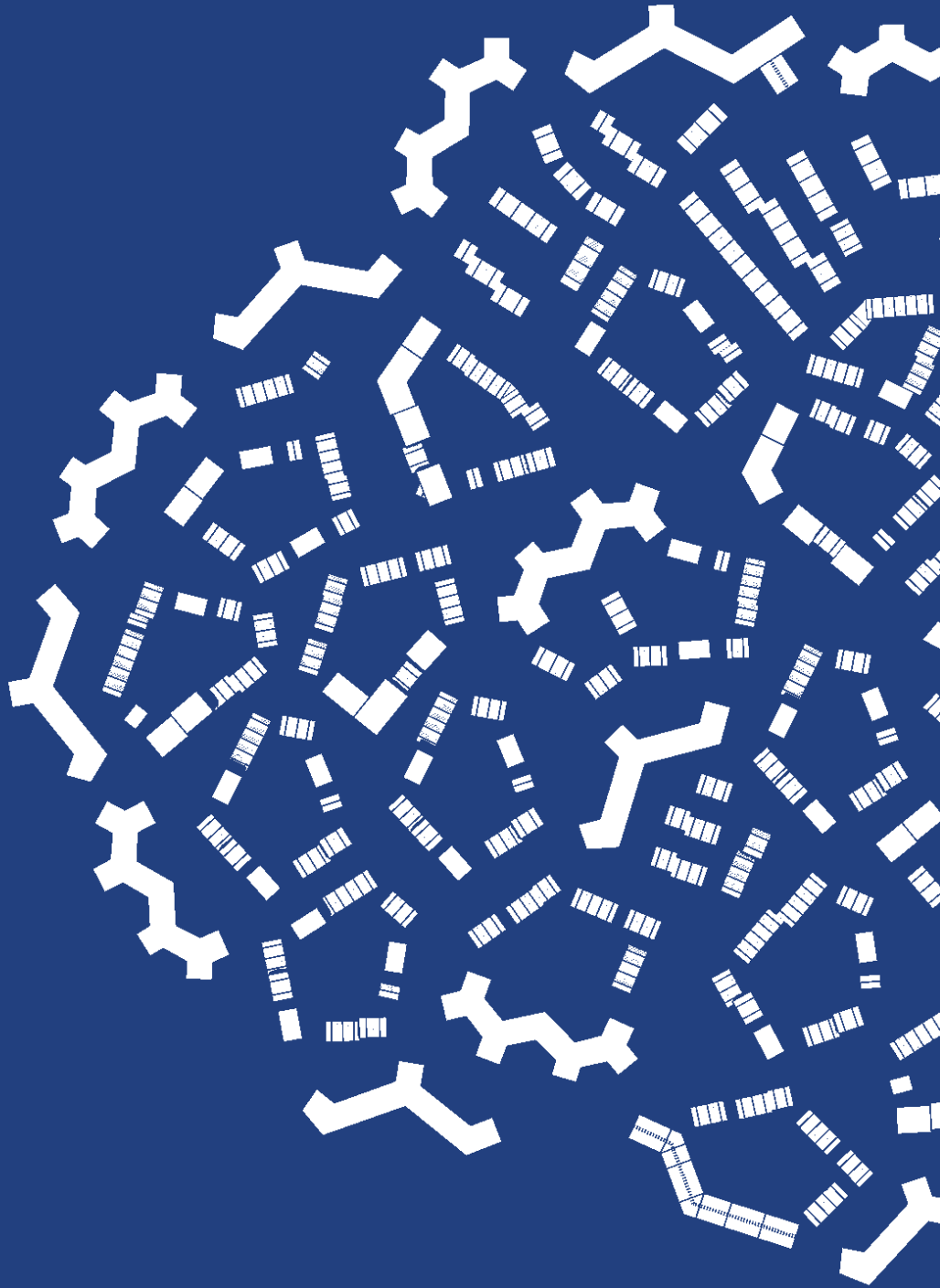


Outdoor Comfort in the Cold

CFD-Informed Microclimate
Design for Subarctic Cities

Jonna Pestrea



Examiner: Nils Björling | Supervisor: John Hemfridssons
Department of Architecture and Civil Engineering | MPARC
Urban Architecture | 2026



CHALMERS
UNIVERSITY OF TECHNOLOGY

Author: Jonna Pestrea
Examiner: Nils Björling | Supervisor: John Hemfridssons
Department of Architecture and Civil Engineering | MPARC
Urban Architecture | 2026

Abstract

This thesis investigates how urban morphologies and spatial configurations can be adapted to Arctic conditions, with a focus on environmental comfort and resilience.

The thesis aims to evaluate how variations in urban morphology influence outdoor thermal comfort in Kiruna's subarctic climate. Using Kiruna as a case study, a city relocating due to mining induced ground deformation, the research addresses the need for climate responsive urban strategies in an extreme environment. Due to ongoing climate change, Kiruna is experiencing rising average temperatures, increased rainfall, greater seasonal variability and extreme weather. This creating new challenges for outdoor environmental comfort and climate resilient planning. This in turn highlights the need for iterative design workflows that directly integrate CFD analysis and microclimate data.

A persistent knowledge gap exists between architects, planners and engineers regarding the use of CFD simulations, microclimate knowledge and simplified climate studie methods. Although increasingly recognized as essential for resilient development, these tools remain poorly integrated in mainstream practice due to differences in technical training, methods and professional boundaries. This highlights the need to translate complex environmental analysis into accessible and design driven insights for subarctic development.

