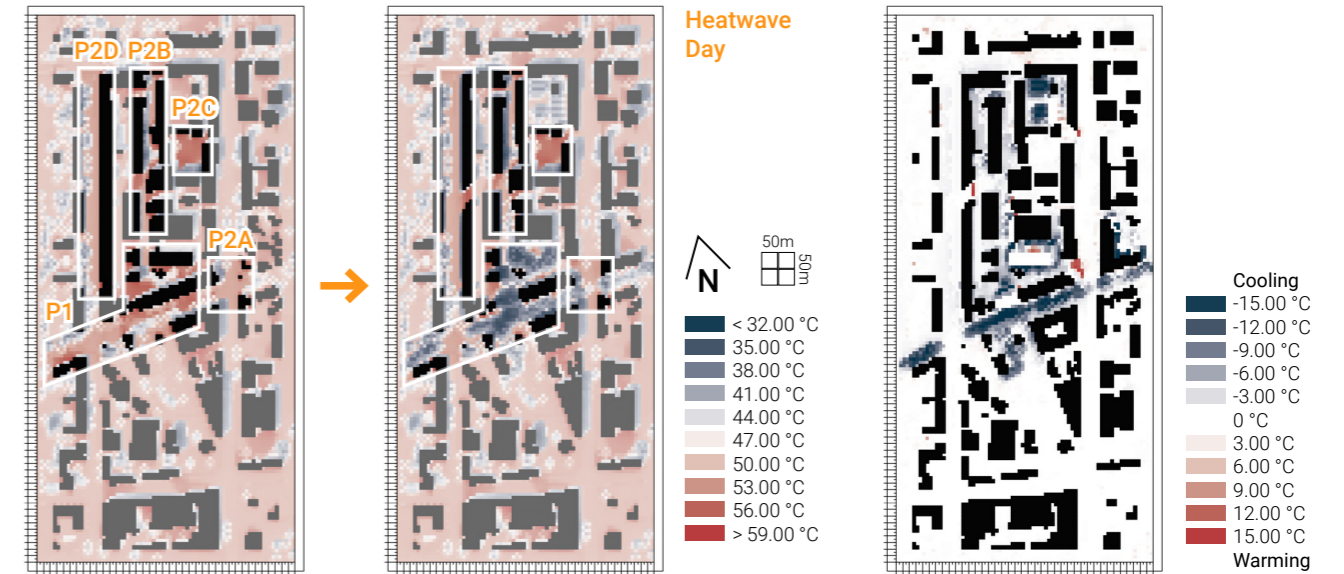


Figure 263. Evaluation Maps, illustrating PET changes of a typical heatwave, during 14.00h for Children (8y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.

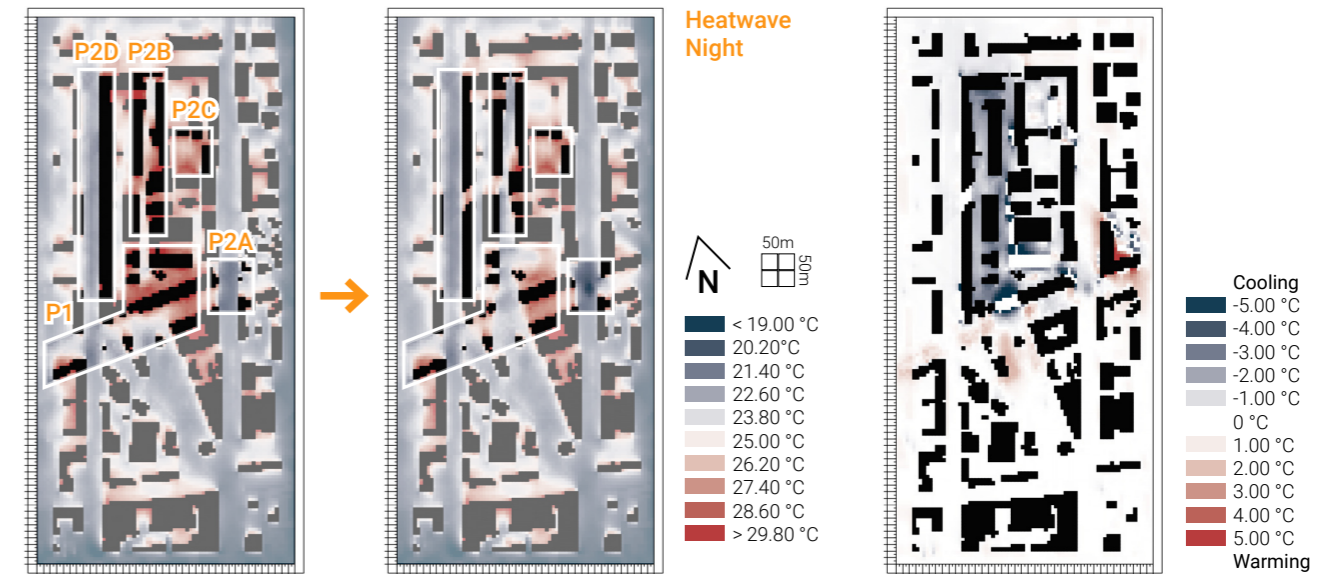
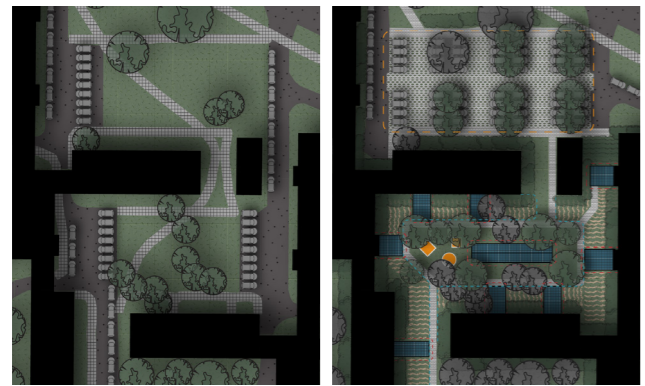


Figure 262. Evaluation Maps, illustrating PET changes of a typical heatwave, during 22.00h for Children (8y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.

**Transformed Site 02 – Karoliniškės**

An equivalent evaluation method was conducted for site no. 02, for patterns developed for an open-midrise environment. The previous and transformed environments were compared by PET values, calculated for elderly, shown in the evaluation maps. The outlines mark spaces implemented with pattern designs: Garden Communities, marked as P1, Oasis Corridors, as P2, and Schools for Everyone, as P3. All three design strategies were successful in creating more comfortable environments in both extremes, compared to the current situation.

Beginning with Garden Communities, during a heatwave the inner courtyards previously showed PET values up to 59°C, while open spaces were around 56°C. After the transformation, the increased vegetation, created larger spaces inside that showed temperatures fall to 41°C, significantly decreasing exposure. However, the decrease in windspeed through the courtyard, in some spaces intensified the perceived temperature by 3°C, illustrating a required compromise, that needs to be explicit. For the cold spell adaptation, the design shown only positive results. The inner courtyards not only expanded the warmer spaces to areas in shadow; almost all the extended entrances were surrounded by the highest recorded temperatures of 8.75°C, making them less uncomfortable.

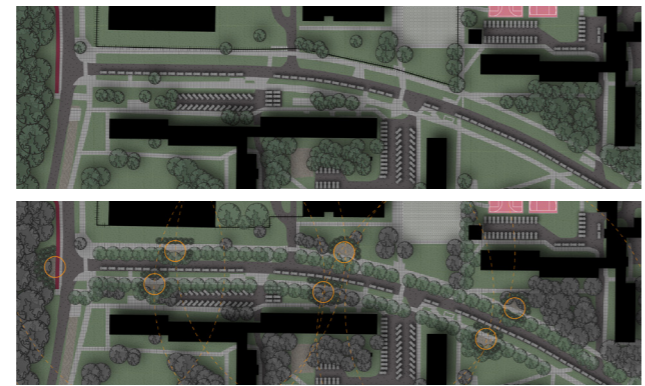


**Figure 265.** Garden Communities (P1) pattern design transformation before (left) and after (right).

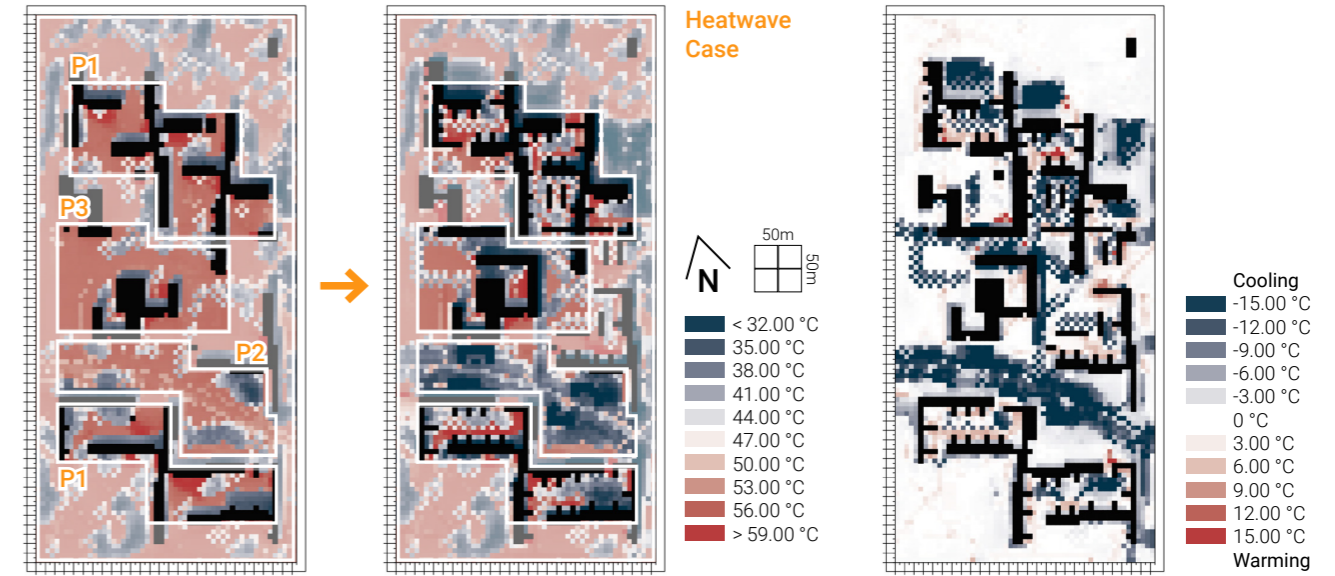
Oasis Corridors pattern evaluation showed the largest decrease of PET values during a heatwave, with temperatures across the whole path falling to 38°C, decreasing by 18°C, while the designated resting spaces reducing to 32°C. For cold spell conditions, the resting spaces were only affected, increasing the temperature by 3°C, proving individual spaces the better mitigate cold. This illustrates, that the obtained benefits can be achieved through different structures and scales, as mitigation to heat was realised by a larger linear structure, while for cold, only point clusters helped by creating more comfortable microclimates.

Lastly, Schools for Everyone, also showed more comfortable microclimates around the building, as the new school extension created cool spaces of 32°C PET next to the building, allowing people to stay inside or outside the public building. During a cold spell, the almost enclosed private school grounds showed better comfort levels. Providing a safer outdoor environment for children to play, while the public façade showed minimal changes in PET.

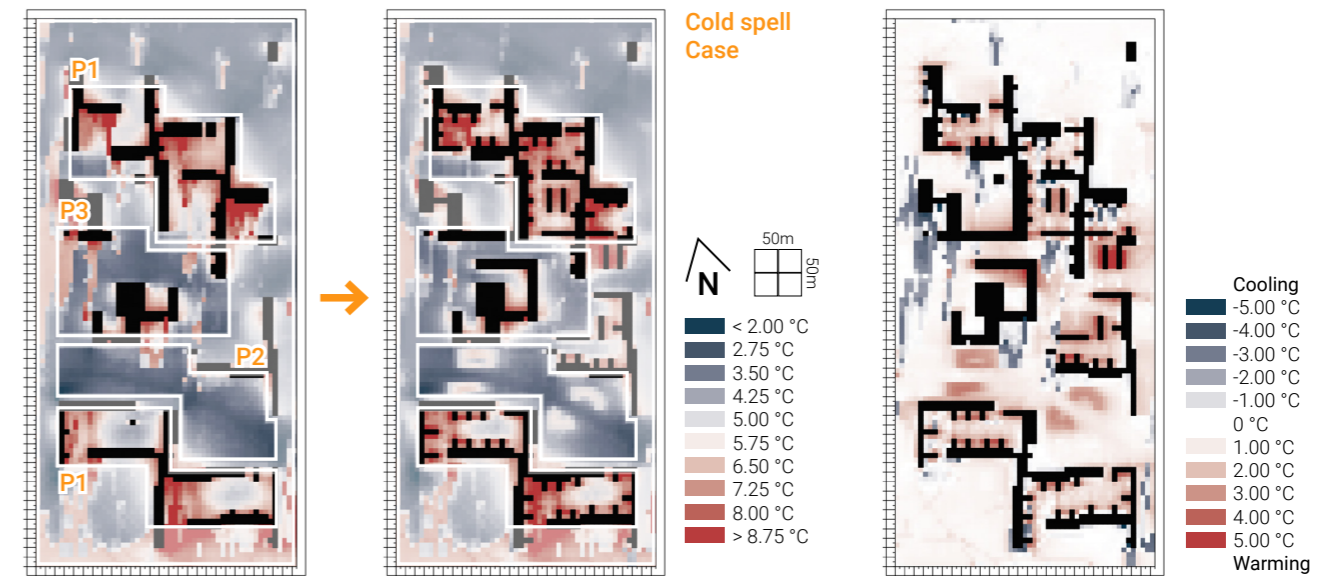
The evaluation proves, that it is possible to create a balanced temperature sensitive design with spaces that are adapted to temperature extremes. This also proves, that the developed patterns successfully inform spatial implications when adapting to temperature, and work as a valuable tool to help categorise and combine smaller design elements into an integrated design.



**Figure 264.** Oasis Corridors (P2) pattern design transformation before (above) and after (below).



**Figure 267.** Evaluation Maps, illustrating PET changes of a typical heatwave, during 14.00h for Elderly (80y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.



**Figure 266.** Evaluation Maps, illustrating PET changes of a typical cold spell, during 14.00h for Elderly (80y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.

**Transformed Site 03 – Northern Verkiai**

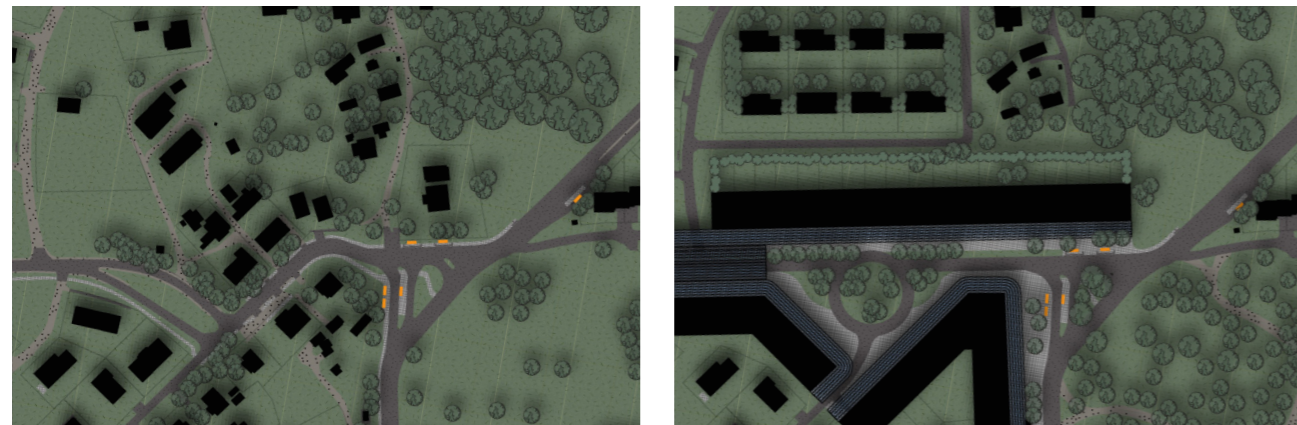
To evaluate the last patterns designed for an open low-rise site, a small area was modelled and simulated. The previous and transformed environments were compared by PET values, calculated for elderly, shown in the evaluation maps. The outlines mark spaces implemented with pattern designs: Thermal Collective Gardens, marked as P1, Oasis Corridors, marked as P2, Community Shopping Streets, marked as P3, and Traversable Landscapes, as P4. While all design strategies were successful in creating more comfortable environments during a heatwave, some strategies created worse situations during a cold spell, compared to the current situation.

Beginning with Thermal Collective Gardens and Community Shopping Streets, the spaces around single-family homes previously provided no relief during a heatwave, while spaces to the south of buildings were the warmest during a cold spell. To improve the summer conditions and retain the benefits in winter, the new building arrangement ensures that spaces to the North can reduce PET values up to 20°C and preserves the south-facing facade and its adjacent space at the consistent 10°C. While the warm space during a cold sunny day has minimised, especially for residential buildings, after the sun sets, the spaces with expanded paved surfaces and more clustered buildings with larger south facades increase PET by 6°C. Additionally, these cold spell scenarios

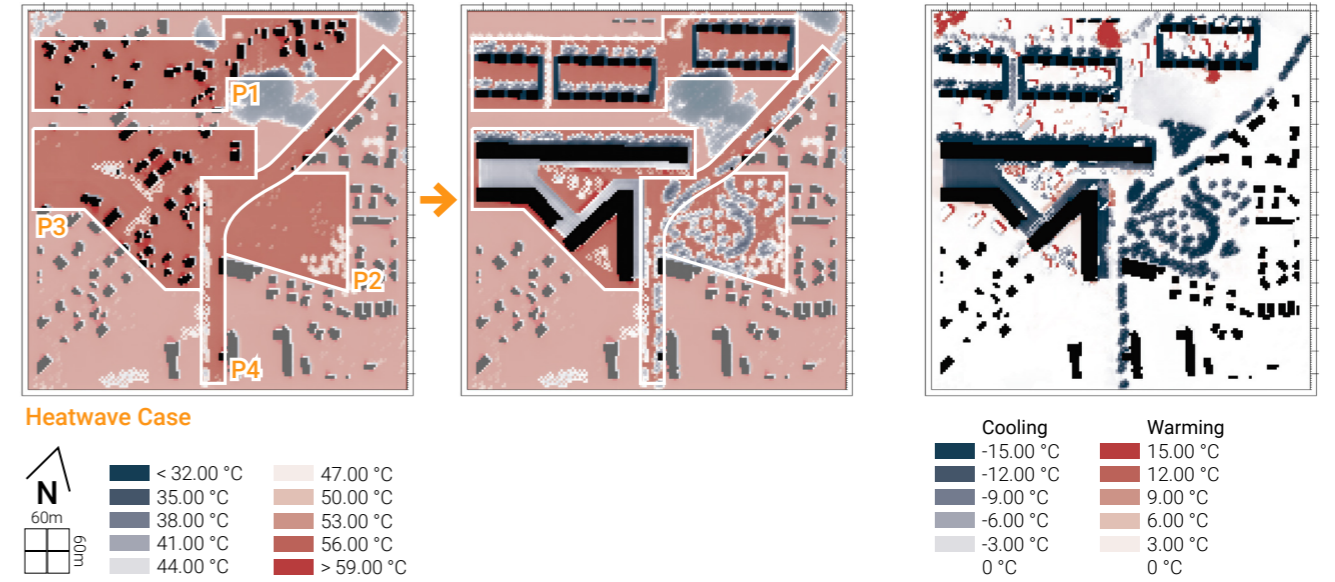
are tested when the sun is at the lowest angle, meaning that on other winter days the warm space is not limited as much as this worst case.

Oasis Corridors and Traversable Landscapes showed, that by including a small park with densely clustered trees as well as trees covering the main transport paths can create more comfortable spaces, that have reduced PET values from 56°C to 38°C. However, these pattern of introducing vegetation only provide benefits during heatwaves, as tree shadows do reduce PET values by 5°C during a cold spell, making the spaces less comfortable. This means, that the placement of Oasis Corridors pattern requires considering and finding spaces, which would be beneficial and used during a heatwave, while less important and hardly used during the marginal seasons. For the Traversable Landscapes pattern, this thermal comfort evaluation does not consider other elements, such as more frequent heated public transport or heated sidewalks. Alternative evaluation, such as measuring thermal comfort on site, by walking, waiting and taking public transport to move through the site currently and after implementation of a pilot path, would fully test this pattern.