The study includes interviews, microclimate modelling, wind and solar radiation simulations and comparative case studies to evaluate the performance of several urban configurations. Simulations are carried out using Autodesk Forma and Forma plugins for Rhino 8 which assesses solar exposure, wind flow and microclimatic interactions. The workflow is iterative and scenario based, using seasonal boundary conditions to compare typologies and street configurations against outdoor thermal comfort criteria.

The results are based on comparisons between different examples of urban morphology. These have been tested within the subarctic climate and urban context of Kiruna. The design is grounded in the insights and outcomes generated by the tests. One configuration will then be developed in detail, integrating rainwater management, social functions and green infrastructure. Ultimately, the thesis contributes a design oriented framework that bridges environmental simulation and urban morphology, supporting resilient and comfortable public realm design in subarctic contexts.

Keywords:

Urban morphology
CFD simulations
Outdoor thermal comfort
Weather resilience
Subarctic urban design

Acknowledgements

I would like to express my sincere gratitude to my classmates and family for their continuous support and encouragement throughout this process.

A special thank you to Sigrid Vestling, Urban Planning Strategist at the Kiruna Municipality, for her valuable input and genuine interest in this thesis, as well as her thoughtful reflections on the future of urban planning, both in Kiruna and Sweden.

I would also like to thank the following individuals for their time and insights shared through interviews: Angel Perez Morata, Calculation Specialist at White Architects; Emanuel Toft, Investigator at the Environmental Administration, Malmö City; and Viktor Sjöberg, Project Manager at Energicentrum, Stockholm City.

Lastly i also like to thank my supervisor, John Hemfridsson, for his guidance, humour and interest throughout the writing process, and my examiner, Nils Björling, for his valuable feedback and examination of this thesis.

About me



Jonna Pestrea holds degrees in both Architectural Design from Chalmers University of Technology and Information Design from Mälardalen University. This interdisciplinary background combines visual communication with sustainable architecture. With experience as a communicator in the public sector, Jonna brings clarity and purpose to her work. Her passion centers around future architecture, transformation, ecosystem services, and urban planning, guided by the principle: *"If a job is worth doing, it's worth doing well."*

Mail: pestreaarkitektur@outlook.com

Chalmers university

Chalmers education aims to broaden students horizons for working with urban planning at various scales during bachelor's and master's studies. During the first semester of the master's program, students are introduced to tools such as Grasshopper and various Rhino plugins. Through this academic and practical background, there is a clear academic connection to *my master's program specialization in urban planning and architecture.*

Architecture and udesign master - MPARC

YEAR 1 - 2024

Architecture in the anthropocene
Sustainable development and the design professions
Urban prototypes
Building climatology
Managing design projects
Building climatology
Prototypes and assemblages

YEAR 2 - 2025

Master's thesis preparation course
Building on building
Master thesis

Previous education

2016 - 2020

Batchelor in informationsdesign and illustrator
MÄLARDALEN UNIVERSITY

2021 - 2024

Batchelor in Architecture
CHALMERS UNIVERSITY

3

Academic framework

- Abstract
- Student background
- Thesis delimitation
- Background

12

Adressing arctic urban design

THEORY

- Climate and its borders
 - Nordic Climate
 - Swedish Climate Zone
 - Coastal Climate
 - Inland Climate
 - Subarctic Climate
- Arctic ideologies and their development
 - Paradise of the North (1900-1950)
 - Technocratic urbanism (1950-1970)
 - Softening the north (1970-1980s)
 - Climatic cities (1980-1990s)
 - Place-specific urbanism (2000-...)
 - Place-specific urbanism (2000- Present)
- Dimensions of Arctic urbanism
 - The utopian city
 - The postcolonial city
 - The provisional city
 - The experimental city
 - The ecological city
- Urban morphology and the Arctic challenges
- Simplified microclimate methods to study in Kiruna

METHOD

- Strategies, tools and their limits
 - The data and the Tools
 - Design strategy
- Urbana Selection criteria for simulations

25

CFD tools and their uses in architecture

- 3D and simulation tools
 - Interviews about CFD tools & uses
 - Analysing others wind analyses
 - Key information and key findings from the interviews.
 - Felt comfort

- CFD tools
 - Programs and their limits
 - Autodesk Vasari
 - Autodesk Flow Design
 - ODS-Studio
 - CFD Phoenixics
 - ANSYS CFX
 - Mini wind tunnel
 - Autodesk forma
 - Rhinoceros 8

Design principles
Wind mitigation
Solar maximization on the ground
Ground materials and greenery
Snow-, stormwater, and flooding management.

35

The city, the site, the simulations

Kiruna

Place, city, climate, architects, urban planners
Land division and industries
Actors in Kiruna
Urban transformation

The industrial site

New Kiruna city center, Comparison of microclimate studies
Forma comparative simulation (2026)
Ebrahimabadi et al. (2016)
White architects & EPFL simulations (2017)

Kiruna simulations , Studies and instructions

Reading the simulations

Historic compact low-rise urban fabric
Dragør, DNK
Ribe, DNK
Wolfenbüttel, Niedersachsen DEU
Celle, Altstadt, DEU
Greifswald, GER

Open urban fabric

Älvsjö, Stockholm, SWE
Vannkunsten, Oslo, NOR
Billund, DNK
Västra Rostaparken, Örebro, SWE
Mellanheden, Malmö, SWE

Half open blocks

Brunnsbo, Gothenburg, SWE
Fosie, Malmö, SWE
Mong Kok, Hong Kong, CHN 1 & 2
Marmorbyen, Copenhagen, DNK

Closed blocks

Eixample, Barcelona, ESP
Nordhavn, Copenhagen, DNK
Tårnby, DNK
Kungsladugård, Gothenburg, SWE
Kvillebäcken, Gothenburg, SWE

60

Designing with the microclimate

DESIGN

Observations and design choices
Design and mitigation
Design simulations
Exposing design weaknesses in extreme wind

RESULT

Conclusion
Discussion
Bibliography

Research Question

How can architects use urban morphologies and CFD simulations, to design microclimates and outdoor comfort, in a subarctic urban climate?

Thesis delimitations

Limit of the context

This thesis does not engage with broader social or political dynamics, such as the relationships between LKAB, the Municipality of Kiruna, the Sami and local residents. While themes such as cultural heritage, -local identities, and the implementation of ecosystem services fall outside the scope of this study, they may be referenced briefly where relevant.

Comparison and evaluation of CFD tools

Two readily available programs used by architects are Autodesk Forma and Rhino 8. In addition to these, a comparison between general academic CFD programs is conducted.

Design limitation

The thesis project is limited to a central site near Kiruna city centre. with the purpose of exploring and designing urban blocks.

Thesis Structure

Chapter 1

Climatic zones, examples of Swedish climatzoons, architects' impact on the Arctic, Ralph Erskine's work, Simplified microclimate methods

Chapter 2

Interviews, analysis of other people's wind analyses, comparison of cfd tools,

Chapter 3

Kiruna's actors and challenges are introduced. Urban morphological examples are presented.

Chapter 4

The results and observations of the previous chapters lay the foundation for the result and the design.

Chapter 5

Conclusion and discussion

AI

Several AI tools were used for summarizing text, comparing CFD tools, checking grammar, organizing text and testing readability and clarity. One AI was also used as a discussion tool. The AI tools used were ChatGPT, Claude, Co-Pilot.

Glossary

CFD

Computational Fluid Dynamics

CFD simulations

A computer simulation that visualizes how fluids and air move. Often used by engineers.

Outdoor thermal comfort

The perceived outdoor comfort in response to local thermal conditions, which includes human and weather related factors like wind frequencies, wind speed, humidity, temperature and solar radiation.

Climate

The overall long-term patterns and averages of weather in a region, including temperature, wind, humidity and precipitation.

Urban morphology

The study of the physical form and structure of urban areas, including layout, building typologies and spatial configuration.

BACKGROUND

Architecture and urban design work with flows, materiality, places, zones, and experiences of these. There are also newer fields like climate adaptation and sustainability, which are becoming more incorporated. The building industry often focuses on CO₂ emissions in the building process and using alternatively reusing sustainable materials, neglecting to design for outdoor comfort. One exception to this was Ralph Erskine, a visionary architect who included outdoor comfort in his design process.

To understand the temperature extremities that shape the outdoor comfort seasonally, the town of Kiruna was chosen. The town is in northern Sweden in a subarctic climate zone. As a result of this, Kiruna has extreme seasonal changes with temperatures ranging from -40°C to +30°C. The temperature greatly affects the experienced outdoor comfort, as weak winds will have a greater cooling effect due to the temperature.

Kiruna is also undergoing a relocation due to ground deformation caused by iron ore mining. The old Kiruna Town centre was located further to the northwest on the slope, where the town was protected from cold winds thanks to the mountain. The new Kiruna town is more exposed to the subarctic weather. Historically Kiruna have been designed and planned in accordance with local climate, but the new city center was mostly planned and built on planning principles that fits warmer more southern climates.

This outdoor comfort can be simulated using Computational Fluid Dynamics (CFD) tools, which simulates microclimate factors like wind and sun radiation. The factors, combined with urban morphology, gives a good starting point for how outdoor comfort can be designed when working with sustainable urban design.

A study made by Ebrahimabadi et al. (2016) explored how architects can use simplified CFD tools and methods to make climate studies more accessible in early design stages, allowing architects and planners to have more easily accessible climate simulations and use these as arguments in their design decisions. This results in urban morphologies being grounded in local climate conditions.

Climate and its borders

Climate can be described as the documented daily weather situation in a geographical area that has been documented for a long time. This often includes weather elements like temperature, wind, precipitation, air pressure, humidity, and solar radiation. Climate data are calculated using a 30-year climate normal period. With the latest Swedish reference, the climate normal period spans the years 1991-2020. Climatic zones are the classification of long-term, similar weather patterns in geographical areas that share similar seasonal changes, weather elements, and temperature. (SLU, 2025)

The book *Build to Suit the Climate* has devised its own climate classification system using building-relevant parameters. These are physical climate parameters founded on comfort conditions and building strategies, suited for a specific climate zone or condition. The parameters are temperature [°C], absolute humidity [g/kg], solar radiation [W/m²] or wind speed [m/s], relative humidity unit, dew point, and enthalpy [J/kg]. Together, the parameters classify the climate zones Cool (Moscow), temperate (Munich), subtropic (Shanghai), tropical (Bangalore), dessert costal climate (Dubai) and desert continental (Riyadh). (Pelsmakers, Donovan, Hoggard, & Koźminska, 2022)

A psychrometric chart displays the relationship between absolute humidity and outdoor air temperature within the comfort zone over the 8760 hours of a year. The chart gives an overview of the building adaptations needed on the site and the challenges posed by the climate zone, for example heating, cooling, and dehumidification required for interior comfort conditions. (Pelsmakers et al., 2022)