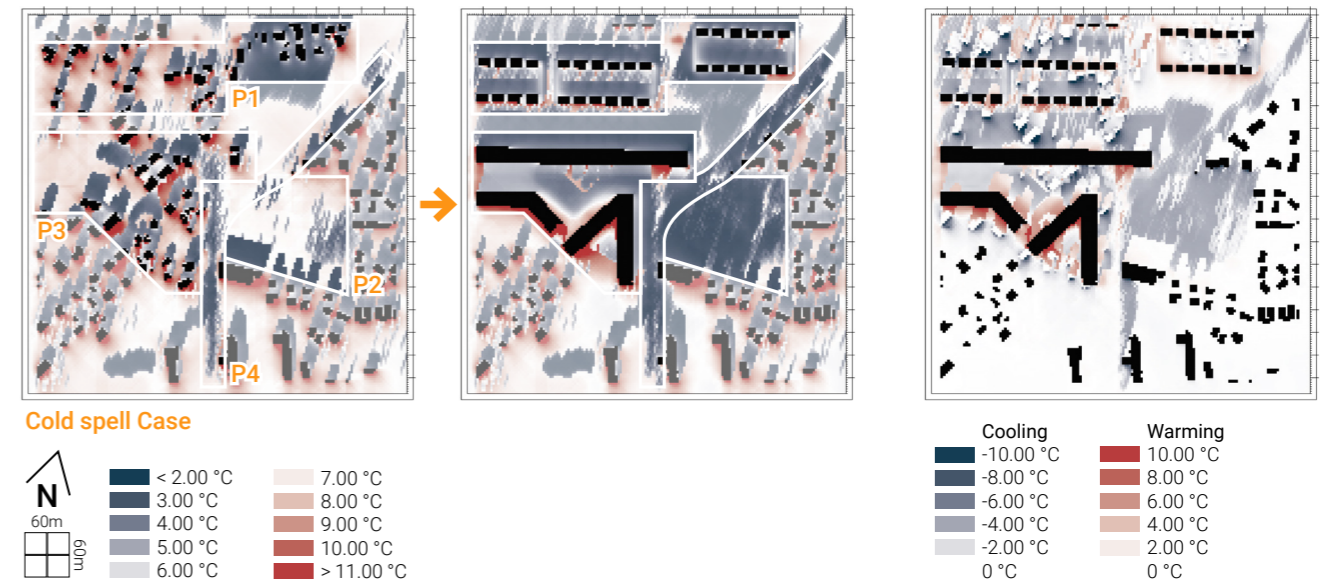
The evaluation proves that for dire cases it requires creating temperature sensitive designs that designate separate spaces for heat and cold adaptation, by preserving or improving most comfortable forms and spaces, which the developed patterns successfully addressed.



**Figure 268.** Thermal Collective Garden (P1), Community Shopping Streets (P2) and Traversable Landscapes (P3) pattern design transformations before (left) and after (right).



**Figure 270.** Evaluation Maps, illustrating PET changes of a typical heatwave, during 14.00h for Elderly (80y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.



**Figure 269.** Evaluation Maps, illustrating PET changes of a typical cold spell, during 14.00h for Elderly (80y.) before (left) and after (middle) implemented design strategies, with the map (right) illustrating the change of PET.

**08**

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**Reflection**

## Reflection

### What are the research results? How were the research and design method chosen and justified? What did you learn from the Graduation Thesis?

The research results illustrate that vulnerability should be considered and analysed through three different concepts of Exposure, Sensitivity and Adaptive Capacity. This approach revealed that different urban contexts are vulnerable in various ways, as in the example of Vilnius, the urban core is vulnerable through exposure to extreme heat, the intermediate city is vulnerable due to high sensitivity of elderly residents, while the city's periphery is vulnerable, as it has very limited adaptive capacity. All these areas require distinct adaptation strategies to cope with extreme temperatures.

Geo-spatial analysis and the pattern language approach were chosen as the research and design methods. It is because of their potential to combine space and climate data, bridge between research and design and, especially the pattern language's ability, to analyse and catalogue complexity.

Additionally, the research illustrated that solution patterns are highly interlinked together and provide a design framework for many possible site-specific temperature adaptation designs. These patterns were tested to design in three distinct urban climate environments to create potential space adaptation strategies containing new interlinked patterns to deal with the most relevant temperature extreme and the area's problems. The design process led to the development of a pattern atlas, containing possible adaptation solution, that can be used to adapt other urban environments in similar contexts. Outdoor thermal simulations were used to evaluate their success in mitigating temperature extremes, while a pattern language workshop evaluated the developed patterns' ability to convey adaptation rules and design aspects to urban designers. With these evaluations the developed pattern atlas demonstrated to be an intuitive adaptation design tool set.

With these results, the chosen research methodology seems to be successful, however it could have been better sequenced. By beginning the thesis with geo-spatial analysis, the thesis provided with a foundational understanding, which bridged between meso-scale vulnerability assessment to local-scale development strategies. Pattern language methodology was used as a bridge between research and

design providing an intuitive approach to categorise the complexity of urban climate design. The patterns provided a more holistic design approach by combining and excluding them to develop new patterns throughout the study. The developed pattern language set was tested through a workshop, conducted with urbanism master students, to evaluate the usability and design capabilities of the patterns. The results of the workshop were informing and created a feedback loop to improve the pattern relations by linking them and defining them more clearly.

The thesis methodology was set up to be a linear approach in the beginning and when reaching the design phase, it would become more integrated and provide feedback loops between design and research. When reflecting now, a quicker transition to design and even having analytical simulations in the beginning would have been more beneficial, as the design process seems to ask more precise questions that do not arrive when reading and researching literature. With this in mind, the thesis should have incorporated small design tasks in the analytical geo-spatial analysis section of the thesis.

The feedback from mentors on clarity helped me learn more concise usage of terminology. By defining and clearly stating what the project is doing, I was able to structure the thesis more clearly and develop a narrative beginning with large concepts and bridging them with emerging goals that linked to specific solutions. As the thesis contains many categories of adaptation goals and solutions, the clear distinction and consistent use of the titles helped me make it easier for the reader to follow the narrative.

The graduation thesis process introduced me to the Urban Climate Design domain, pushing me to develop an understanding for urban design and climate adaptation. The biggest achievement, which pushed me out of my comfort zone, was working with climate adaptation throughout the scales. As adapting to climate in practice is limited to large scale analytical work or microscale design project, the thesis delved into analysing the climate through scales, while extending the designs from the architectural scale to local neighbourhood scales.

### What is the relation between your graduation project topic, your master track (A, U, BT, LA, MBE), and your master programme (MSc AUBS)?

As my graduation project focuses on climate adaptation strategies for urban public spaces in Vilnius, Lithuania, addressing seasonal temperature extremes, it directly aligns with the Metropolitan Ecologies of Places studio's Urban Climate Design (UCD) sub-theme's research on environmental performance and sustainable urban design. The chosen studio and its tutors led me to develop my topic and refine the scope, problem and its following research questions. The studio's system thinking and iterative design approaches are applied to understand urban vulnerability and create design solutions for better public space adaptation.

I chose the Urbanism master track, as I wanted to expand my knowledge on urban environments and spaces between the buildings, coming from an architectural background. Personally, urbanism links larger societal problems, such as climate change, to cities and their spatial characteristics, such as form and function, to people and nature living in these environments. This is why public spaces were defined as my projects research domain, as in these spaces environmental, social and physical urban aspects are intertwined.

The MSc Architecture, Urbanism, and Building Sciences (AUBS) program approaches learning through an interdisciplinary way to create integrated solutions for the built environment. It forces the students to consider combining planning, environmental, and technological considerations, to develop sustainable and inclusive futures, which I strive to learn from and achieve. My thesis bridges the program's, master track's and studio's learning objectives, by developing a novel method of approaching spatial adaptation to climate extremes.

### How did your research influence your design and how did the design influence your research?

In the beginning, up to the second presentation (P2), the graduation thesis was focused on only research to develop a strong foundation and to grasp the current extent of literature about climate/ temperature adaptation. The design aspect of the project was postponed, due to unfounded concerns that before transitioning to design, a full understanding of the problem and all nuances are required to avoid "mistakes".

However, this mentality changed in the second part of the thesis, when the bridge to design was made.

The collected knowledge from literature, made the design decisions more critical and precise, while their implementation and most importantly their failures informed back into the research, making each design as a small research project that provided more spatial understandings and more practical uses of the read information.

This became very noticeable, when designing the patterns. The patterns were first developed by collecting various design solutions from adaptation projects and action plans with additional readings on evaluating the effects of the design. From here, pattern transformations, such as upscaling, downscaling, merging, splitting or cloning, allowed me to design new patterns that were similar with their approach, while prioritising a different temperature extreme. Similarly, when the patterns were applied to specific places, questions arose: where, what size, for whom? To answer these questions, circling back to research was required to improve and detail the design, which then rewrote the pattern, creating an iterative design loop.

**Example:** The pattern Porous Path (E12) was inspired from heat adaptation designs. The design focuses on dealing with water and cooling down the environment. From here, I developed a similar approach to path design, that would focus on dealing with snow and provide heating in the environment, which became integrating heating tiles within the walking paths. Additional readings were made to find a similar design approach in Iceland, which became the research justification for the new pattern - Radiant Path (E14).

### How do you assess the value of your way of working (your approach, your used methods, used methodology)?

The value of the graduation project's methods can be reflected and assessed by their ability to provide new insights for the project, that justify or lead the design into novel interpretations of the topic.

My research process took up many different ways of working to explore and see which method of analysis, design or evaluation can provide the most insights. This way of

working stayed consistent and proved beneficial, when tackling different aspects of the thesis simultaneously. Due to the topics holistic approach, I was able to explore and learn new ways of researching, designing or representing my work.

Within my process and discussions with the tutors, there were times of reflection, that asked, what new knowledge my methods have provided and where are they leading the project. While the spatial adaptations, illustrated how the analytical (data-based design, and local value analysis) and explorative (pattern language) methods can lead to a variety of spatial transformations, the methods drove me to a larger reflection of how the current mindset of shelters and common resources requires a new shift to achieve urban adaptation to temperature extremes for the future. The approach was also altered to make this narrative of the graduation thesis stronger and more compelling.

While the written graduation project's methodology is defined, throughout the research process these methods were shifting, as the methodology written for the second presentation (P2) has evolved by transforming adaptive capacity indicators and public space evaluation indicators to reflect new knowledge gained from the process. These changes were undertaken due to time or data limitations, as well as exploring alternative methods, that became apparent when beginning to design adaptive spaces, requiring to reasonably justify the design. If a specific analysis provided limited or insufficient guidance for temperature adaptation, alternative approaches were explored by analysing other spatial properties.

**Example:** Integrating space syntax network analysis to understand the reach of adaptability, while visibility analysis illustrated possible spaces for community led adaptations. These methods became relevant and important for the thesis, when a new question arose of what adaptive capacity signifies from a local scale.

### How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

This graduation project addresses the critical challenge of adapting urban public spaces to extreme seasonal temperatures, with a focus on cities in continental climate zones, that face both heat and cold extremes, limiting the use of public spaces negatively impacting sociability, comfort and in dire cases, pose threat to vulnerable age groups, such as elderly, children and low-income residents.

The project's societal relevance contributes to creating urban public spaces that are adaptive to hazards and remain safe, comfortable and accessible throughout the year. By extending the use of public spaces, the project aims to increase physical activity opportunities, improve social cohesion and most importantly ensure that neighbourhoods are provided with collective shelters from temperature hazards. The developed solutions are created to be transferable and transformative, providing a valuable example for other cities in a similar climatic context.

At present, there is insufficient knowledge concerning temperature adaptation of public spaces for both heat and cold extremes. While heat resilience is well-studied and a growing field of research and there have been studies focusing on cold resilience, especially in colder regions, literature on bridging these study fields is still lacking (Stout et al., 2018). From an academic perspective, this thesis integrates the research from both problems and develops a holistic design approach to ensure public spaces can adapt to urban temperature extremes without undermining one or the other extreme.

The project emphasises ethical adaptation considerations of inclusivity, accessibility, and environmental justice. By prioritising the needs of vulnerable populations, that have limited adaptive capacity, the designs and design solutions promote equity. The project's outcome is intended to support policymakers, municipalities, planners and designers in making decisions that mitigate and adapt to impacts of temperature extremes in urban areas, creating adaptive cities for all.

### How do you assess the value of the transferability of your project results?

To fulfil the research's aim of expanding the knowledge of temperature adaptation, transferability was always a concern as the problem of temperature extremes is a global issue.

The operationalisation of vulnerability and application to a city provides a transferable method, that not only examines the risks of different areas within the city but also leads the analysis towards action to adapt unsafe spaces for people. While the graduation thesis puts emphasis on groups vulnerable to temperature extremes, ensuring safety and comfort, an alternative method could swap the sensitivity lens to focus on infrastructures that can be damaged due to snow or high heat, as well as natural spaces, such as forests, that can be susceptible to forest fires, illustrating that the conceptual framework is transferable as well.

Other specific outcomes, such as the pattern language atlas, were developed with the intention to be applicable to a larger extent. As Vilnius, Lithuania acts as a case study the design solutions can be implemented into similar climate contexts facing temperature problems in both extremes. The collected solutions were carefully redesigned to reproduce the method of adaptation and not to copy the exact solution as different contexts and climates have varying effects, which transferring identical solutions to other cultures can be impractical.

The developed pattern language atlas was tested through a workshop with urbanism students to examine the transferability of developed design patterns. The workshop provided only the essential information for the patterns, to test their ability to inform other designers and observe how intuitive they would be. The student explorations of the given site and the developed designs provided positive feedback of the outcome's transferability.

Lastly, the core value of the thesis, putting focus on climate adaptive shelters, emphasises not only the need to adapt our spaces to unavoidable impacts of climate change, but also to rethink the equity aspects of these shelters, as only collective adaptation can prepare for these challenges.

### What are the key limitations of your research and how did these influence the project findings?

Tackling a graduation project focusing on climate change and adaptation to temperature extremes requires considering a wide range of future uncertainties, varying human perception to temperature and interpretation of vast amounts of data. While temperature can be objectively measured and projected, its effects and interactions with people are very social and cultural. One person's experience of a temperature extreme differs from another's, even between people located in the same space. This subjective dimension influenced how the thesis frame temperature, not as a fixed point, but as ranges, that adaptation attempts to influence by lowering or increasing it.

This influenced the selection of adaptation strategies, prioritising those that respond to the most critical extreme situations. The justification for this was, that transformations, that are prepared for worse climate hazards, will also benefit temperature adaptation in more moderate conditions. However, this meant that all patterns are presented as equally important, without the separation of their impact's extent. While the thesis reflects on the hierarchies between the newly developed patterns and their implementation related to temperature risks, a broader designation of adaptation from high-risk extremes to moderate uncomfortable temperatures could have led to different exposure reduction priorities for the pattern atlas.

A second key limitation of the study was a narrow operationalisation of sensitivity. While age demographics do indicate groups of people that are susceptible to temperature extremes, other important aspects of sensitivity, that are absent from this thesis, are people with pre-existing health issues and people from a lower economic background. The exclusion of these vulnerable groups was due to limited available data and ethical constraints related with handling sensitive personal information. The inclusion of these indicators would have revealed other areas that require urgent adaptation, influencing the sensitivity mapping, and possibly leading to alternative intervention areas. These cases would require specific adaptation implementation strategies as these vulnerable groups also indicate lower adaptive capacity, as people with limited mobility and capital are less prepared for an extreme event.

To categorise urbanised environment to climate contexts, the study used the previously developed Local Climate Zones. However, each LCZ could have been divided into smaller urban contexts by their densification intensity, land zoning and urban form, such as perimeter or open planning structures. This approach would have grouped similar urban climate zones to varying built contexts, providing more insights for the vulnerability assessment for each LCZ. The current drawback of the study is that open mid-rise environments encompass both soviet residential micro-districts as well as newly built apartment complexes. These environments should possess different vulnerability results, as their demographics and quality of public spaces differ drastically, but due to this urban classification the Exposure, Sensitivity and Adaptive Capacity findings are averaged out. A more detailed classification could have led the thesis to focus on other cases and provide even more nuances and varying adaptation goals between the same LCZ.

Another limitation was the evaluation of which public spaces are actually valued and used by residents. To truly map these spaces, expansive questionnaires and multiple long-term observation studies would have been required. Due to time constraints, the project mapped urban spaces with maintained quality as an indicator for valuable and used space to overcome this issue. While this offered insight into where people gather and what activities they engage in, it possibly excluded functions that are currently missing in the area. This limitation shifted the emphasis towards already-successful spaces, overlooking areas and functions that could provide the most benefits to the neighbourhood. A more expansive observation studies and participatory mapping might have revealed alternative potential spaces for adaptation as well as linking adaptation patterns to temporal changes.

Lastly, the use of ENVI-met as an evaluation tool brought technical constraints when examining the developed adaptations. Although ENVI-met offers microclimate modelling, it performs best at small scale simple grid geometries. When applied to larger urban environments, compromises have to be made between resolution, area, and simulation time. This restricted the evaluation to urban blocks without a broader understanding of how design interventions can interact at the neighbourhood or city scale.

As a result, some adaptation strategies may not have shown their full potential or impact in the simulations.

These methodological constraints influenced both the interpretation of temperature performance and the selection of adaptation strategies. In future studies, an improved simulation tool, that can integrate both large scale city simulations with granular design of public space at the same time, would provide a comprehensive evaluation method for climate adaptation. Additionally, combining simulation with qualitative insights, such as interviews and resident participation, could lead to a truly examined adaptation design pattern.

#### **In what ways does your research consider public space as climate commons or shelters, and what is the role of these collective spaces in climate adaptation efforts?**

By undertaking the research focused on adapting our built environment and public spaces to temperature extremes, the project, while not being centred around the idea, became reflective of the concept of Climate Commons. Building on the traditional concept of "commons", the Institute of Public Policy Research (IPPR, 2021) expand the definition in the context of climate change and defines Climate Commons as a space, system or resource that despite the ownership can be accessed and used by a community.

While Climate Commons discourse is often set on natural and green spaces, my graduation project extends this framework by also considering public accessible buildings and infrastructure, such as community centres, libraries or public transport stops, as an extension of these commons. This highlights, that urban structures as adaptive shelters are also crucial in ensuring climate resilience. This extension towards urbanised structures raises a critical reflection on the governance and ownership models of these spaces, illustrating the differences between public owned and privately owned commons. Publicly owned commons are often seen as more secure and accessible, although these spaces are vulnerable to mismanagement, which leads to privatisation. Privately owned commons may develop from bottom-up initiatives and active communities but risk of becoming exclusionary.

This becomes an especially difficult problem for vulnerable groups within the current trends of social and economic exclusion. These groups are usually not capable of individually adapting to temperature extremes, lack access to privatised commons and are dependent on unfunded and unfit publicly owned commons. All of these challenges imply, that there is a need to develop a new form of ownership, that bridges partial ownership, shared responsibility and additional institutional support.

Other insights from the thesis spatial designs and developed adaptation patterns illustrated the importance of collective community-led and managed shelters, emphasising shared ownership and benefits. By viewing adaptation shelters through the lens of Climate Commons, adaptation strategies become not only a technical challenge but also a socio-political one. By sharing ownership and responsibility, adaptation becomes not only sustainable but also more equitable and inclusive, especially for those most effected and least capable to adapt.

To design for this just transition, the pattern language methodology also becomes an essential tool. Although Christopher Alexander's work has been criticised for being contrary to the current capitalist economic system, such as his pattern "Access to Water" re-appropriating the use of private land, the criticism can be reflected not as a design flaw but rather the current system's constrain that has to be addressed.

**"The pattern 'Access to Water' argues that we should 'preserve a belt of common land immediately beside the water and allow dense settlements to come right down to the water only at infrequent intervals along the water's edge'. Water access, however, is a prime commodity and much of it has been privatized in advanced capitalist cities. Thus the pattern would require the re-appropriation of such access against formidable opposition from private land owners and a widely held belief in the inalienable right to private ownership of land." (Dovey, 1990; p.5)**

However, implicit equitable ideology in design presses the question whether our current resource governing can achieve adaptation to climate change or if a change in the system as well as new ownership systems are required, should be part of the adaptation discourse. And rather than

dismiss Alexander's patterns as utopian, the project views them as aspirations that highlight the need for a broader shift to create a more just society, that can handle climate adaptation collectively.

#### **How do your temperature adaptation patterns relate to how public spaces are designed in Vilnius today, and what could support their implementation in local planning?**

As the developed adaptation patterns are intended for designers to use them for a more holistic approach to public space design by including adapting to temperature extremes, they should be part of the future Vilnius planning and urban design processes. In Vilnius, the Green City Action Plan (GCAP) is a recent adaptation plan, that is the city's first attempt to develop a structured strategy to become carbon-neutral (Vilnius city municipality et al., 2025). Additionally, there has been practices in Vilnius, which have been making the city more resilient to climate change and in a way temperature extremes.

The most prominent projects that are greening the city, in a way developing the Comfort Trails Goal, are the Green Wave and independent planting initiatives. With these initiatives Vilnius municipality are including communities to transform public spaces together and to use this as an opportunity to teach the public about adapting to climate change. Here I see a possible bridge to use my developed patterns for not only designers but for residents. This way the greening of Vilnius could be used to create new designs with the residents together, rather than just increasing greenery in areas where it is possible.

The city is also transforming its public transport, improving cycling infrastructure and improving conditions for pedestrians, in a way developing solutions for the Sanctuary Routes Goal. Here the developed pattern could be used as an additional tool set for urban designers and planners that are transforming Vilnius mobility.

Initiatives that are renovating old buildings and transforming courtyards and open spaces nearby are in a way developing for the Community Refuge and Shelter-in-Place Goals. For these initiatives, the developed pattern set could be used as a communication tool between the municipality, designers and the residents, which are renovating and adapting their spaces.

Lastly, I would like to reflect on the city being chosen as the European Green Capital of 2025 (Vilnius Green Capital, 2025). This shows that the city is making incredible efforts in mitigating and adapting to climate change, together with many initiatives explained before. However, all of them seem to be isolated from one another. By using the developed vulnerability framework, there is an opportunity to manage these transformations together, generating synergies between the different adaptation processes, as seen in this thesis.

Here the developed pattern Atlas set could be used as an interdisciplinary tool that guides urban greening implementation, transport infrastructure planning and urban renovation and redevelopment plans all together through the lens of temperature adaptation. This would allow the departments to priorities and distribute adaptation strategies, such as reducing Exposure, safeguarding Sensitivity and increasing Adaptive Capacity, in different neighbourhoods, while reducing vulnerability to temperature extremes throughout the whole city.

**Figure 271.** More frequent and carbon-neutral public transport following the Urban Sustainable Mobility Plan, overseen by Vilnius municipality and municipal company “Susisiekimo Paslaugos” [Transport Services] (JUDU). (top-left photo: Vilnius Green Capital, 2025)

**Figure 272.** Greening the city and planting over 100,000 trees with the help of citizens, local communities, businesses and organisations, overseen by Vilnius municipality and Žalioji banga [Green Wave] initiative. (top-right photo: Vilnius Green Capital, 2025)

**Figure 273.** Schools incorporating outdoor classrooms, establishing lessons focused on the environment, overseen by Vilnius municipality and the affiliated schools (bottom-left photo: Žiūra, 2023)

**Figure 274.** Renovation of old apartment buildings and their courtyards as well as surrounding areas in Vilnius, overseen by Vilnius municipality and municipal company “Atnaujinkime miestą” [Renew the City]. (bottom-right photo: Vilnius Green Capital, 2025)

### Recommendations for Vilnius Adaptation

- Separate Vilnius into adaptation regions, that require their own budgets and different Adaptation Goals and required strategies.
- Focus on increasing vegetation in the urban core and compact mid-rise zones, by re-allocating some streets to be transformed into pedestrian zones, acquiring more space for urban trees and reducing sealed surfaces.
- Include climate adaptation strategies for industrial zone redevelopments, require stricter adaptation regulations for industrial building refurbishment projects or introduce a climate adaptation tax for these developments.
- Include climate adaptation strategies into apartment renovations, courtyard transformations and neighbourhood redevelopments in the intermediate city and open mid-rise zones, to ensure homes and adjacent social spaces are adapted to extremes.
- Construct safe and accessible paths to large natural elements from residential neighbourhoods
- Establish more frequent and expansive public transport networks as well as alternative transportation methods in the city's periphery and open low-rise zones.
- Identify local hubs within the city's urban sprawl that are well-connected to public transport, and designate them for higher-density, mixed-use development to provide essential amenities, such as shops, workspaces and recreation areas.
- Conduct possible future climate hazard simulations and projections to evaluate the need to integrate climate shelters within neighbourhood public buildings and services.
- Utilise the Vulnerability framework and the solution pattern atlas across the different departments to expand on the Green City Action Plan or to develop an interdisciplinary Urban Climate Adaptation Plan.



# 09

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## Results

Conclusions

References

## Conclusions

The aim of this research was to advance the understanding of public space climate-adaptive design by addressing the dual challenge of intensified heat stress and persistent cold stress.

Therefore, the main research question was:

**How could public spaces in Vilnius, Lithuania be adapted to seasonal temperature extremes, while simultaneously fostering social well-being throughout the year?**

To answer this main question, the thesis follows the structure of the following sub-questions:

*Answer to sub-question 1 //*

*What is the current vulnerability of public spaces in Vilnius, concerning seasonal temperature extremes?*

This thesis asserts that vulnerability is not a one risk factor, but rather a combination of three lenses of Exposure, Sensitivity and Adaptive Capacity. This establishes that public spaces in Vilnius have varied vulnerability to seasonal extremes, depending on the distribution of temperature, susceptible resident groups and the ability for residents to adjust their surroundings.

During heatwaves, public spaces in commercial zones and compact built areas have the highest Exposure to heat, while urbanised environments in open and permeable landscapes are severely exposed to cold. Meanwhile, industrial areas, which lack vegetation, are particularly exposed to both extremes.

In terms of Sensitivity, population densities of children up to 14 years old and elderly above 65 years old were used as indicators to measure the sensitivity of urban blocks. These areas are more affected by temperature extremes, as their sensitive age demographics have lower physical resilience, limited social capital and movement capabilities. In Vilnius, residential environments with high concentration of children are found in the city's peripheries, while neighbourhoods with high density of elderly populations are in the intermediate city districts, especially older Soviet micro-districts.

Finally, Adaptive Capacity, intended in this thesis as a function of accessibility, indicates the ability reach temperature robust public spaces. Areas within the inner

city have the highest adaptive capacity due to better access to indoor public buildings and transport corridors. On the other hand, although the city's intermediate zone contains many possible collective spaces, they are outdoors and less connected and more dispersed. Meanwhile peripheral areas heavily depend on nearby natural spaces, as they lack other Adaptive Capacity approaches.

Based on the combination of all three vulnerability factors, some peripheral neighbourhoods show higher vulnerability to extreme cold, than inner city areas are to extreme heat, due to the periphery neighbourhoods having larger sensitive communities and very limited adaptive capacity to deal with extreme temperature hazards.

This analysis allows to define three Adaptation Goals to transform public space, according to the examined spatial characteristics and residing demographics. Areas with high exposure and limited mobility and access to resilient spaces, especially where sensitive groups are concentrated, require the highest priority to adapt to temperature extremes.

*Answer to sub-question 2 //*

*How to classify urban climate zones in the context of Vilnius based on morphological characteristics?*

Urban climate zones in Vilnius are classified using the Local Climate Zone (LCZ) system. The mapping of LCZs in Vilnius reveals that there are 7 built types and 5 land cover types in the city. Assessment using vulnerability indicators narrows them down to three most temperature relevant zones, which are compact mid-rise, open mid-rise and open low-rise.

Compact mid-rise areas are exposed to heat with disproportionately high concentrations of children. These spaces are dense and multi-functional, although have limited greenery. Open mid-rise zones have high sensitivity due to concentrated elderly populations and are characterised by open and exposed public spaces. Lastly, open low-rise zones are populated with both sensitive demographics. These zones are car-dependant with limited indoor public spaces as well as being highly exposed to cold extremes.

This LCZ based classification approach allows to contextualise vulnerability results, by linking urban form to temperature extreme impacts, as well as guiding public space interventions through derived Adaptation Goals.

*Answer to sub-question 3 //*

*Which design strategies and technologies have been proven effective in managing urban temperature extremes?*

Effective design strategies to manage temperature extremes are collected from literature review and developed as a Pattern Language. These patterns are linked to the established Adaptation Goals and are structured into three categories: Exposure Reduction, Social Well-being and Coping Networks.

Exposure Reduction patterns include design elements that increase shading, vegetation, humidity, surface albedo and higher windspeeds to limit solar radiation and heat accumulation during heatwaves. During cold spells, design solution patterns prioritise elements blocking wind, removing snow, and increasing solar gains.

Social Well-being patterns include user-selected public spaces, for example, courtyard gardens or larger seating spaces near the entrance of an apartment building, that offer social and physical benefits, especially for sensitive demographics, such as children and elderly.

Coping Network patterns include strategies, that focus on improving accessibility and reach of designated climate shelters, by applying 15-minute city principles. Additional patterns, that provide resources that increase capacity to adapt as well as more active and temporary measures, such as sharing resources or increasing public transport for a limited time, are also part of this category.

These patterns together form a Pattern Atlas to be used as a set of design solutions across different urban forms and scales. This system allows to develop integrated, specialised and site-specific temperature adaptation spatial designs.

*Answer to sub-question 4 //*

*What are the potential spaces for heat/cold adaptation, that improve social well-being, in Vilnius urban fabric?*

In Vilnius, potential spaces for heat and cold adaptation, that enhance social well-being, vary per each Local Climate Zone. The vulnerability analysis indicated that LCZs are differently exposed to heat and cold extremes. In this study three main residential LCZs: compact mid-rise, open mid-rise and open low-rise, were examined to find potential spaces for adaptation. Exemplary cases for each LCZ were selected. These cases represent generalised morphological conditions, which also corresponds to the designated adaptation goals of each LCZ.

In Naujamiestis, a typical compact mid-rise environment, the most potential for adaptation spaces is found in public streets, as these spaces are where most of the social activities take place and the urban form, consisting of a perpendicular street grid. Interventions in public streets such as increasing ventilation have the potential to dissipate heat in summer, while some mostly paved spaces can be kept to retain heat in winter.

In Karoliniškės, a representative open mid-rise environment, the highest level of urgency is placed on spaces nearby and adjacent to apartment buildings, as these are everyday spaces for the elderly residents. Here open left-over spaces within as well as outside the residential courtyards can provide new functions that foster social cohesion, while offering shelter during extreme temperatures. Additionally, spaces around and inside public buildings can become central meeting spaces supporting community ties and act as indoor public shelters during severe extremes.

In Northern Verkiai, a typical open low-rise environment, transportation routes and spaces around public transport nodes are the most active, providing opportunities to create accessible community clusters that enhance mobility, increasing the area's Adaptive Capacity. In these environments the potential public spaces for adaptation are linear corridors that ensure mobility and spaces around transportation interchanges, that can sustain amenities within a low density-built environment. In addition, residential plots could be optimised to collect solar radiation to mitigate extreme cold.

*Answer to sub-question 5 //*

*What design solutions can be implemented to public spaces in Vilnius to enhance their functionality and social well-being throughout the year?*

Public spaces in Vilnius are adapted to temperature extremes through site-specific patterns, developed throughout this study, by integrating several solution patterns, that enhance the spaces functionality and social well-being. The new possible adaptation strategies are **In-Fill Parks, Heat-proof Canyons, Garden Communities, Oasis Corridors, Schools for Everyone, Thermal Collective Gardens, Community Shopping Streets and Traversable Landscapes**. **In-fill parks** provide dense vegetation by replacing streets with pedestrian-friendly areas to lower air temperatures during heatwaves and provide nearby residents with resting spots, sports grounds, and commercial plinths to develop an active community space. **Heat-proof Canyons** integrate water features, vertical vegetation and temporary sunshades along regional streets and busy pedestrian paths to protect pedestrians from heat exposure, while ensuring mobility. **Garden Communities** transform inner courtyards into garden spaces, that provide shade, higher humidity, and enclosed greenhouses, which give protection from both extremes while fostering neighbourly engagement. **Oasis Corridors** strategically plant vegetation to create continuous shaded paths and interval windbreaks to ensure better thermal comfort for pedestrians and cyclists. **Schools for Everyone** provide accessible indoor shelters from temperature extremes and offer the surrounding area a collectively maintained and shared community space. **Thermal Collective Gardens** combine passive solar gains and wind protection to create private spaces adapted to temperature extremes through urban design. **Community Shopping Streets** provide densely built district amenity hubs acting as local shelters situated along the main public transport routes. Lastly, **Traversable Landscapes** ensure that low density residences have access to public transport or alternative mobility methods to increase sustainable and temperature-proof mobility.

Implemented together, these patterns create a network of spaces that ensure urban adaptation to temperature extremes as well as extended use of social spaces throughout the year.

*Answer to sub-question 6 //*

*How effective are the integrated adaptive design solutions during seasonal temperature extremes?*

The integrated adaptive design solutions prove effective in mitigating seasonal temperature extremes by enhancing thermal comfort and Adaptive Capacity, as examined through physiological equivalent temperature (PET). Computational simulations verify, that during heatwaves, the implemented patterns can lower temperatures from dangerously hot to warm and tolerable temperature range, with the largest reduction of PET reaching 20°C. For cold conditions, the same patterns increase temperatures from extreme cold to only cold, having a smaller but still significant effect, compared to heat mitigation, increasing the PET by 3°C.

In all cases, increasing vegetation provided the largest impact to mitigate the extent of a heatwave. On the other hand, both building orientation to allow solar radiation and to block strong cold winds, are required to mitigate extreme cold. This is because urban design is less effective in influencing temperature during colder periods, as temperature is mostly dependent on direct solar radiation. During the worst cold extremes, when there is no solar radiation, adaptation patterns oriented around managing wind are the most effective.

Therefore, these solutions allow to reach a balance between protection from heat and cold relief, confirming that the adapted public spaces are more comfortable during temperature extremes, extending their usability during heatwaves and can be used longer into the cold seasons

All answered sub-questions provide the information needed to answer the main research question:

**How could public spaces in Vilnius, Lithuania, be adapted to seasonal temperature extremes, while simultaneously fostering social well-being throughout the year?**

The thesis concludes that to adapt public spaces in Vilnius to seasonal temperature extremes while fostering social well-being throughout the year, it is necessary to have a deep diagnosis at multiple scales to identify components of vulnerability and potential spaces for intervention. This would allow prioritising public spaces that are most vulnerable, that excessively retain heat during heatwaves or quickly dissipate it during cold spells, where sensitive groups are concentrated and where access to thermally comfortable spaces is limited.

To address these challenges, the use of pattern language as a design method is able to facilitate the design process and boost the integration between climatic, spatial and social adaptation dimensions as well as any potential conflicting strategies. Design patterns include Exposure Reduction, Social Well-being and Coping Networks category strategies that improve thermal comfort, integrate socially valuable spaces and enhance accessibility and mobility respectively.

Specific urban climate contexts with Exposure reduction patterns ensure that design solutions are shaped to correspond to distinct characteristics of Vilnius' urban fabric. Dedicated Social Well-being patterns make sure that adaptation is not only a matter of technological solutions but also a matter of just social inclusion. While Coping Networks expands the understanding of adaptation to include accessibility, urban mobility and public shelters. The integration of these solutions contributes to the transformation of public spaces, that promotes social cohesion and extends their usability for both hot summer days and colder marginal months.

In the end, this thesis advocates for a balanced approach to urban adaptation to climate, guided by vulnerability assessments and implementation of adaptation patterns, as a sustainable way to improve thermal conditions, accessibility and social functions of public spaces in Vilnius, under worsening temperature extremes.

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# 10

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## Appendix

# Site 01 | Heatwave 14:00h

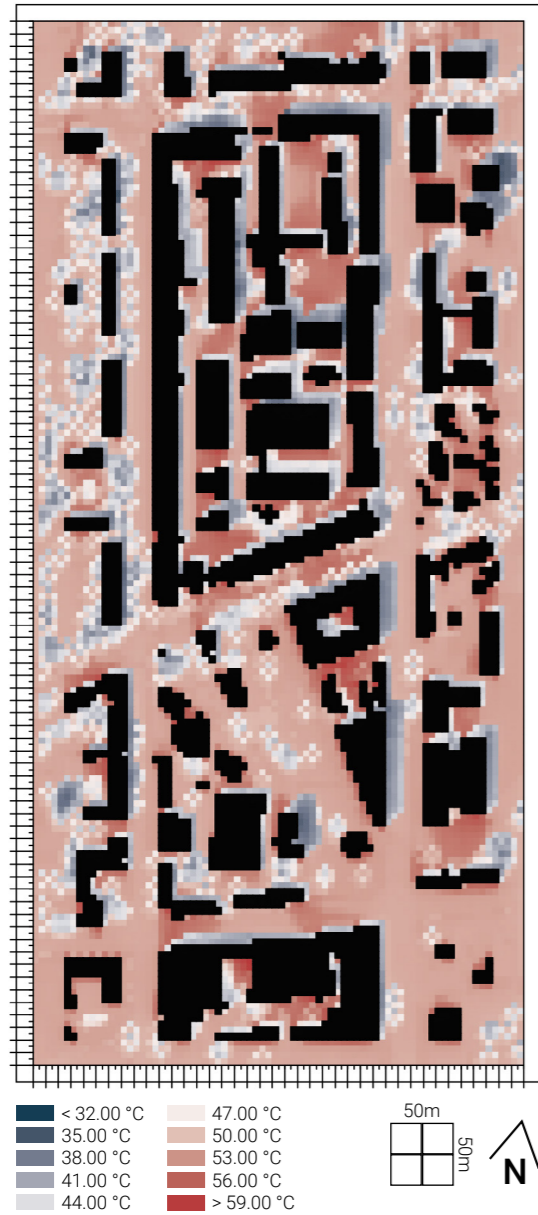


Figure 276. PET calculations of a typical heatwave scenario, during 14.00h for Children (8y.)

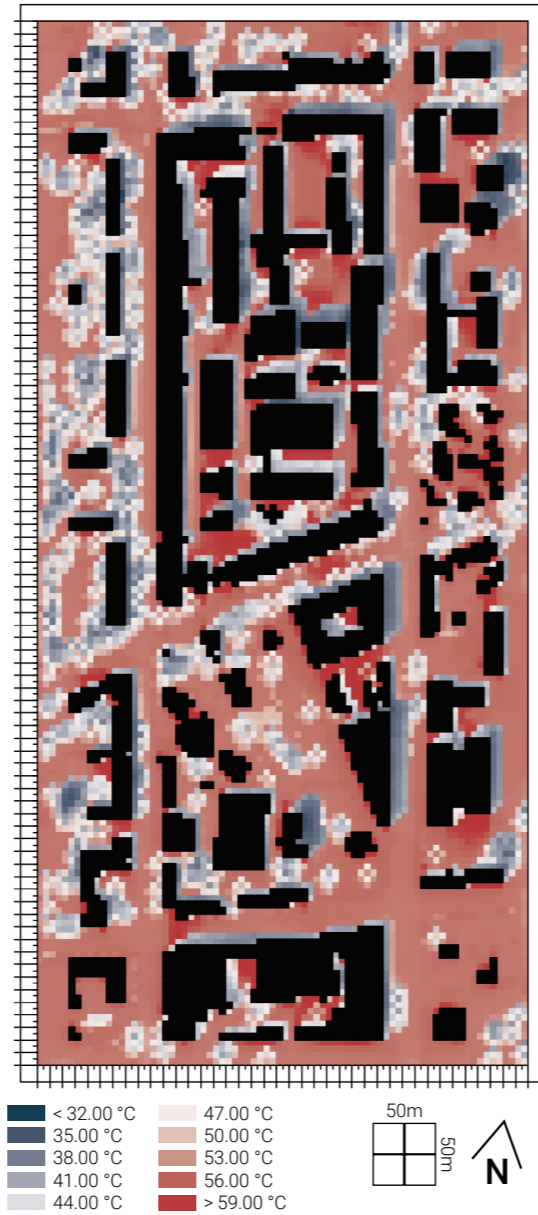


Figure 275. PET calculations of a typical heatwave scenario, during 14.00h for Elderly (80y.)