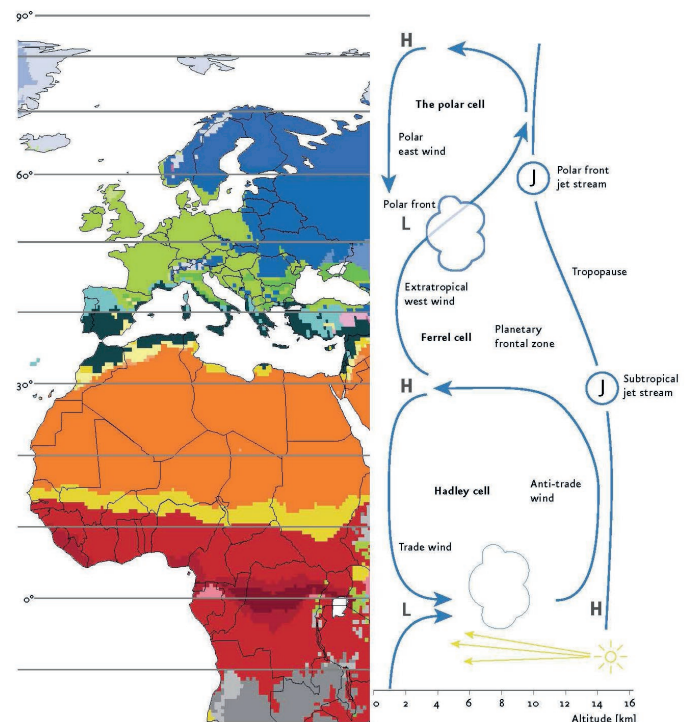


Figure 1. [The creation of climate zones] (s. 13), by G. Hausladen, P. Liedl, & M. Saldanha, 2012, *Building to Suit the Climate: A Handbook*, Birkhäuser. The figure describes how different climate zones are affected by wind flows and various weather situations.

Psychrometric Chart

INDICATOR:
Dry Bulb: 23.00 °C
Rel Humidity: 40.00%
Abs Humidity: 7.09431 g/kg
Vap Pressure: 1.14319 kPa
Air Volume: 0.84819 m³/kg
Enthalpy: 41.18435 kJ/kg
Dew Point: 8.94 °C
Wet Bulb: 14.78 °C



Figure 2. Psychrometric chart based on EPW data (generated using Marsh, 2018). The figure maps out how different climate areas require different solutions for indoor comfort.

The psychrometric chart illustrates where different outdoor conditions fall in relation to the indoor comfort zone. The Nordic climate is generally located in the bottom left corner.

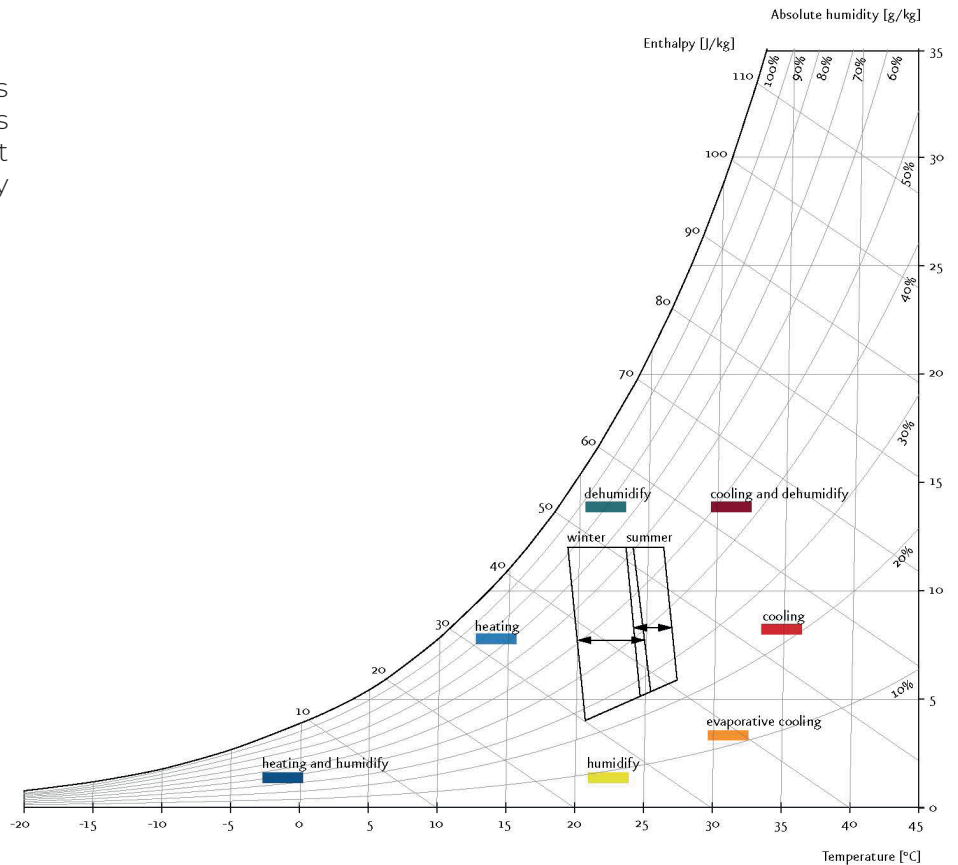


Figure 3. [Room climate conditioning methods, in psychrometric chart format] (s. 39), by S. Pelsmakers, E. Donovan, A. Hoggard, & U. Koźmińska, 2022, *Designing for the Climate Emergency: A Guide for Architecture Students*, RIBA Publishing. The figure shows a mapping of solutions for indoor comfort.

This Psychrometric chart visualizes the climatic range of different climate zones that move within. It is essential to note that these climate zones and their extent on the psychrometric chart may change in response to climate change.