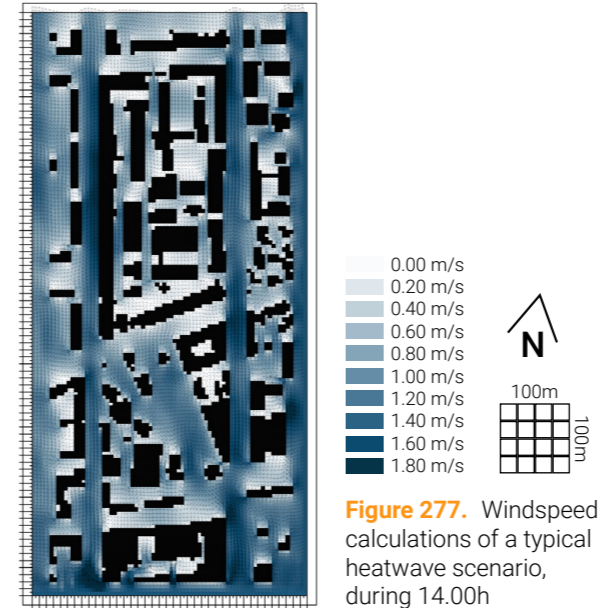


Figure 277. Windspeed calculations of a typical heatwave scenario, during 14.00h

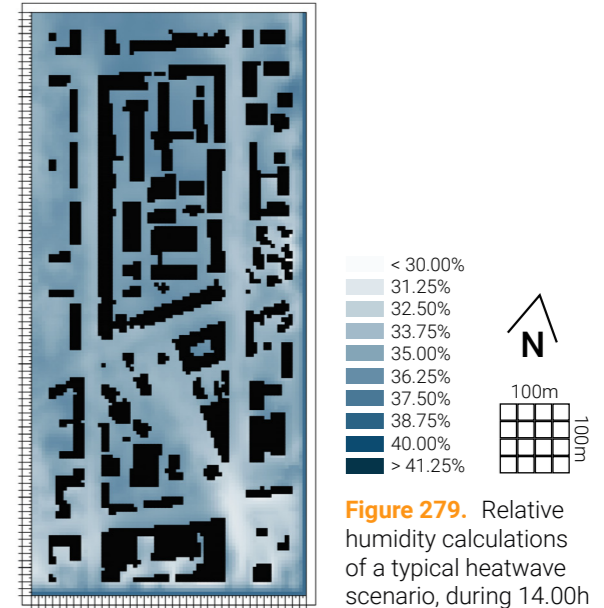


Figure 279. Relative humidity calculations of a typical heatwave scenario, during 14.00h

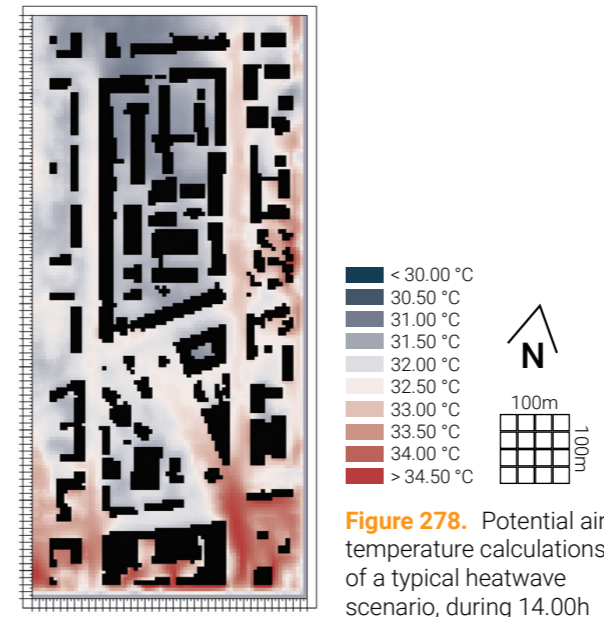


Figure 278. Potential air temperature calculations of a typical heatwave scenario, during 14.00h

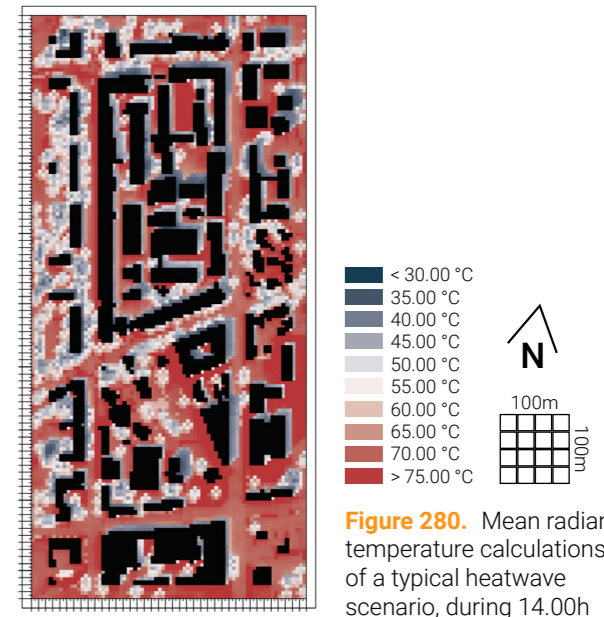
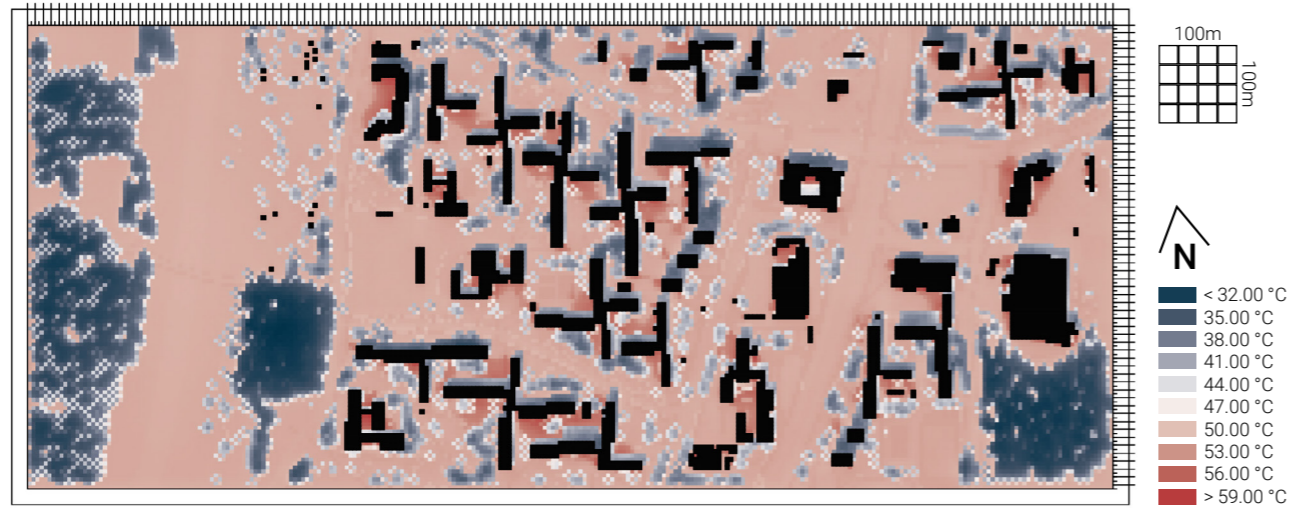
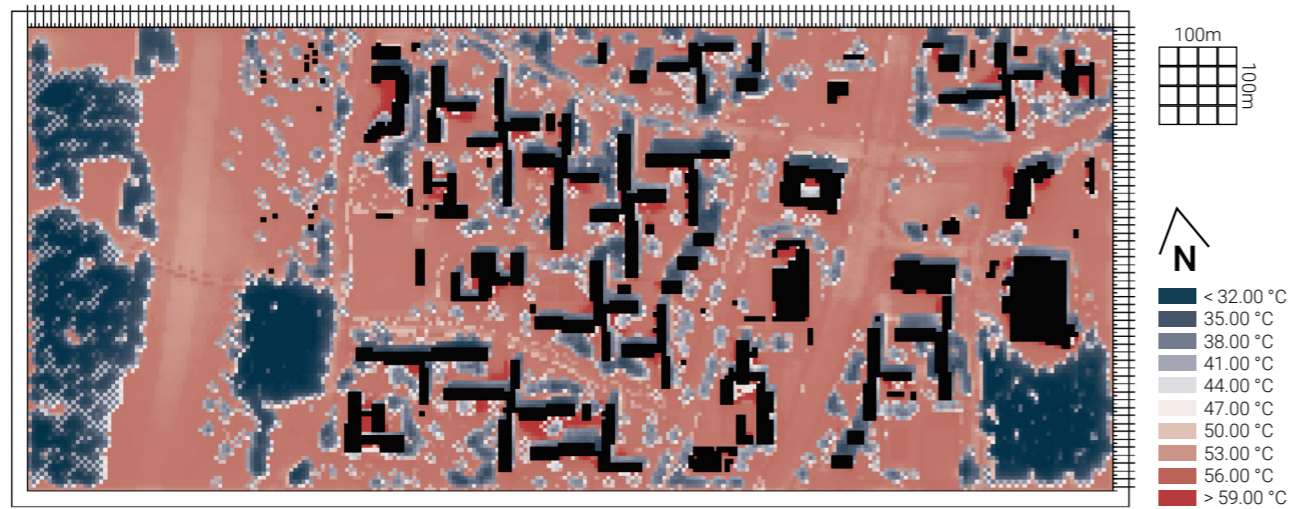


Figure 280. Mean radiant temperature calculations of a typical heatwave scenario, during 14.00h

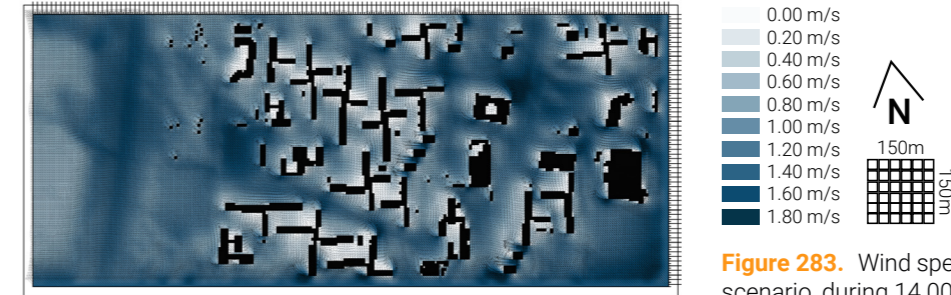
## Site 02 | Heatwave 14:00h



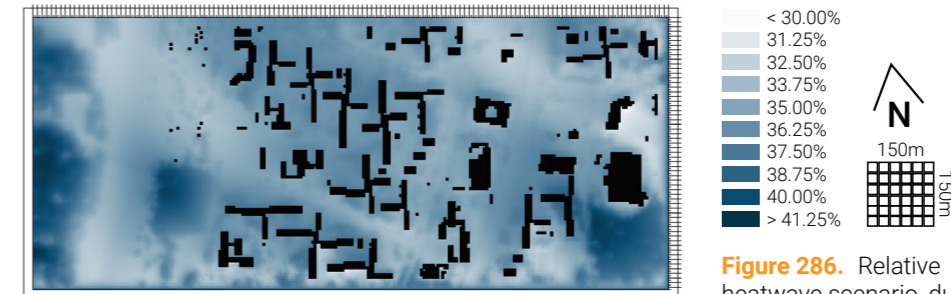
**Figure 281.** PET calculations of a typical heatwave scenario, during 14.00h for Children (8y.)



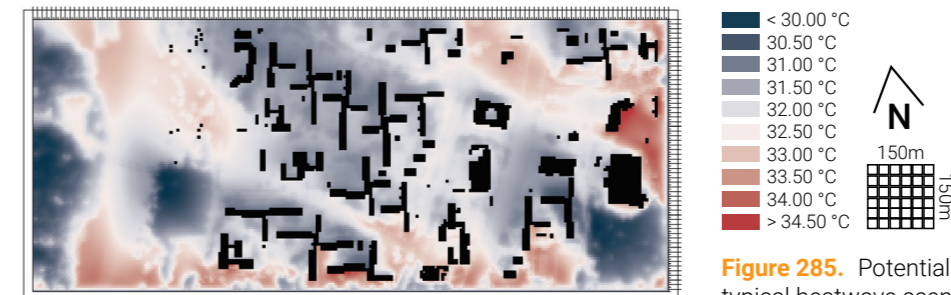
**Figure 282.** PET calculations of a typical heatwave scenario, during 14.00h for Elderly (80y.)



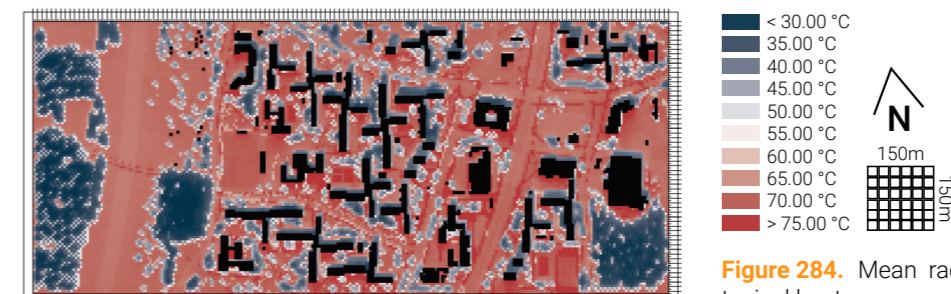
**Figure 283.** Wind speed calculations of a typical heatwave scenario, during 14.00h



**Figure 286.** Relative humidity calculations of a typical heatwave scenario, during 14.00h



**Figure 285.** Potential air temperature calculations of a typical heatwave scenario, during 14.00h



**Figure 284.** Mean radiant temperature calculations of a typical heatwave scenario, during 14.00h

# Site 03 | Heatwave 14:00h

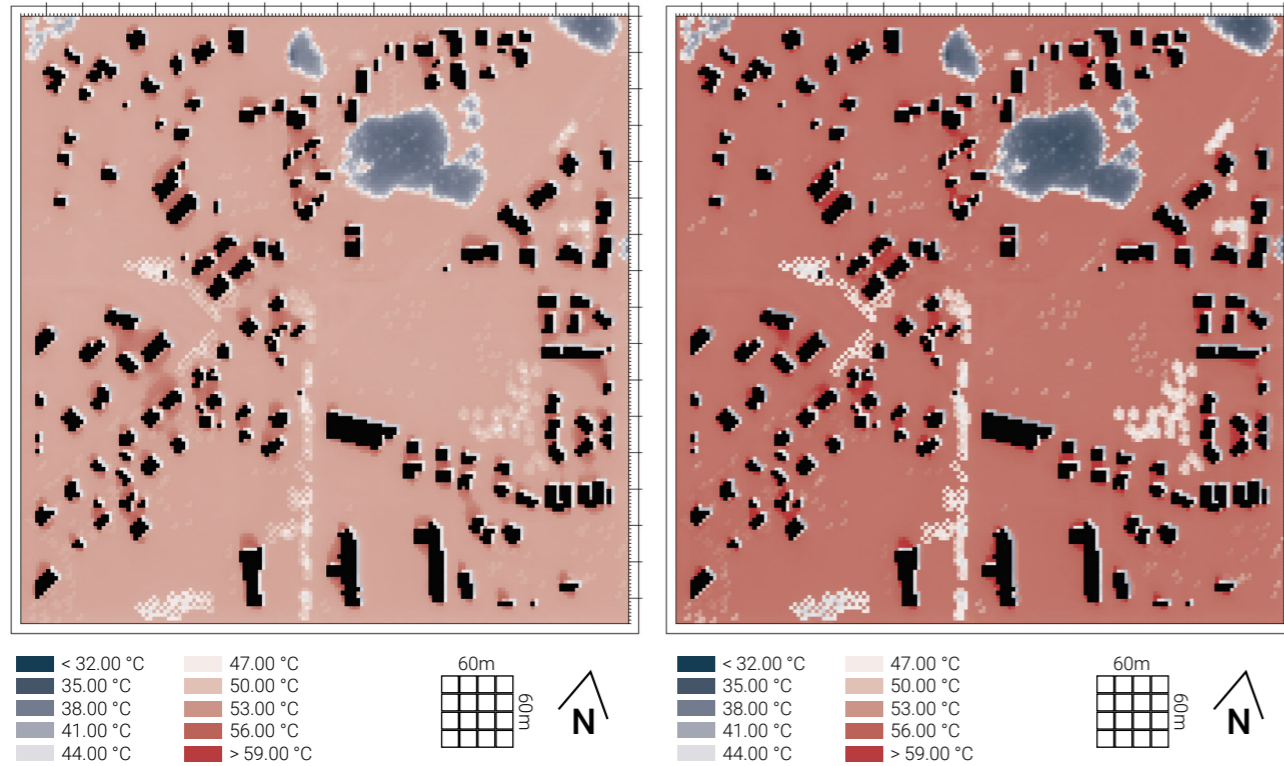


Figure 288. PET calculations of a typical heatwave scenario, during 14.00h for Children (8y.)

Figure 287. PET calculations of a typical heatwave scenario, during 14.00h for Elderly (80y.)

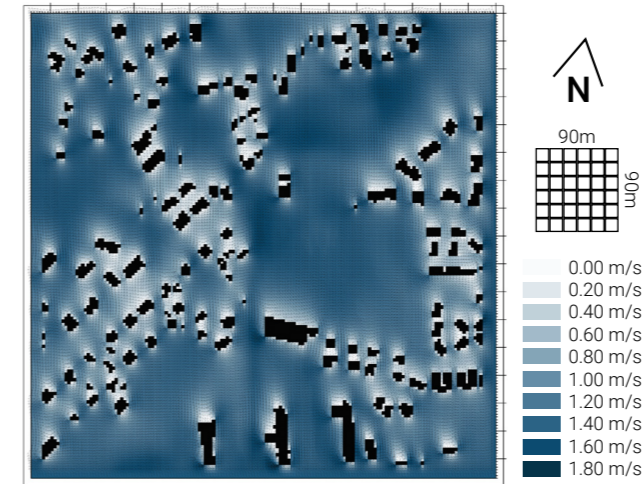


Figure 289. Wind speed calculations of a typical heatwave scenario, during 14.00h

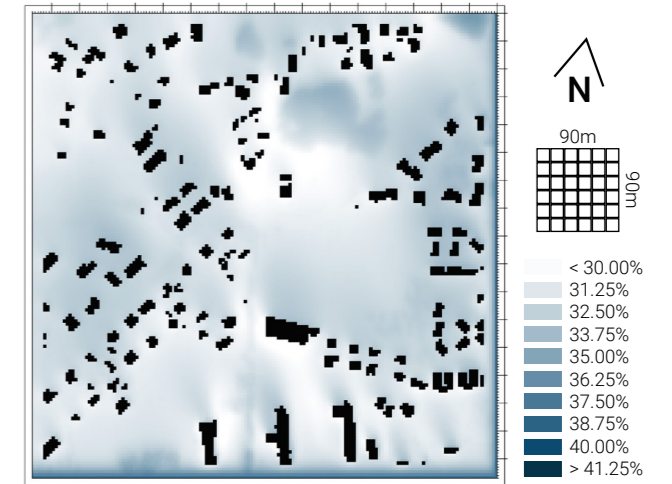


Figure 290. Relative humidity calculations of a typical heatwave scenario, during 14.00h

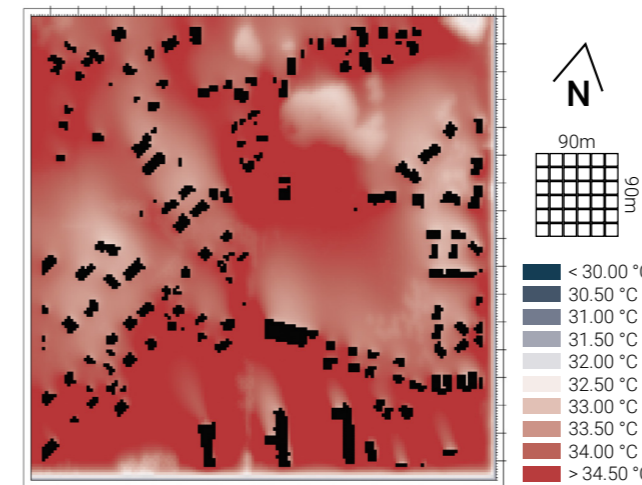


Figure 291. Potential air temperature calculations of a typical heatwave scenario, during 14.00h

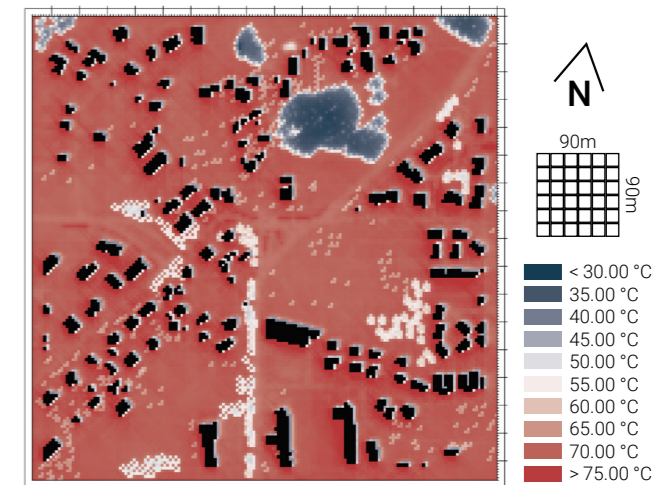


Figure 292. Mean radiant temperature calculations of a typical heatwave scenario, during 14.00h

# Site 01 | Heatwave 22:00h

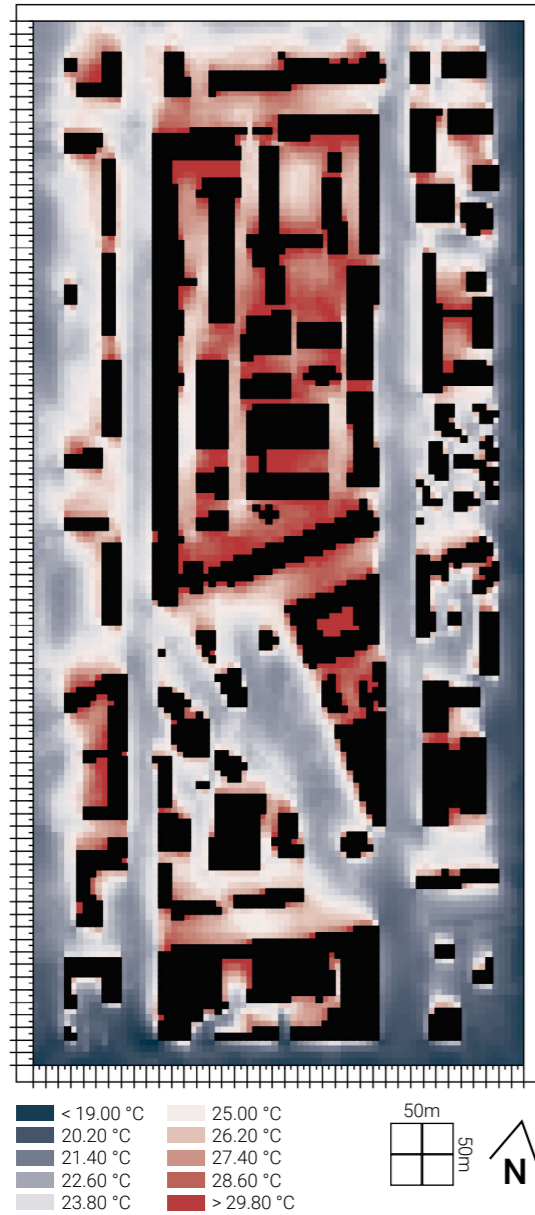


Figure 294. PET calculations of a typical heatwave scenario, during 22.00h for Children (8y.)

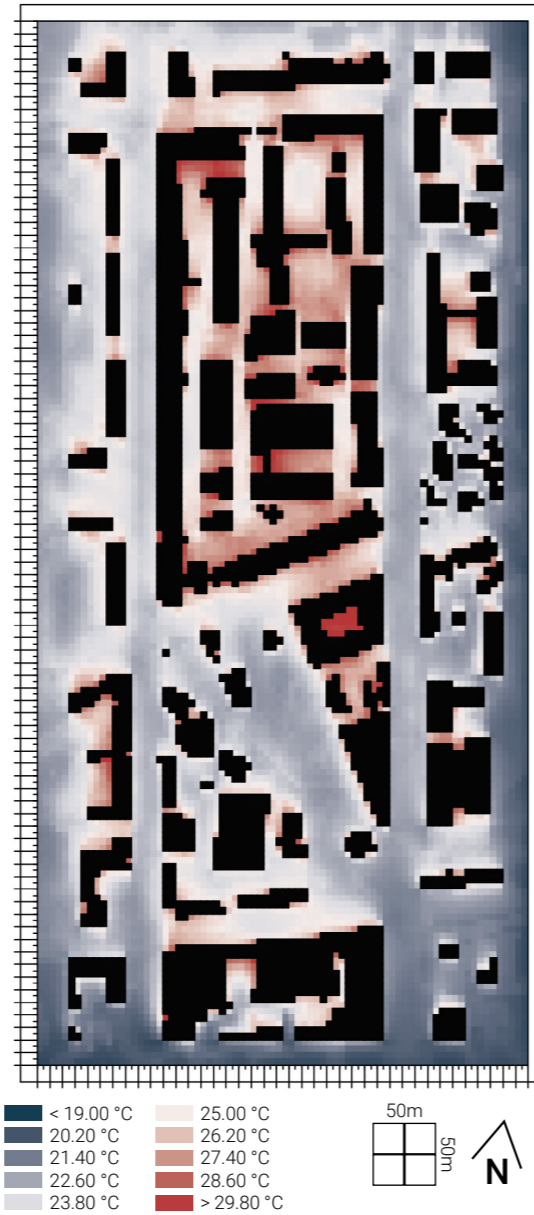


Figure 293. PET calculations of a typical heatwave scenario, during 22.00h for Elderly (80y.)

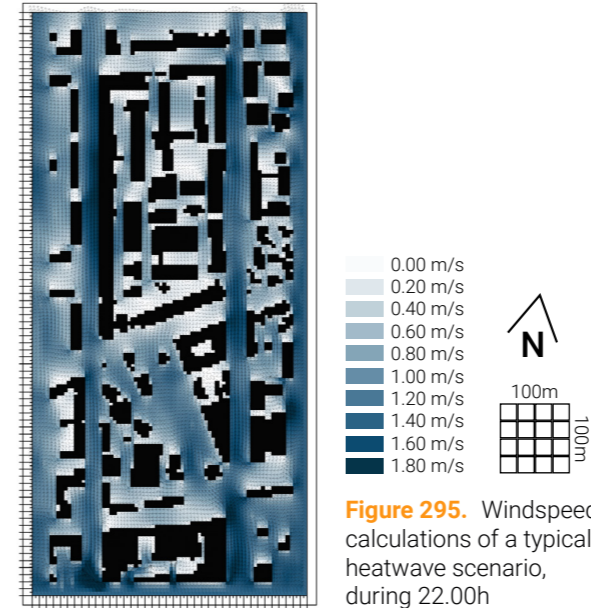


Figure 295. Windspeed calculations of a typical heatwave scenario, during 22.00h

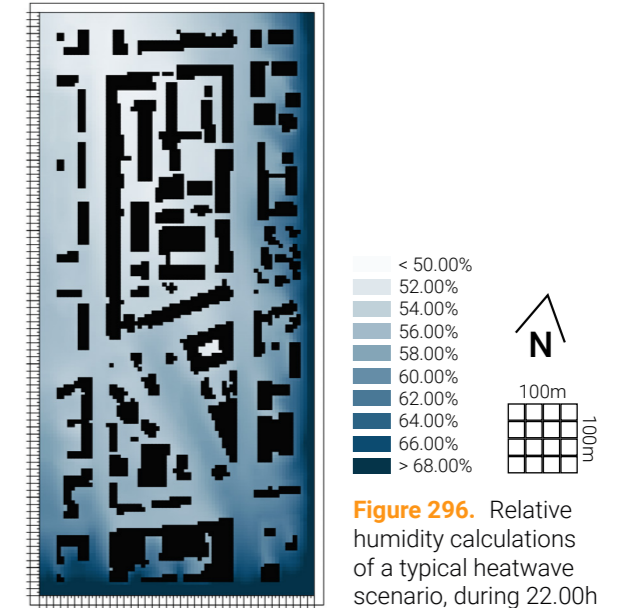


Figure 296. Relative humidity calculations of a typical heatwave scenario, during 22.00h

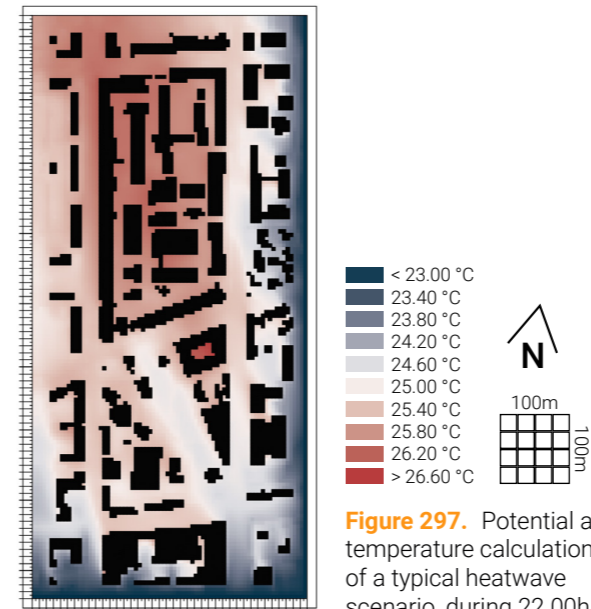


Figure 297. Potential air temperature calculations of a typical heatwave scenario, during 22.00h

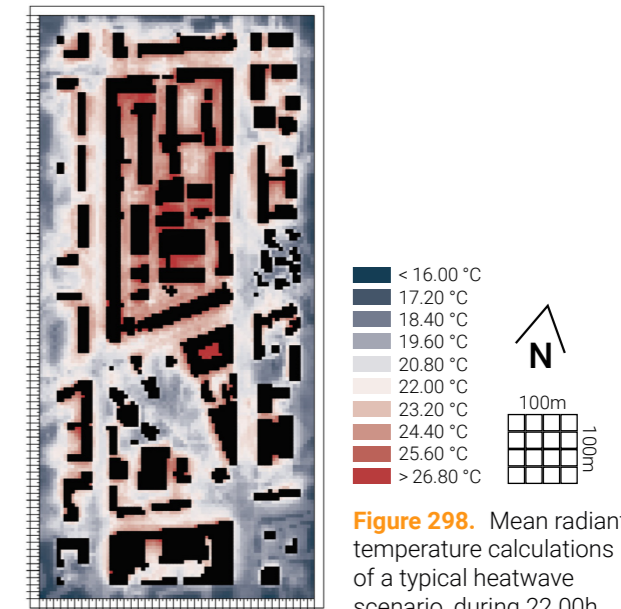
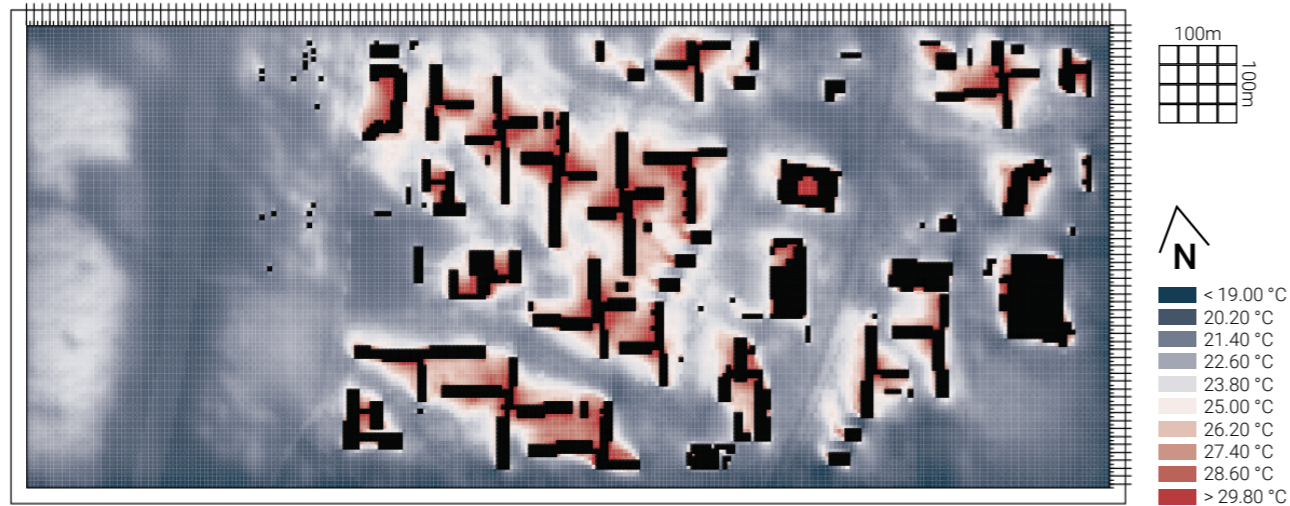
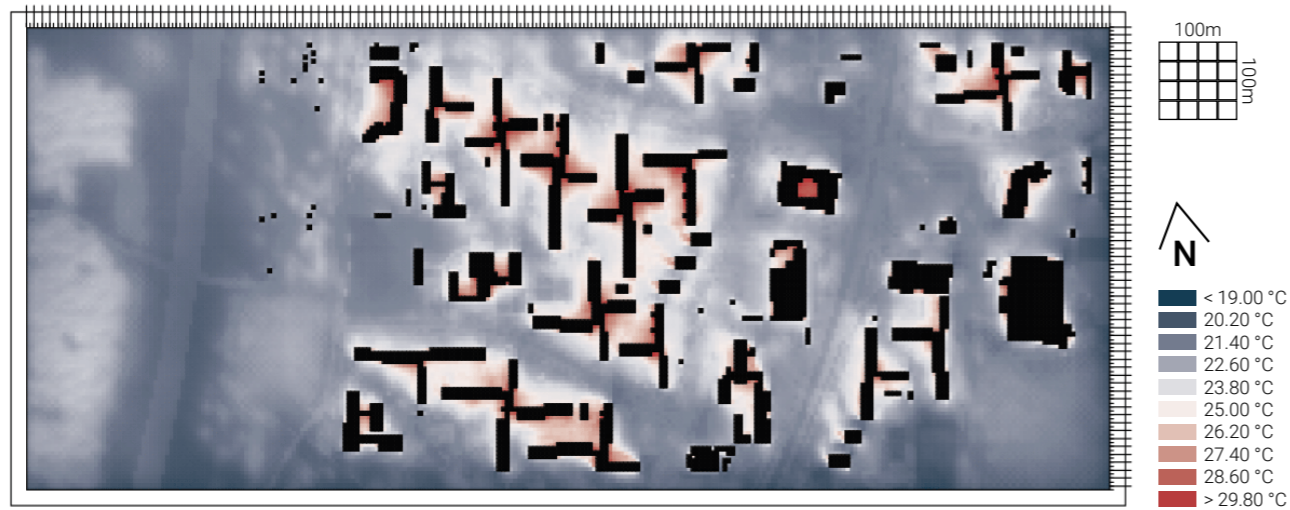


Figure 298. Mean radiant temperature calculations of a typical heatwave scenario, during 22.00h

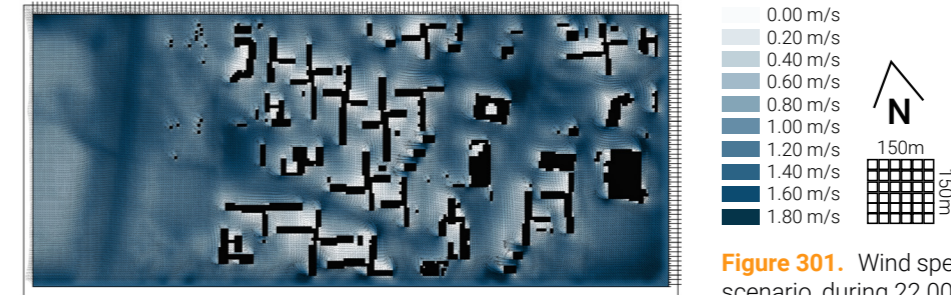
## Site 02 | Heatwave 22:00h



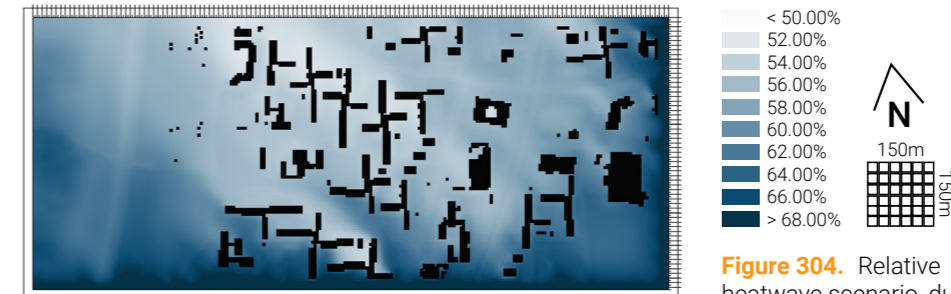
**Figure 299.** PET calculations of a typical heatwave scenario, during 22.00h for Children (8y.)



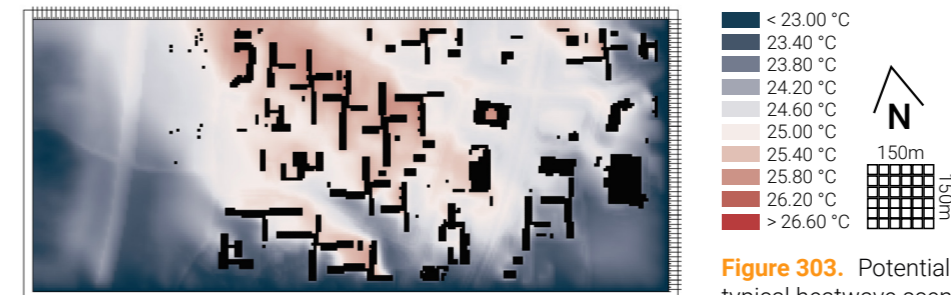
**Figure 300.** PET calculations of a typical heatwave scenario, during 22.00h for Elderly (80y.)