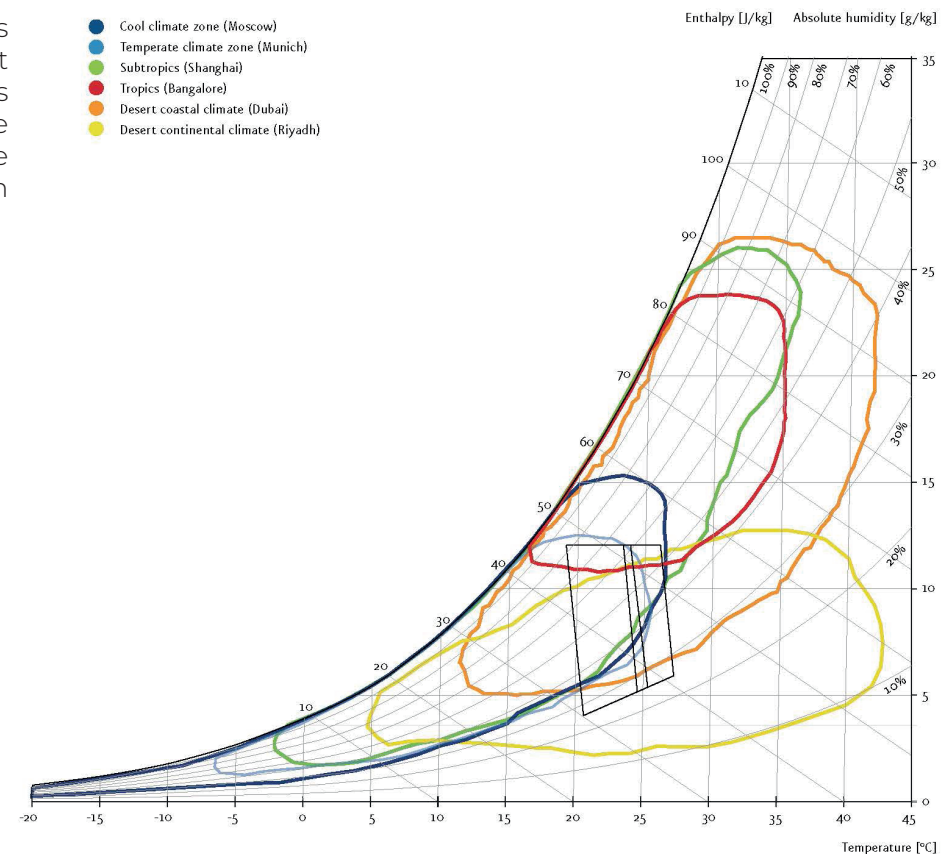


Figure 4. [Climate zones for building climate system room conditions, shown in psychrometric chart format] (s. 31), by S. Pelsmakers, E. Donovan, A. Hoggard, & U. Koźmińska, 2022, *Designing for the Climate Emergency: A Guide for Architecture Students*, RIBA Publishing. The figure shows a mapping of climate zones.

Nordic Climate

To obtain further insight into how climate zones set the conditions for a comfortable outdoor and indoor climate, An overview of Sweden's three climate zones will be given.

Swedish Climate Zone

Sweden is divided into three estimated regional climate zones, as a result of the country's geographical length from south to north. These zones are affected by the seasons, local factors, human factors, proximity to bodies of water, lakes, sea, geographical heights, and much more. (Sveriges lantbruksuniversitet [SLU], 2025)



Figure 5. Climate zones in Sweden, adapted from H. Bark, 2025, *Agenda 2030 delegationen*.

Coastal Climate

Coastal climates generally have milder winds, cooler summers, and increased humidity. They are strongly influenced by westerly winds and the North Atlantic Drift, which is an extension of the Gulf Stream. Coastal climates are generally milder and warmer than inland climates, especially on the west and south coasts. Bark (2025)

An example of a city in a coastal climate is Malmö. Their biggest challenges are the westerly winds and the risk of flooding.

Inland Climate

Svealand and the southern part of Norrland, excluding the mountains. The contrast between seasons is more pronounced. With cold winters and warm summers. Inland climate have partly less precipitation than the coast climate. Bark (2025)

Örebro city is exposed to extreme weather such as torrential rain, heat waves and is at risk of flooding.

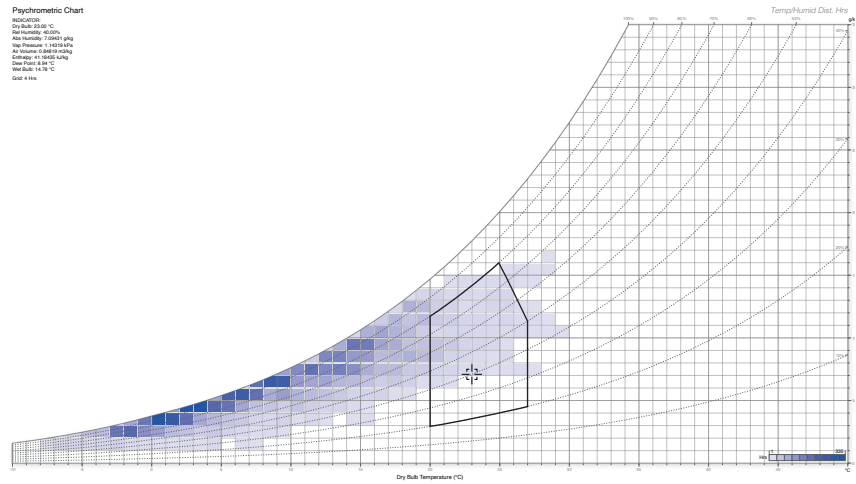
Subarctic Climate

The northernmost part of the country and the mountain range. With even bigger contrast between summer and winter lengths and temperatures, lower precipitation, and higher snow precipitation. Bark (2025).

Umeå, the largest city in northern Sweden, is periodically affected by floods and sharply increasing precipitation, but also heat waves.