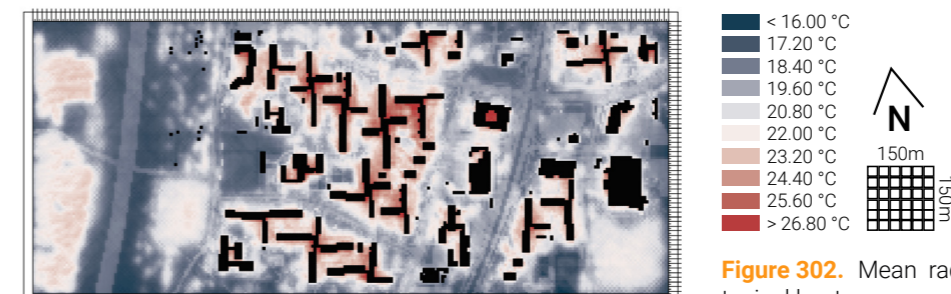
**Figure 301.** Wind speed calculations of a typical heatwave scenario, during 22.00h



**Figure 302.** Relative humidity calculations of a typical heatwave scenario, during 22.00h



**Figure 303.** Potential air temperature calculations of a typical heatwave scenario, during 22.00h



**Figure 304.** Mean radiant temperature calculations of a typical heatwave scenario, during 22.00h

# Site 03 | Heatwave 22:00h

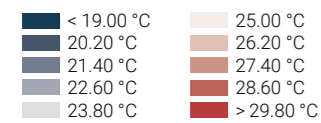
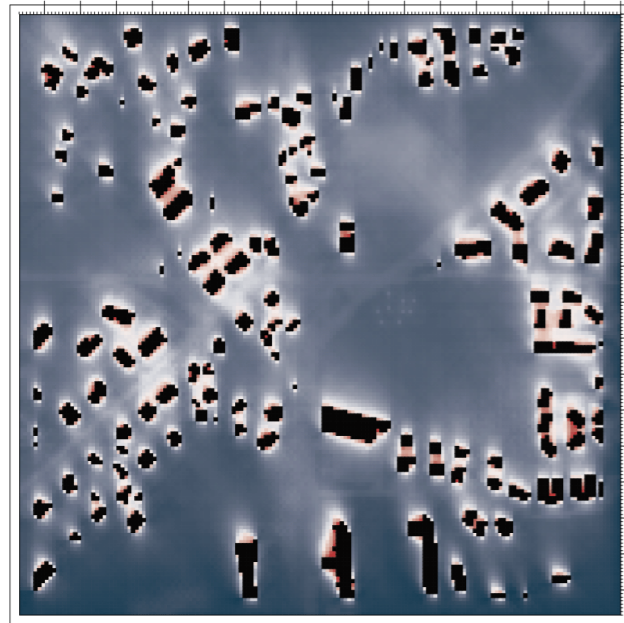


Figure 306. PET calculations of a typical heatwave scenario, during 22.00h for Children (8y.)

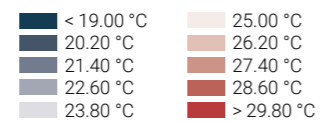
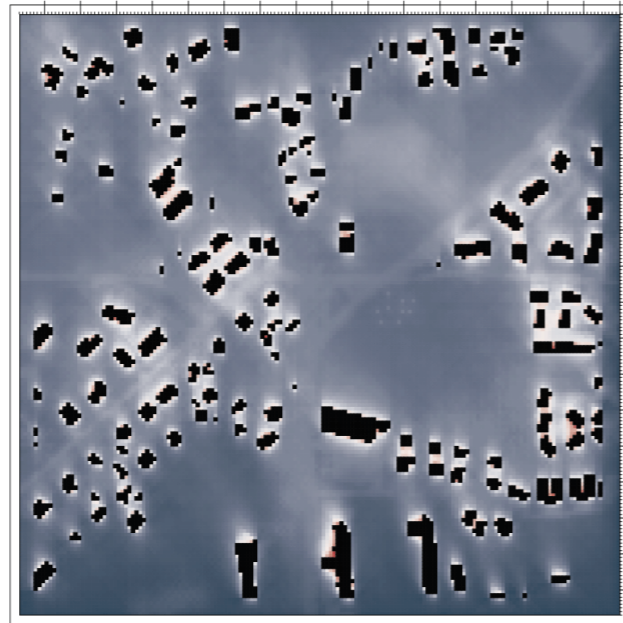


Figure 305. PET calculations of a typical heatwave scenario, during 22.00h for Elderly (80y.)

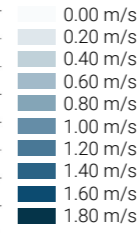
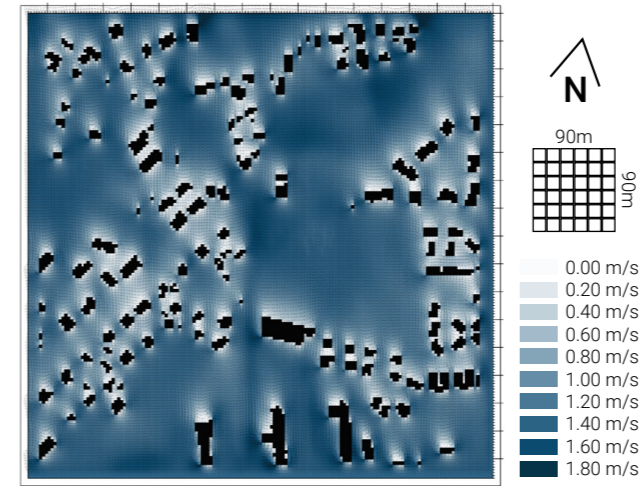


Figure 307. Wind speed calculations of a typical heatwave scenario, during 22.00h

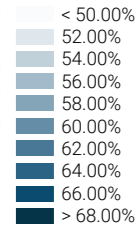
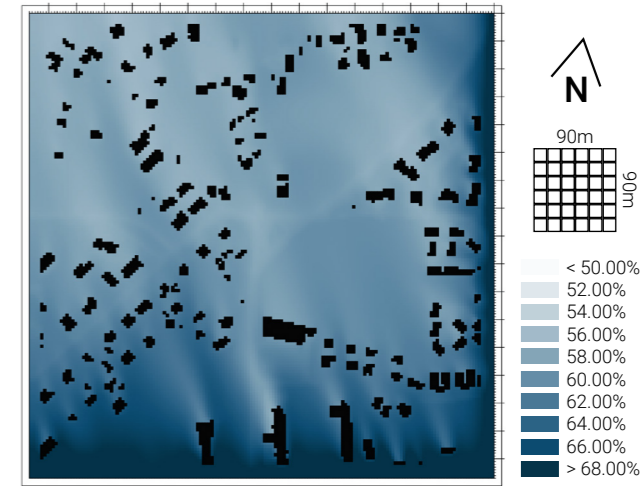


Figure 309. Relative humidity calculations of a typical heatwave scenario, during 22.00h

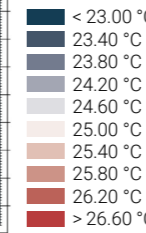
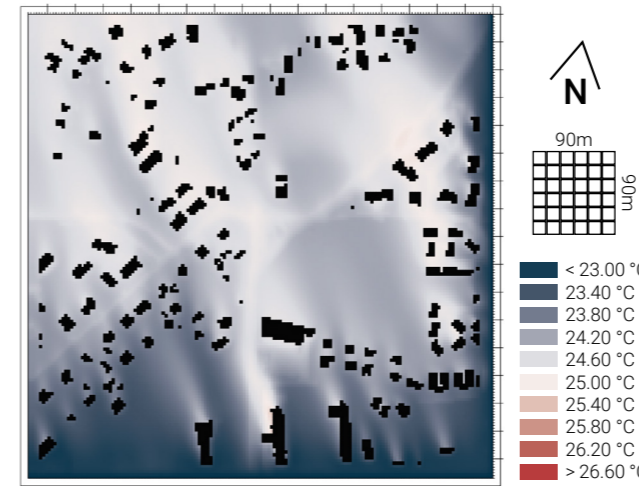


Figure 308. Potential air temperature calculations of a typical heatwave scenario, during 22.00h

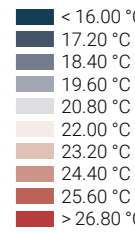
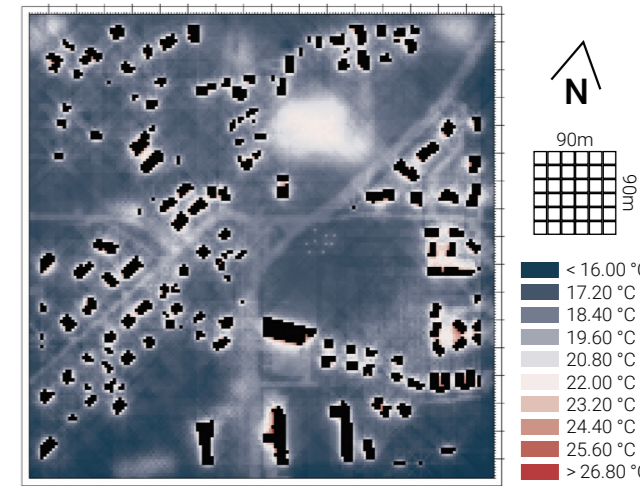


Figure 310. Mean radiant temperature calculations of a typical heatwave scenario, during 22.00h

# Site 01 | Cold spell 14:00h

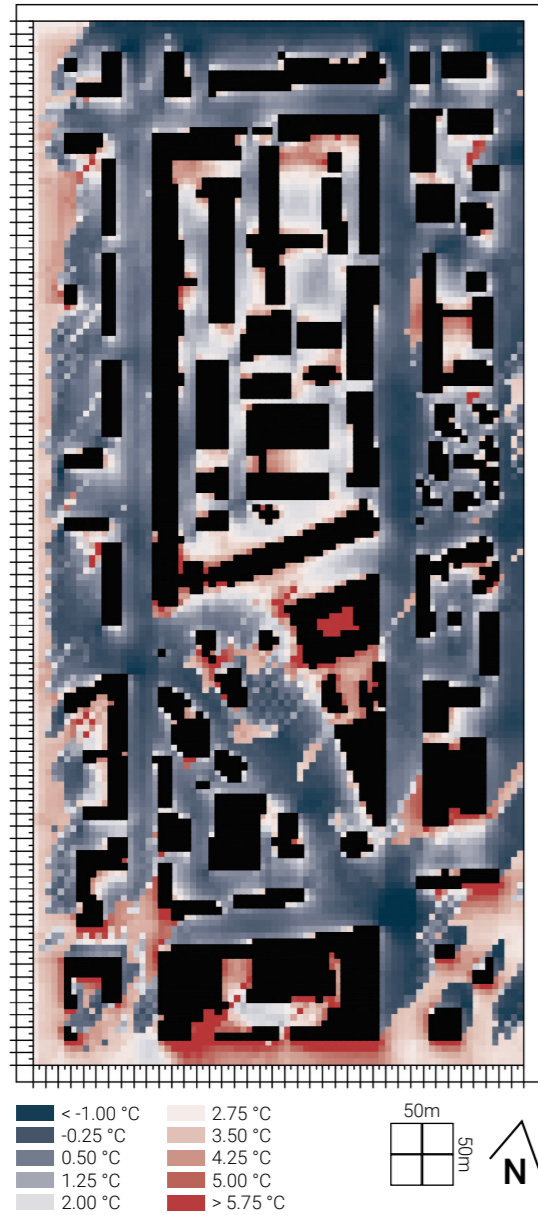


Figure 312. PET calculations of a typical cold spell scenario, during 14.00h for Children (8y.)

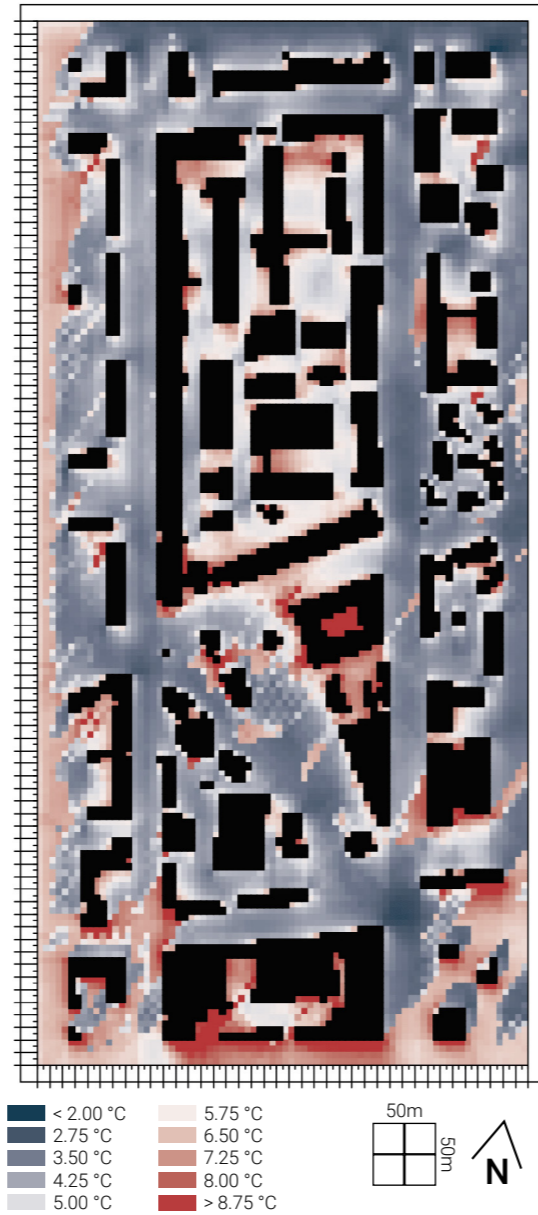


Figure 311. PET calculations of a typical cold spell scenario, during 14.00h for Elderly (80y.)

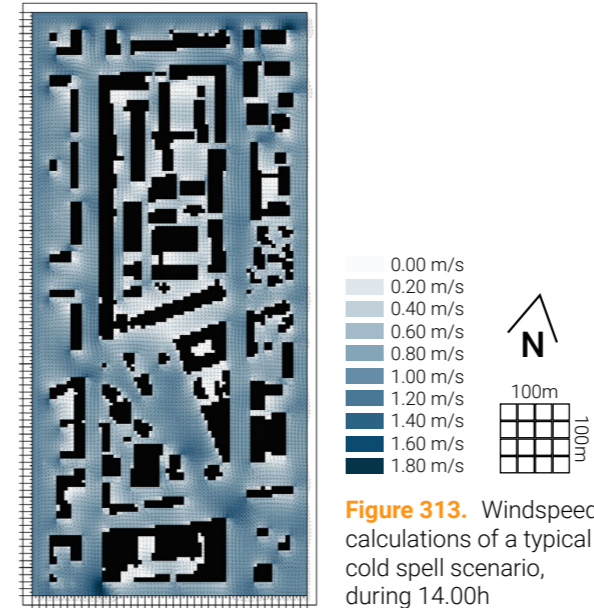


Figure 313. Windspeed calculations of a typical cold spell scenario, during 14.00h

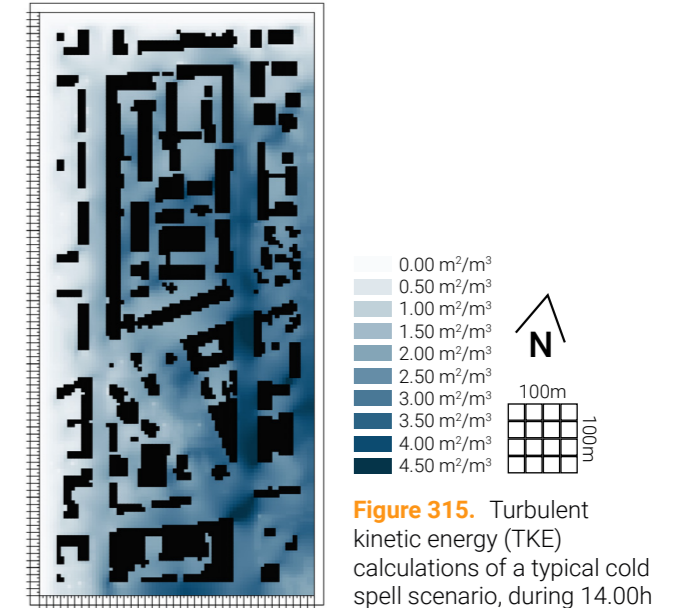


Figure 315. Turbulent kinetic energy (TKE) calculations of a typical cold spell scenario, during 14.00h

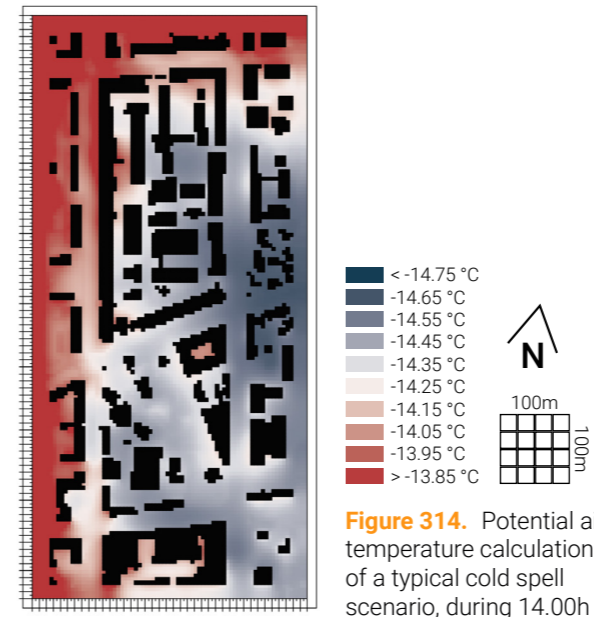


Figure 314. Potential air temperature calculations of a typical cold spell scenario, during 14.00h

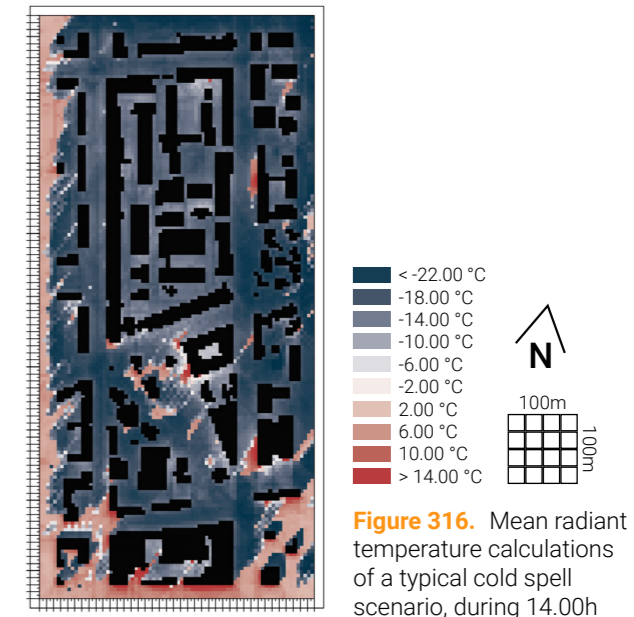
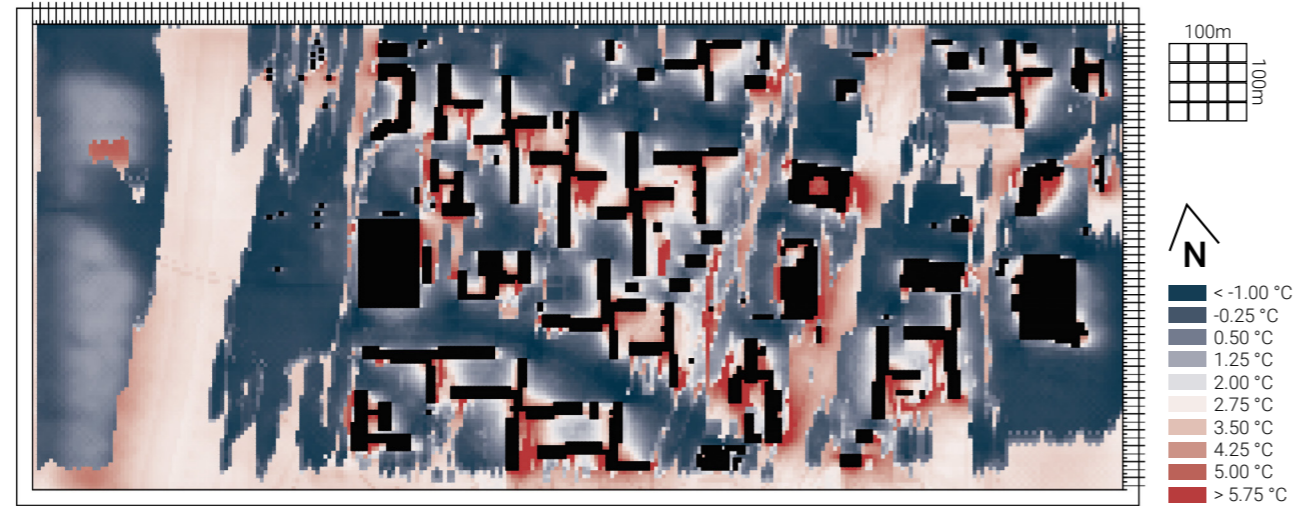
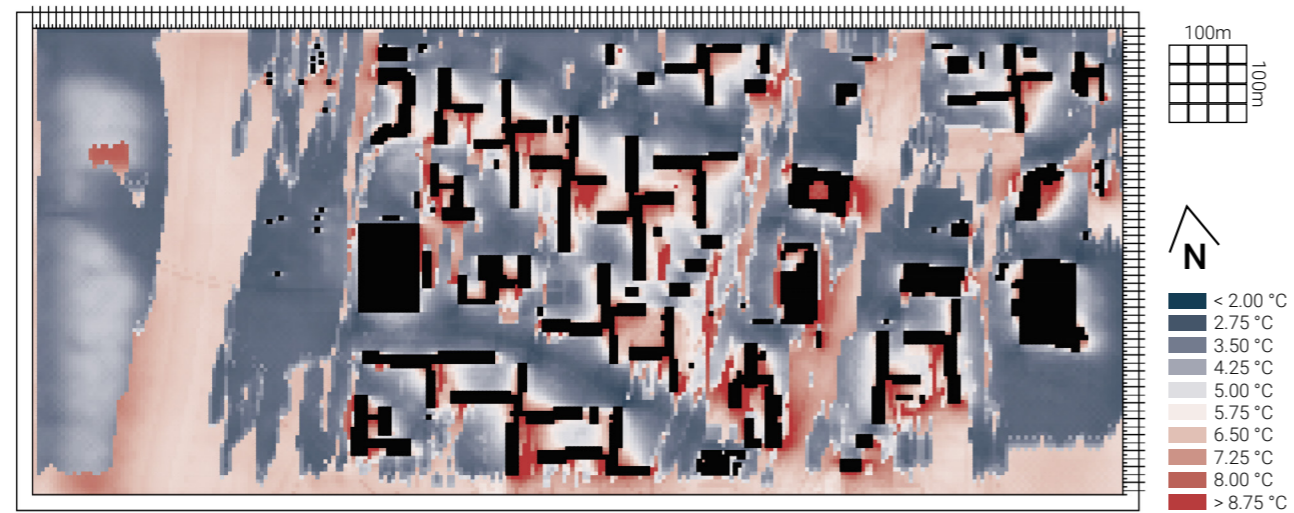