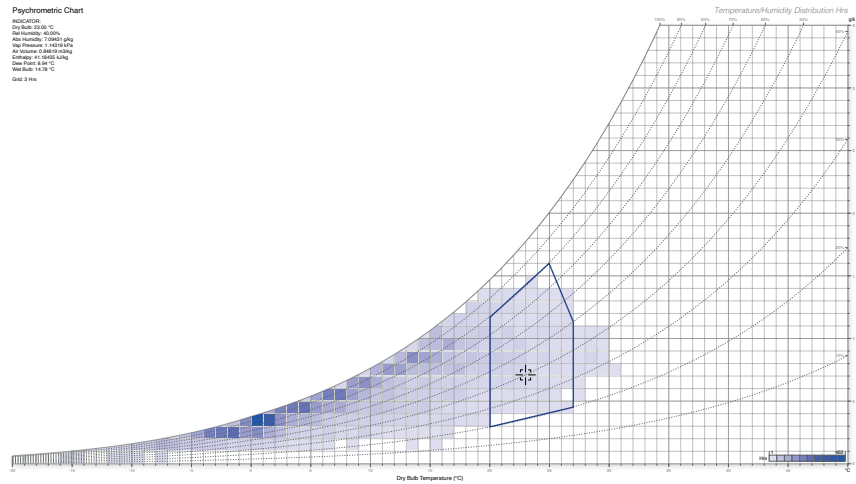
Figur 6. Turning Torso, by L. Bendroth, 2020, *Malmö stads mediabank*.



Figur 7. Psychrometric chart based on EPW data, generated using A. Marsh, 2018, *Psychrometric Chart*, AndrewMarsh.com.



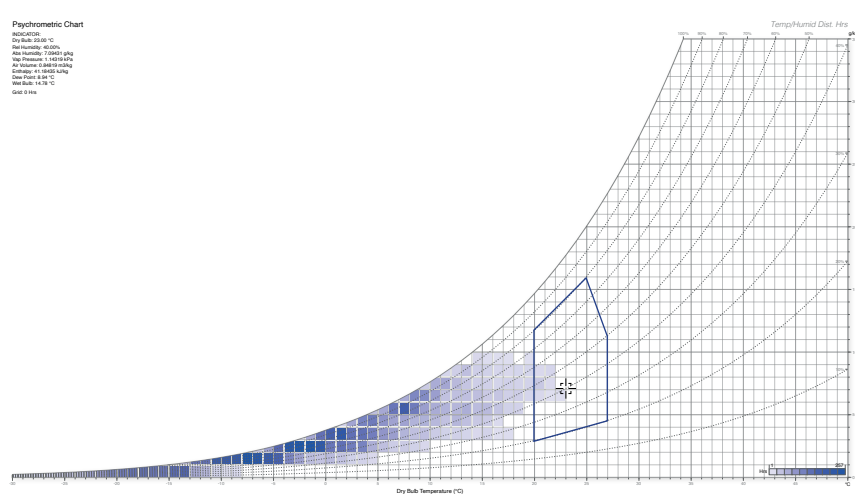
Figur 8. Fotografi av Örebro kommun i samband med uppdatering av invånarantal, by A. Olofsson, 2024, *Örebro nyheter*.



Figur 9. Psychrometric chart based on EPW data, generated using A. Marsh, 2018, *Psychrometric Chart*, AndrewMarsh.com..



Figur 10. Kiruna urban transformation, by LKAB, 2025, *LKAB*.



Figur 11. Psychrometric chart based on EPW data, generated using A. Marsh, 2018, *Psychrometric Chart*, AndrewMarsh.com.

Arctic ideologies and their development

Hemmersam took inspiration from Norbert Schoenauer's idea that urban planning can be likened to genealogy. That is, urban planning changes over time and is based on historical experiences from previous city planners, politicians and architects. Hemmersam summarized this as five generations of the Arctic urbanism.

Paradise of the North (1900-1950)

This generation was inspired by the aesthetically oriented City Beautiful movements with little to no consideration for the indigenous people. During this time, cities were often built from scratch in the middle of nowhere. The urban design was inspired mostly by classical European design ideology and vocabulary with the purpose of creating civic pride and the current state ideology. A clear example of this was the Stalinist settlements with a strong design focus on representing the socialist conquest of the Russian north. Here forced labor camps called Gulag labor were used. (Hemmersam, 2021)

One unusual example for the time was when LKAB organised the settlement of Kiruna. The design strategy by Per Olof Hallman was to work with the typology, conditions, and climate of the place. This was very innovative and unusual at the beginning of the 20th century (ArkDes, 2020)

Technocratic urbanism (1950-1970)

This generation started from social, infrastructure and industrial knowledge in the north. It had more attention to the poor economic situation of the indigenous people and including them in the modern society and expanding modern urbanism. The current urban models followed international modernistic principles and used mass-produced industrial housing. This generation of architects and urban planners published utopian high-tech proposals for the Arctic. (Hemmersam, 2021)

Softening the north (1970-1980s)

The continuous modernisation, anti-colonial and anti-territorial movement. The continued establishment of industries in the Nordic countries now needs to attract workers and citizens from the south. The urban goal is to soften the cities, making

them more attractive. At this time, the architects and planners gradually abandoned functionalism and modernism. Instead, the current urbanism started differentiating, forming the Arctic urbanism, focusing on making the Arctic current and new administrative settlements more livable. During this time, researchers and architectural institutions published various proposals related to Arctic urbanism but the most celebrated was Ralph Erskine. The previously mentioned Gulag labour system from the Paradise of the North generation was abolished. (Hemmersam, 2021)

Climatic cities (1980-1990s)