Figure 316. Mean radiant temperature calculations of a typical cold spell scenario, during 14.00h

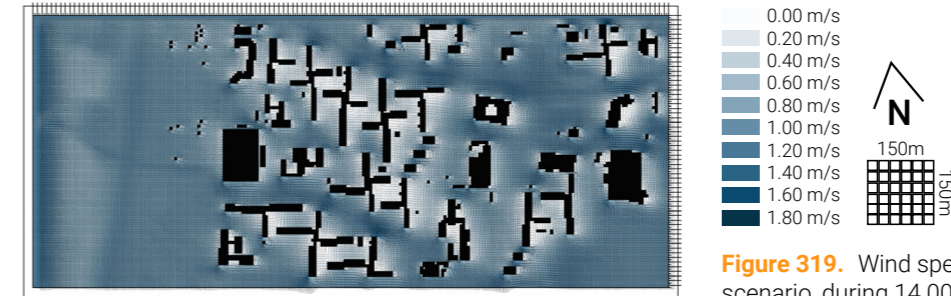
## Site 02 | Cold spell 14:00h



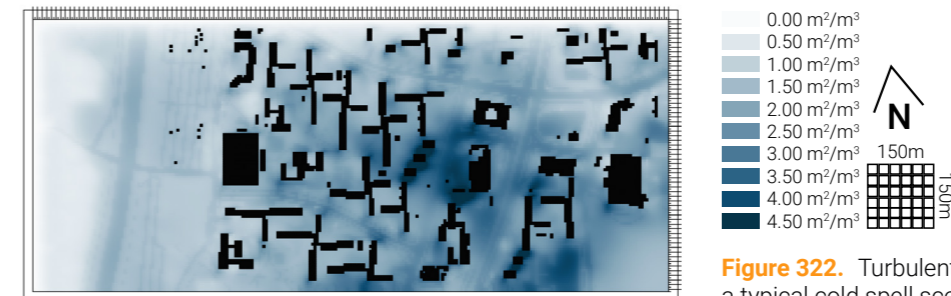
**Figure 317.** PET calculations of a typical cold spell scenario, during 14.00h for Children (8y.)



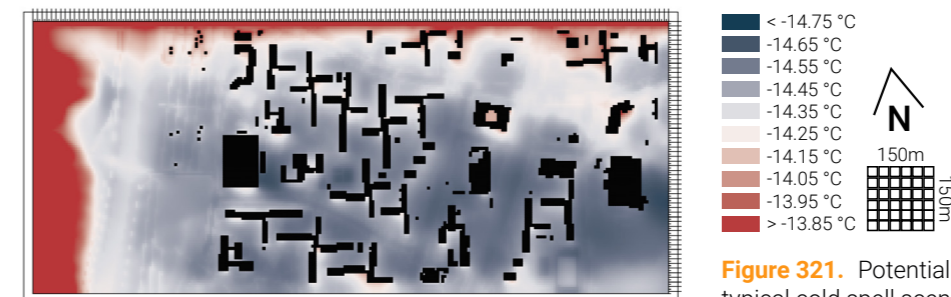
**Figure 318.** PET calculations of a typical cold spell scenario, during 14.00h for Elderly (80y.)



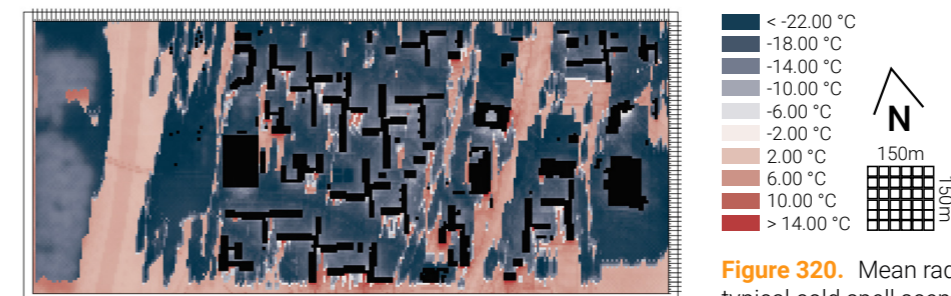
**Figure 319.** Wind speed calculations of a typical cold spell scenario, during 14.00h



**Figure 320.** Turbulent kinetic energy (TKE) calculations of a typical cold spell scenario, during 14.00h

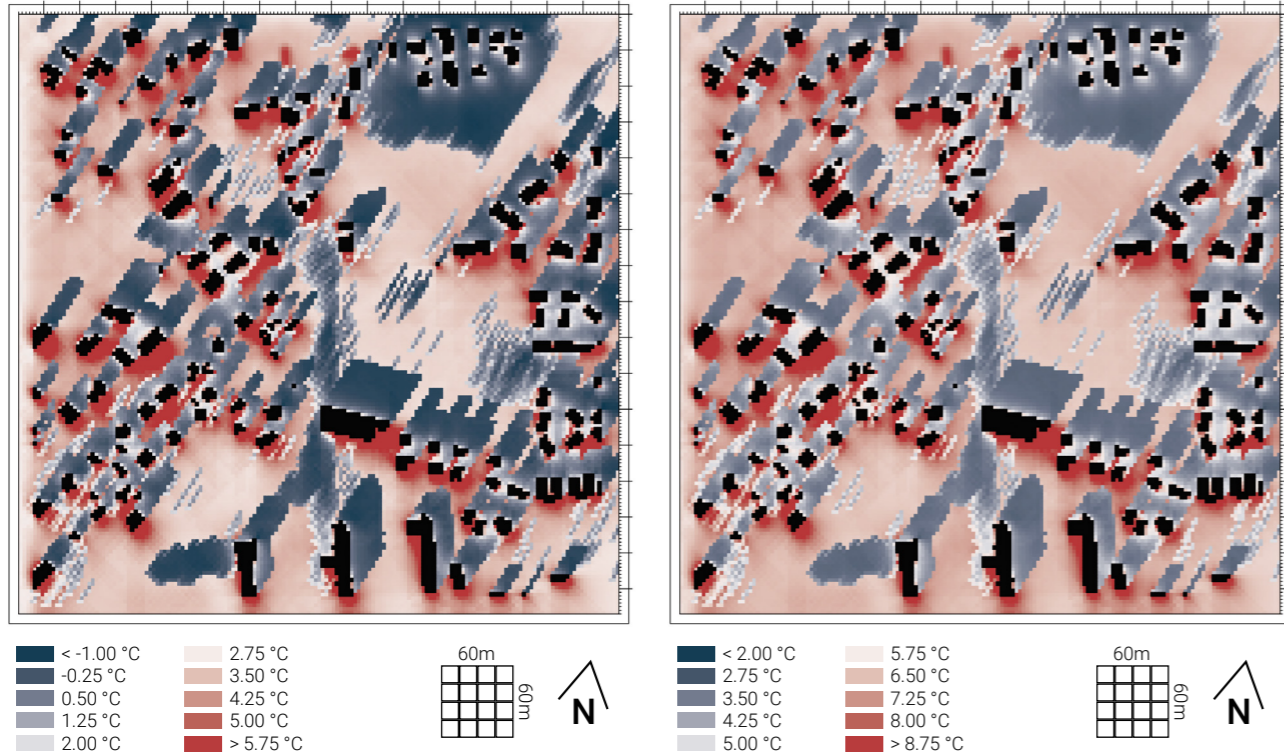


**Figure 321.** Potential air temperature calculations of a typical cold spell scenario, during 14.00h



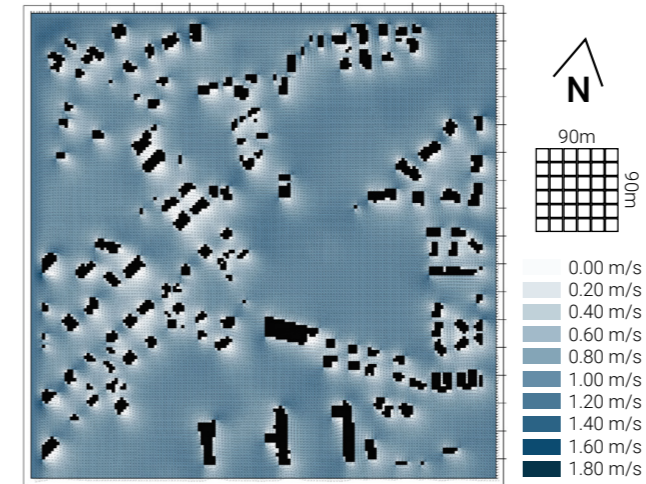
**Figure 322.** Mean radiant temperature calculations of a typical cold spell scenario, during 14.00h

# Site 03 | Cold spell 14:00h

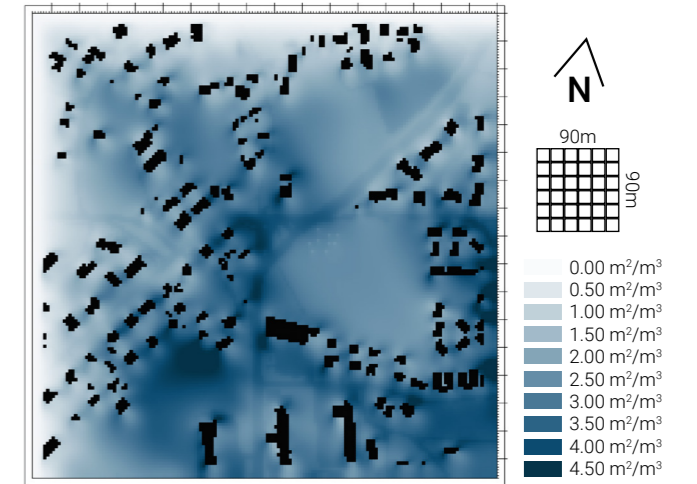


**Figure 324.** PET calculations of a typical cold spell scenario, during 14.00h for Children (8y.)

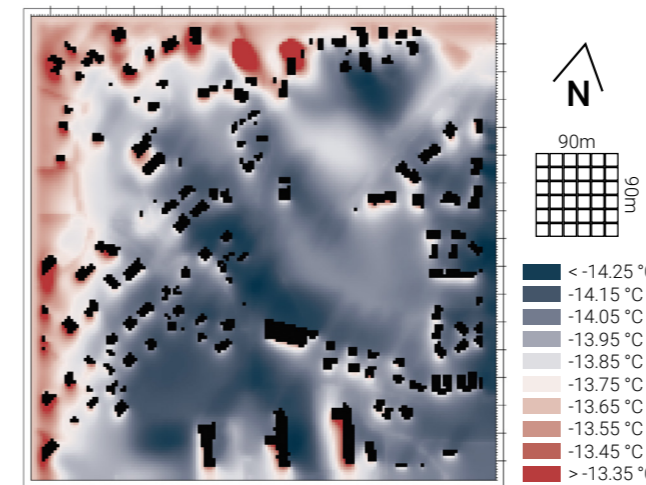
**Figure 323.** PET calculations of a typical cold spell scenario, during 14.00h for Elderly (80y.)



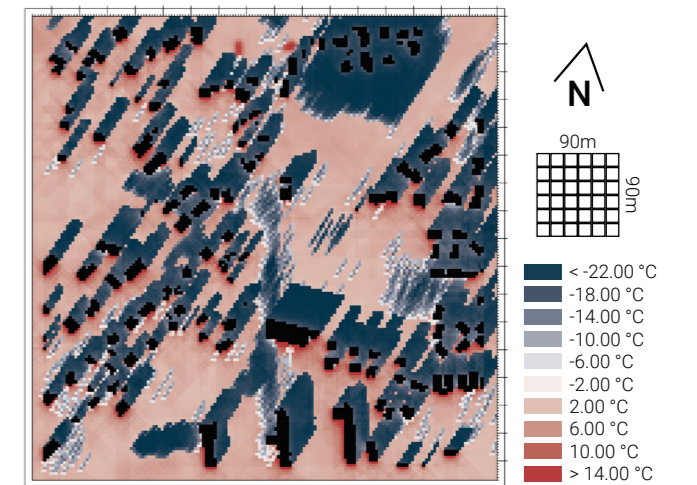
**Figure 325.** Wind speed calculations of a typical cold spell scenario, during 14.00h



**Figure 327.** Turbulent kinetic energy (TKE) calculations of a typical cold spell scenario, during 14.00h



**Figure 326.** Potential air temperature calculations of a typical cold spell scenario, during 14.00h



**Figure 328.** Mean radiant temperature calculations of a typical cold spell scenario, during 14.00h

# Fieldwork Climate Recordings

## Site 01 - Naujamiestis

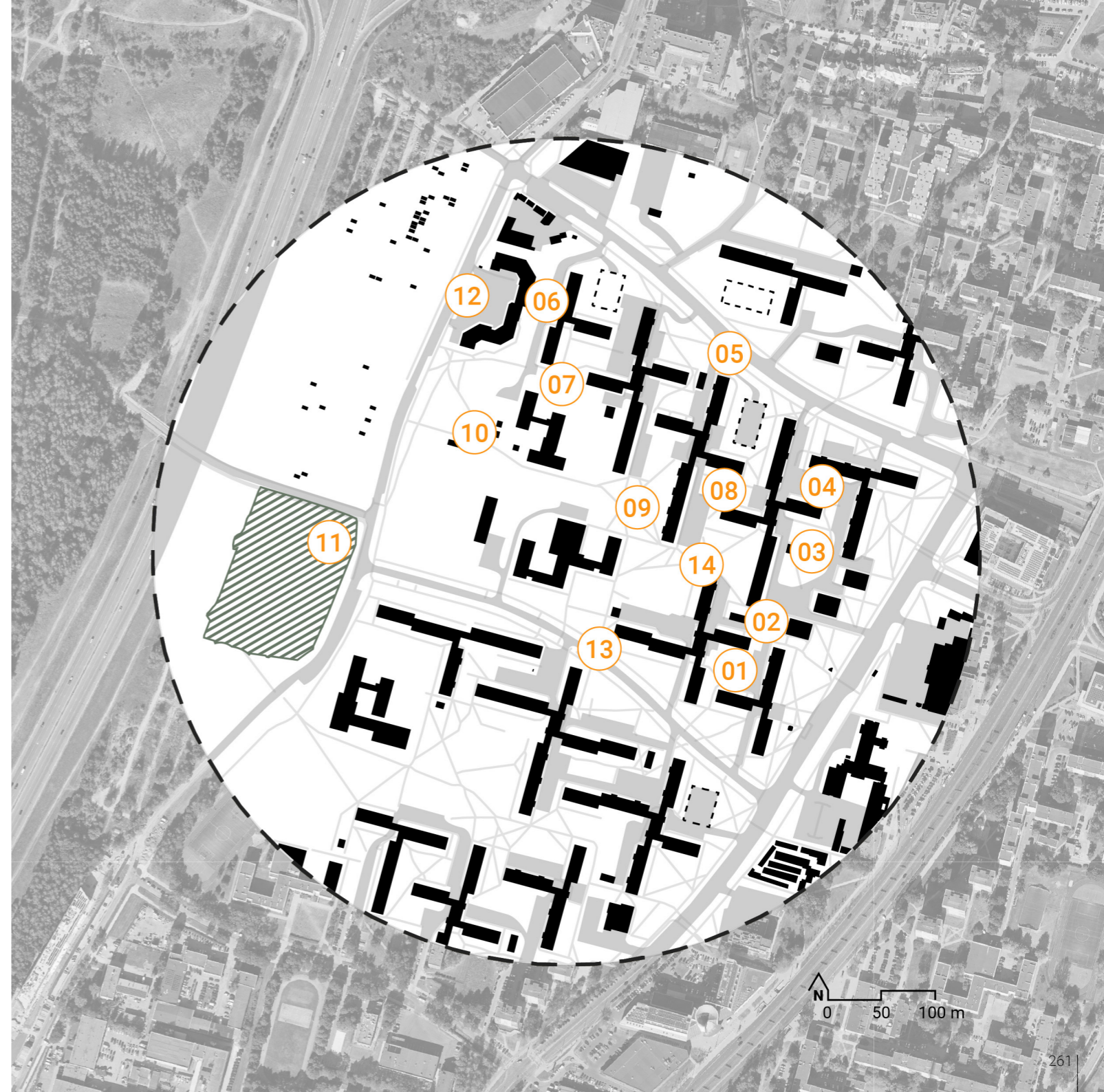
Device Name	HEAT - 2732855 (13)									
Device Model	5400CL									
Serial Number	2732855									
Recording Site	Formatted Date_Time	Temperature	Wet Bulb Temp	Globe Temperature	Relative Humidity	Wind Speed	Heat Index	NWB Temp	Wet Bulb Globe Temperature	Wind Chill
Area	YYYY-MM-DD HH:M-M:SS	Å°C	Å°C	Å°C	%	km/h	Å°C	Å°C	Å°C	Å°C
<b>Cold period</b>										
Area 01	12 Jan 2025 / 6:09:21 pm	0.708	-0.075	-0.533	85.867	0.125	0.667	-0.367	-0.3	0.667
Area 02	12 Jan 2025 / 6:06:38 pm	0.342	-0.358	-0.5	86.9	1.608	0.283	-0.492	-0.392	0.283
Area 03	12 Jan 2025 / 6:04:08 pm	0.558	-0.15	-0.3	86.492	0.317	0.508	-0.5	-0.4	0.508
Area 04	12 Jan 2025 / 6:02:12 pm	0.4	-0.3	-0.3	87.008	2.125	0.342	-0.5	-0.4	0.342
Area 05	12 Jan 2025 / 6:00:24 pm	0.569	-0.2	-0.362	86.108	0.808	0.515	-0.308	-0.208	0.515
Area 06	12 Jan 2025 / 5:58:02 pm	0.658	-0.1	-0.3	86.117	1.058	0.6	-0.167	-0.067	0.6
Area 07	12 Jan 2025 / 5:56:16 pm	0.675	-0.083	-0.1	86.325	0.65	0.65	-0.625	-0.425	0.65
Area 08	12 Jan 2025 / 5:52:42 pm	0.85	0.017	-0.2	85.592	0.358	0.783	-0.4	-0.3	0.783
Area 09	12 Jan 2025 / 5:50:52 pm	0.867	0.008	-0.475	85.017	0.1	0.825	-0.158	-0.1	0.825
<b>Warm period</b>										
Area 2	17 Apr 2025 / 2:38:03 pm	28.2	18.892	34.685	41.677	1.392	27.654	19.962	23.585	28.154
Area 3	17 Apr 2025 / 2:35:27 pm	27.875	18.492	32.125	40.717	3.7	27.208	19.175	22.533	27.833
Area 4	17 Apr 2025 / 2:32:53 pm	26.962	18.123	29.338	42.615	3.223	26.208	18.369	21.377	26.923
Area 6	17 Apr 2025 / 2:40:30 pm	27.633	18.917	36.05	44.133	0.925	27.192	19.55	23.333	27.575
Area 7	17 Apr 2025 / 2:43:08 pm	26.723	17.923	33.969	42.469	2.823	25.892	19.785	23.323	26.685
Area 9	17 Apr 2025 / 2:45:05 pm	27.358	18.567	34.767	43.425	1.992	26.758	20.217	23.742	27.325
Area 10	17 Apr 2025 / 2:48:39 pm	29.3	19.358	32.25	39.533	1.817	29.008	19.267	22.658	29.267
Area 11	17 Apr 2025 / 2:30:44 pm	27.275	18.417	32.508	42.725	1.092	26.575	19.95	23.217	27.233
Area 12	17 Apr 2025 / 2:25:43 pm	29.283	19.75	35.475	41.6	1.425	29.242	20.125	23.85	29.217
Area 13	17 Apr 2025 / 2:19:02 pm	26.317	17.458	33.908	41.842	8.933	25.367	19.525	23.067	26.258
Area 14	17 Apr 2025 / 2:14:31 pm	27.408	18.883	34.117	44.892	1.958	26.958	20.142	23.558	27.367
Area 15	17 Apr 2025 / 2:05:01 pm	26.325	19.425	31.167	53.167	2.767	26.367	20.408	23.075	26.258