The current generation involved themselves with the critical regionalism movement and created a network between countries and regions, which gave the Scandinavian North many similar policies. This generation of architects highlighted the value of including participatory approaches and democracy. This also includes individual well-being and the right to the city in marginal groups such as workers and indigenous people. Danish architect Jan Gehl and the authors of the Winter City movements, including Norman Pressman, advocated developed strategies with a focus on urban livability, which resulted in the climatic cities policies that would expand beyond the Arctic. (Hemmersam, 2021)

Place-specific urbanism (2000- Present)

One has abandoned the knowledge that was built up and the understanding of how things function in the northern regions. Both in terms of the environment and identity, as well as building techniques and architecture, historically proven effective. This has meant adopting a more standardized form of urbanism, which has contributed to the disappearance of previously more regional cultures and standards, replaced instead by more global norms and policies. The largest resources are found in cities, which leads to an unequal distribution of jobs, resources, and people between thriving cities and struggling communities. As a reaction to standardized urbanization, architects, designers, and others have begun to combine cultural motifs and traditional knowledge with modern building technologies and materials. (Hemmersam, 2021)

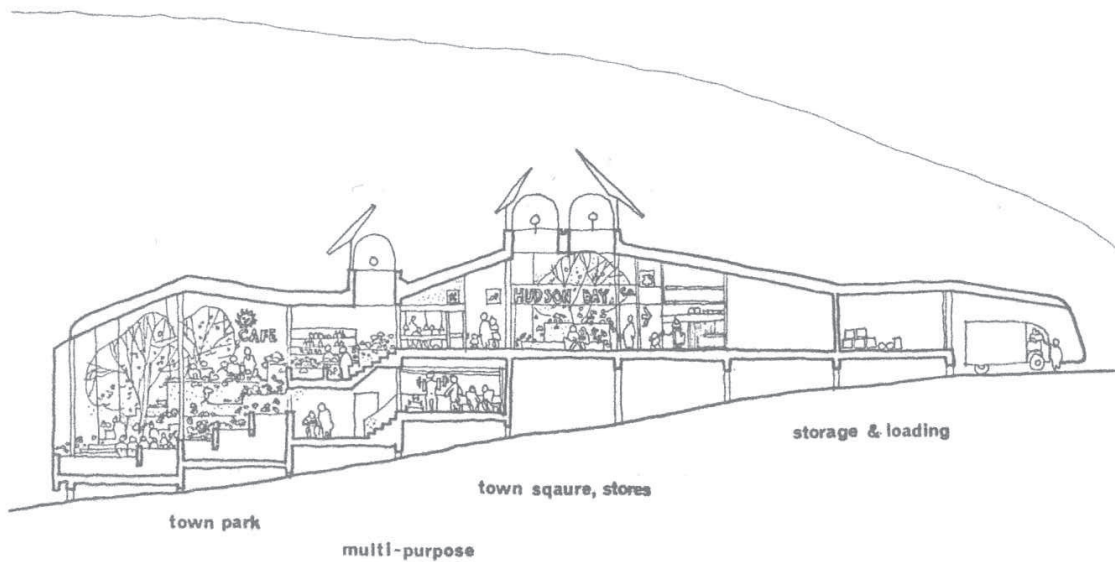


Figure 12 Section of the center with winter garden, beneath skylights which thanks to reflectors receive sunlight (s. 99), by P. Hemmersam, 2021, *Making the Arctic City: The History and Future of Urbanism in the Circumpolar North*, Bloomsbury Visual Arts.

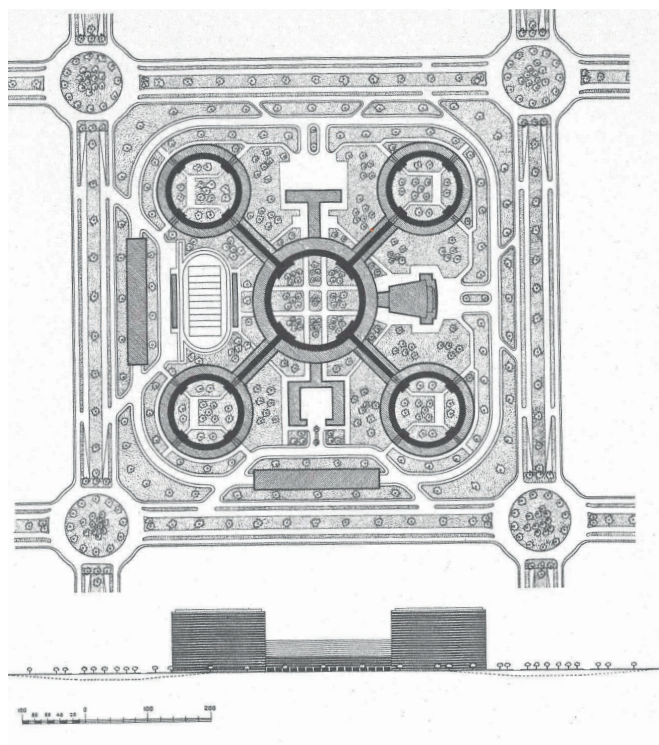


Figure 13 Study of a town in the antarctic zone (s. 25), by P. Hemmersam, 2021, *Making the Arctic City: The History and Future of Urbanism in the Circumpolar North*, Bloomsbury Visual Arts.