# Fieldwork Climate Recordings

## Site 02 - Karoliniškės

Device Name	HEAT - 2732855 (13)									
Device Model	5400CL									
Serial Number	2732855									
Recording Site	Formatted Date_Time	Temperature	Wet Bulb Temp	Globe Temperature	Relative Humidity	Wind Speed	Heat Index	NWB Temp	Wet Bulb Globe Temperature	Wind Chill
Area	YYYY-MM-DD HH:M-M:SS	°C	°C	°C	%	km/h	°C	°C	°C	°C
<b>Cold period</b>										
Area 01	12 Jan 2025 / 2:45:32 pm	0.55	-0.25	-0.167	85.667	1.1	0.508	-0.225	-0.2	0.508
Area 02	12 Jan 2025 / 2:43:20 pm	0.458	-0.292	0.042	86.658	0.3	0.4	-0.433	-0.258	0.4
Area 03	12 Jan 2025 / 2:40:56 pm	0.158	-0.583	0.383	86.725	1.775	0.1	-0.583	-0.292	-0.192
Area 04	12 Jan 2025 / 2:38:56 pm	0.608	-0.242	0.167	84.825	0.458	0.533	-0.4	-0.2	0.533
Area 05	12 Jan 2025 / 2:35:11 pm	0.508	-0.508	0.308	82.325	1.833	0.4	-0.383	-0.2	0.458
Area 06	12 Jan 2025 / 2:31:48 pm	0.667	-0.383	0.233	81.817	1.758	0.55	-0.275	-0.117	0.625
Area 07	12 Jan 2025 / 2:29:48 pm	0.95	-0.133	0.167	80.758	0.342	0.825	-0.5	-0.308	0.925
Area 08	12 Jan 2025 / 2:23:34 pm	0.4	-0.667	0.192	81.142	2.533	0.283	-0.633	-0.367	0.258
Area 09	12 Jan 2025 / 2:21:03 pm	0.333	-0.667	0.083	82.208	2.542	0.2	-0.558	-0.325	0.142
Area 10	12 Jan 2025 / 2:17:40 pm	0.55	-0.467	0.067	82.158	1.475	0.45	-0.333	-0.183	0.517
<b>Warm period</b>										
Area 1	17 Apr 2025 / 3:41:52 pm	27.85	17.7	34.4	36.725	2.008	26.667	19.058	22.9	27.792
Area 3	17 Apr 2025 / 3:48:26 pm	26.9	16.733	31.092	35.567	3.5	25.508	17.875	21.408	26.858
Area 4	17 Apr 2025 / 4:04:51 pm	26.967	16.217	32.167	32.633	4.317	25.317	17.608	21.4	26.933
Area 5	17 Apr 2025 / 4:07:15 pm	27.779	16.943	33.686	33.3	3.714	26.264	17.971	21.95	27.736
Area 8	17 Apr 2025 / 4:09:34 pm	28.823	17.515	36.485	32.462	1.762	27.431	19.215	23.538	28.762
Area 9	17 Apr 2025 / 3:35:05 pm	26.433	17.308	34.008	40.525	3.15	25.392	18.925	22.583	26.392
Area 10	17 Apr 2025 / 3:30:04 pm	28.158	18.85	33.942	41.558	2.092	27.6	19.958	23.425	28.083
Area 11	17 Apr 2025 / 4:28:26 pm	26.542	17.467	30.675	40.867	0.475	25.533	18.5	21.725	26.492
Area 12	17 Apr 2025 / 4:20:26 pm	27.783	17.092	36.025	33.942	3.35	26.3	18.883	23.075	27.75
Area 13	17 Apr 2025 / 3:37:46 pm	26.517	16.7	36.042	36.892	5.825	25.175	19.033	23.117	26.45
Area 14	17 Apr 2025 / 3:43:46 pm	27.342	17.117	34.875	35.808	1.017	26.033	19.092	23.042	27.292



# Fieldwork Climate Recordings

## Site 03 - Northern Verkiai territory

Device Name	HEAT - 2732855 (13)									
Device Model	5400CL									
Serial Number	2732855									
Recording Site	Formatted Date_Time	Temperature	Wet Bulb Temp	Globe Temperature	Relative Humidity	Wind Speed	Heat Index	NWB Temp	Wet Bulb Globe Temperature	Wind Chill
Area	YYYY-MM-DD HH:M-M:SS	Å°C	Å°C	Å°C	%	km/h	Å°C	Å°C	Å°C	Å°C
<b>Cold period</b>										
Area 01	13 Jan 2025 / 1:17:08 pm	-1.383	-2.133	-0.5	83.358	1.75	-1.325	-2.967	-2.4	-1.325
Area 02	13 Jan 2025 / 1:13:04 pm	-1.831	-2.462	-0.238	85.308	5.723	-1.785	-2.8	-2.215	-4.462
Area 03	13 Jan 2025 / 1:22:39 pm	-0.585	-1.562	-0.469	80.777	0.231	-0.546	-2.538	-2.054	-0.546
Area 04	13 Jan 2025 / 1:41:20 pm	-1.275	-1.983	-0.767	84.6	0.75	-1.225	-2.542	-2.1	-1.225
Area 05	13 Jan 2025 / 1:25:29 pm	-1.792	-2.315	-0.246	87.369	2.546	-1.746	-2.3	-1.8	-1.754
Area 06	13 Jan 2025 / 1:37:59 pm	-1.669	-2.319	-0.844	85.55	6.863	-1.619	-2.288	-1.925	-5.063
Area 07	13 Jan 2025 / 1:29:36 pm	-1.407	-2.079	-0.464	84.779	2.736	-1.364	-2.243	-1.771	-2.179
Area 08	13 Jan 2025 / 1:32:56 pm	-0.992	-1.692	-0.683	85.417	0.5	-0.942	-2.2	-1.8	-0.942
<b>Warm period</b>										
Area 01	18 Apr 2025 / 1:38:52 pm	26.625	17.108	37.242	38.633	7.217	25.45	19.733	23.892	26.575
Area 02	18 Apr 2025 / 1:33:45 pm	27.083	17.658	36.808	39.733	3.925	26.075	19.675	23.717	27.025
Area 03	18 Apr 2025 / 1:28:50 pm	27.6	17.667	33.892	37.8	2.117	26.475	19.1	22.833	27.525
Area 04	18 Apr 2025 / 1:09:08 pm	26.958	17.433	37.375	39	3.683	25.875	19.983	24.108	26.917
Area 05	18 Apr 2025 / 1:14:02 pm	28.475	17.967	36.792	35.792	1.425	27.4	20.3	24.408	28.433
Area 06	18 Apr 2025 / 1:24:09 pm	28.392	18.415	33.438	38.423	1.3	27.546	18.823	22.485	28.331
Area 07	18 Apr 2025 / 1:19:40 pm	26.279	16.85	32.507	38.714	6.164	25.036	18.486	22.057	26.2
Area 09	18 Apr 2025 / 1:06:55 pm	29.383	19.242	33.25	38.75	0.858	29.025	19.408	22.933	29.342



# Typical Heatwave Hourly Climate Data

Date/Time	Time (h)	Air Temp. (°C)	Rel. Humidity (%)	Wind Dir. (dir)	Wind Speed (m/s)	Wind Direction	Wind Speed	X vector	Y vector	Wind Rose	Typical Extreme	Average Hourly Air Temp. (°C)	Average Relative Humidity (%)	Average Wind Speed (m/s)	Average Wind Direction (°)
22/06/2021	00:00	20.9	73	71	1.2	85-95	0.1	-0.945518	-0.3556815	Wind Rose	00:00	21.2	75	21.2	75
	01:00	20.3	78	104	1.2	85-105	0.1	-1.164349	-0.2900627	Wind Direction	01:00	21.6	77	21.6	77
	02:00	20.0	79	128	1.2	120-135	1.2	-1.370212	-0.1122293	Wind Speed	02:00	19.96	79.2	19.96	79.2
	03:00	20.9	79	133	1.2	120-135	2.3	-1.925196	1.7719720	Wind Direction	03:00	19.82	79.4	19.82	79.4
	04:00	21.9	77	144	2.5	130-145	2.3	-1.4984631	2.022542486	Wind Speed	04:00	21.18	75.4	21.18	75.4
	05:00	22.9	76	148	2.7	140-155	2.3	-1.430792	2.28972899	Wind Direction	05:00	22.82	71.2	22.82	71.2
	06:00	24.2	74	150	3.4	140-155	1.4	-1.299694965	2.912145	Wind Speed	06:00	24.74	64.4	24.74	64.4
	07:00	26.7	61	170	3.4	160-175	3.4	-0.9904038	3.34834436	Wind Direction	07:00	26.84	55.4	26.84	55.4
	08:00	28.3	53	164	3.8	150-165	3.4	-1.047422	3.65297444	Wind Speed	08:00	28.42	50	28.42	50
	09:00	28.4	49	150	3.8	140-155	3.4	-1.087874	3.6664871	Wind Direction	09:00	28.82	44.4	28.82	44.4
	10:00	29.5	49	146	3.8	140-155	3.4	-1.24993	3.159342778	Wind Speed	10:00	30.34	31.6	30.34	31.6
	11:00	29.8	47	147	4.0	140-155	3.4	-1.278561	3.24862272	Wind Direction	11:00	30.9	29.8	30.9	29.8
	12:00	29.7	44	148	4.0	140-155	3.4	-1.212089	3.4097124	Wind Speed	12:00	31.44	26.4	31.44	26.4
	13:00	30.1	47	138	4.9	130-145	4.5	-1.27874	3.64456460	Wind Direction	13:00	31.42	20	31.42	20
	14:00	30.6	45	138	4.8	130-145	4.5	-1.2118289	3.567095162	Wind Speed	14:00	31.38	38.2	31.38	38.2
	15:00	30.7	46	139	4.4	130-145	3.4	-0.824291	3.05838232	Wind Direction	15:00	31.22	38.6	31.22	38.6
	16:00	30.8	44	139	4.8	130-145	4.5	-0.9178718	3.471664949	Wind Speed	16:00	30.8	39.8	30.8	39.8
	17:00	29.9	47	140	3.5	130-145	3.4	-2.047566	2.681155551	Wind Direction	17:00	29.46	44.6	29.46	44.6
	18:00	28.9	50	134	2.4	120-135	2.3	-1.7284155	1.667180899	Wind Speed	18:00	27.72	60.6	27.72	60.6
	19:00	27	57	106	1.7	100-115	1.2	-1.6241449	0.660200305	Wind Direction	19:00	25.74	88.8	25.74	88.8
	20:00	25.8	62	127	1.6	120-135	1.2	-1.2778158	0.962964037	Wind Speed	20:00	24.4	63.8	24.4	63.8
	21:00	24.9	66	119	1.4	110-125	1.2	-1.2244676	0.67873468	Wind Direction	21:00	23.62	68.4	23.62	68.4
	22:00	23.9	71	105	1.3	120-135	1.2	-1.3732089	0.892164928	Wind Speed	22:00	22.64	71.2	22.64	71.2
	23:00	23.5	73	113	1.3	100-115	1.2	-1.1966563	0.507950467	Wind Direction	23:00	21.94	77.2	21.94	77.2
16/07/2021	00:00	22.4	87	285	1.2	280-295	1.2	1.83185165	-0.51763899	Wind Rose	00:00	21.5	81.2	21.5	81.2
	01:00	22.6	89	282	0.9	100-115	0.1	-0.927051	0.252116505	Wind Direction	01:00	21.2	82	21.2	82
	02:00	22.8	92	276	0.9	70-85	0.1	-0.7727497	-0.20706436	Wind Speed	02:00	21.2	82	21.2	82
	03:00	21	92	194	0.5	180-195	0.1	0.1206095	0.485147863	Wind Direction	03:00	22.9	82	22.9	82
	04:00	23.6	91	191	0.5	80-95	0.1	-0.4999238	0.048770203	Wind Speed	04:00	22.6	81	22.6	81
	05:00	25.2	87	182	0.5	100-115	0.1	-0.5581623	0.246739566	Wind Direction	05:00	22.1	81	22.1	81
	06:00	27.2	70	57	1.3	55-65	1.2	-1.092717	-0.70820707	Wind Speed	06:00	22.0	83	22.0	83
	07:00	29.5	57	105	0.1	100-115	0.1	-0.8692528	0.258819045	Wind Direction	07:00	20.8	82	20.8	82
	08:00	30.6	50	121	1.3	110-125	1.2	-1.141375	0.605489749	Wind Speed	08:00	20.9	82	20.9	82
	09:00	31.8	48	149	1.6	70-85	1.2	-1.8609216	0.26201709	Wind Direction	09:00	21.3	79	21.3	79
	10:00	31.8	48	149	1.6	140-155	1.2	-0.8240609	1.371467881	Wind Speed	10:00	21.5	84	21.5	84
	11:00	32.2	48	158	2.3	100-165	2.3	-0.8241345	2.03984448	Wind Direction	11:00	21.7	80	21.7	80
	12:00	33	44	155	2.3	110-125	1.2	-1.308412	0.638378383	Wind Speed	12:00	21.7	80	21.7	80
	13:00	33.1	45	155	2.3	100-165	1.2	-0.8452365	1.812615574	Wind Direction	13:00	21.6	82	21.6	82
	14:00	33	44	155	2.3	100-165	1.2	-0.8452365	1.812615574	Wind Speed	14:00	21.4	85	21.4	85
	15:00	32.9	44	154	1.4	140-155	1.2	-0.7948789	1.720721444	Wind Direction	15:00	21.4	85	21.4	85
	16:00	32.7	44	156	1.2	100-115	1.2	-1.153514	0.330764827	Wind Speed	16:00	21.8	85	21.8	85
	17:00	31.3	48	159	1.2	100-115	1.2	-1.1346223	0.309881783	Wind Direction	17:00	21.6	85	21.6	85
	18:00	29.3	54	104	1.2	100-115	1.2	-1.0712523	0.286114805	Wind Speed	18:00	21.2	84	21.2	84
	19:00	28.8	55	95	0.7	80-95	0.1	-0.673263	0.01001002	Wind Direction	19:00	21.7	81	21.7	81
	20:00	25.4	69	96	0.4	80-95	0.1	-0.3978088	0.041811385	Wind Speed	20:00	21.4	85	21.4	85
	21:00	24.1	81	309	1.4	300-315	1.2	1.0880435	-0.18134859	Wind Direction	21:00	21.7	85	21.7	85
	22:00	23.1	86	286	0.8	280-295	0.1	0.4896841	0.17448748	Wind Speed	22:00	21.8	84	21.8	84
	23:00	22.6	89	217	0.3	160-175	0.1	-0.4680303	0.29630502	Wind Direction	23:00	21.8	84	21.8	84
24/08/2021	00:00	21	60	132	2.6	120-135	2.3	-1.932176	1.78739877	Wind Rose	00:00	21.5	82	21.5	82
	01:00	22.9	55	120	2.6	120-135	1.2	-1.4627074	1.36399716	Wind Direction	01:00	22.2	82	22.2	82
	02:00	19.5	64	120	1.8	110-125	1.2	-1.588467	0.9	Wind Speed	02:00	19.6	80	19.6	80
	03:00	18.6	67	119	2.1	110-125	2.3	-1.8367014	1.018100203	Wind Direction	03:00	19.6	80	19.6	80
	04:00	18.8	68	131	2.1	120-135	2.3	-1.584891	1.377270961	Wind Speed	04:00	19.8	80	19.8	80
	05:00	19	65	129	2.8	120-135	2.3	-1.770071	1.762097166	Wind Direction	05:00	19.7	80	19.7	80
	06:00	22.4	61	124	1.9	110-125	1.2	-1.5751714	1.024668511	Wind Speed	06:00	21.4	86	21.4	86
	07:00	23.7	57	135	2.5	130-145	2.3	-1.767767	1.767769853	Wind Direction	07:00	22.4	86	22.4	86
	08:00	25.1	54	141	2.5	140-155	2.3	-1.4584823	2.25445057	Wind Speed	08:00	22.4	86	22.4	86
	09:00	28.1	43	147	2.7	140-155	2.3	-1.4705254	2.264419533	Wind Direction	09:00	28.1	43	28.1	43
	10:00	30	35	135	2.9	130-145	2.3	-1.2132033	2.132320344	Wind Speed	10:00	28.1	43	28.1	43
	11:00	31.5	33	141	3.1	140-155	2.3	-1.2284654	2.25445057	Wind Direction	11:00	28.1	43	28.1	43
	12:00	30.9	32	171	4.4	160-175	4.5	-0.6883116	4.34826969	Wind Speed	12:00	28.7	83	28.7	83
	13:00	30.8	34	189	4.2	180-195	4.5	0.6570245	4.14829103	Wind Direction	13:00	28.7	83	28.7	83
	14:00	30.1	34	184	3.4	180-195	3.4	-0.406821	3.65889791	Wind Speed	14:00	28.7	83	28.7	83
	15:00	29.6	35	180	3.1	180-195	3.4	-0.347928	2.47967913	Wind Direction	15:00	28.7	83	28.7	83
	16:00	29.6	38	162	1.7	150-165	1.2	-0.525289	1.616796078	Wind Speed	16:00	29.6	38	29.6	38
	17:00	27.7	43	111	1.3	100-115	1.2	-1.120296	0.40041539	Wind Direction	17:00	27.7	43	27.7	43
	18:00	26.9	49	102	0.8	100-115	0.1	-0.8386786	0.446402626	Wind Speed	18:00	26.9	49	26.9	49
	19:00	23.6	60	136	0.6	130-145	0.1	-0.416795	0.43160388	Wind Direction	19:00	23.6	60	23.6	60
	20:00	22	66	129	0.1	120-135	1.2	-0.8548068	0.89223243	Wind Speed	20:00	22	66	22	66
	21:00	22.2	64	127	0.1	120-135	1.2	-1.718208	0.6846637	Wind Direction	21:00	22.2	64	22.2	64
	22:00	20.8	66	142	0.9	130-145	0.1	-0.5549953	0.792092678	Wind Speed	22:00	20.8	66	20.8	66
	23:00	19.7	70	132	1.3	120-135	1.2	-0.9660883	0.898987788	Wind Direction	23:00	19.7	70	19.7	70
16/08/2023	00:00	21.1	83	143	1.8	130-145	1.2	-0.926204	0.771973819	Wind Rose	00:00	21.1	83	21.1	83
	01:00	20.3	85	136											