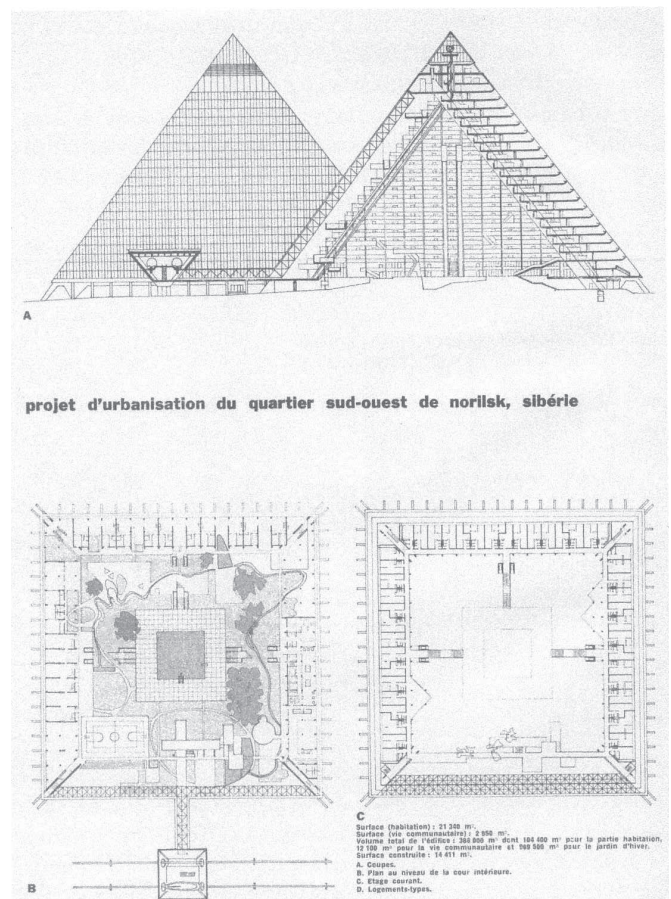


Figure 14 Residential project for the southwest district of Norilsk (s. 62), by P. Hemmersam, 2021, *Making the Arctic City: The History and Future of Urbanism in the Circumpolar North*, Bloomsbury Visual Arts.

Dimensions of Arctic urbanism

In 1978, the United Nations Economic Commission for Europe (UNECE) attempted to develop a set of technical and architectural recommendations. This resulted in a report that detailed challenges in building functioning sewage systems, as well as permafrost construction challenges. UNECE suggested that there is no standardized approach to ensure optimum planning, but 9 points were given by planners across the Arctic, reflecting their concerns across the circumpolar north.

1. **A problematic general tendency to copy southern architecture and building standards,**
2. **A wish to open up settlements towards nature and the need for outdoor recreation,**
3. **The potential for clustering buildings to create a milder outdoor microclimate,**
4. **Compact urban forms that provided a sense of protection, identity and community,**
5. **The need for indoor social and commercial spaces (‘Climate-controlled shopping malls’),**
6. **The need to make harsh northern towns attractive to southerners that contribute local and national economies,**
7. **The need for wind-clearance of snow,**
8. **The use of colour instead of vegetation to improve the visual appearance of settlements,**
9. **And innovative and robust energy supply and distribution systems.**

(Hemmersam, 2021)

This meeting and report raise concerns from planners across the circumpolar north. About who establishes settlements, urbanism development ideals and what effects it could have on indigenous people, the environment, the future and existing urban development. In comparison, the divided concerns from the Arctic planners were a reflection of different cultural, political, and economic differences. Hemmersam tells “the divisive issues include questions of private versus public land ownership, the role of corporations versus governments in city building, the rights and concerns of indigenous

communities, environmental concerns and the place of democratic involvement in planning.” He continues that it shows a broader perception and set of ideas that guides decision-makers, designers, planners and the public perception in the role of the Arctic settlements and those who work there. Hemmersam unfolds this in five parallel and interacting dimensions. (Hemmersam, 2021)

The utopian city

Hemmersam raises the utopian city as a dimension of arctic urbanism. This comes as a reaction to underdeveloping the Arctic, creating architecture based on radical imagination and city design driven by ideas, theories and grand visions of large-scale social engineering. The utopian city ignores the everyday social, cultural and climatic realities, often suggesting grand technological climate-controlled environments. The urban form built with industrialized construction in large housing block with the idea of cities programmed for living, working and organizing communities. With globalization and time, the utopian cities project became fewer and evolved into more normal cities. (Hemmersam, 2021)

The postcolonial city

The post-colonial city often started as a settlement for industries with little to no regard for the indigenous people. These cities often stemmed from southerner governed companies or governmental bodies, creating a paternalistic social social engenerated enviroment where housing and wokring zones of diferent groups, such as workers, indigenous people and classes were seperated. Since the year 1970 the intrest for the arctic has incressed and an incressed colaborational effort is taking place between the goverment, companies responcilbe for the local industries, citizens, and indigenous people. (Hemmersam, 2021)

The provisional city

The relocation, demolition, and abandonment of cities where the material of interest runs out. Or impact the city, that is the essence of the provisional city. Satellite maps still show traces of urbanisation and de-urbanisation of settlements

or towns across the arctic. A Swedish example of this is the 1962 hydropower development at Luleå river, where the road network is still visible. The ongoing relocation of the subarctic city of Kiruna is the most extreme example of a provisional city. (Hemmersam, 2021)

The experimental city

The Arctic has been home to many experimental urbanization projects, hence the name. The reason often lay in a lack of governmental jurisdiction in the north. This, in combination with mining industries, colonization, forced relocation, and the forced labor of indigenous peoples. Arctic communities were used as testers for different design experiments. It was not until 1978, at the UNECE meeting, that research was conducted, and an established discussion led to the planning that should follow practical experience, rather than applying general principles. Before that, most urban experiments were mostly a trial-and-error system, or ad-hoc principle was used. (Hemmersam, 2021)

The ecological city

Arctic cities have often been built according to compact, densifying city principles. Reducing the car-dependence, resilient urban systems and self-sufficient cities. Despite this, the Arctic cities lag behind global sustainability due to resource extraction remaining prioritized. (Hemmersam, 2021)

Urban morphology and the Arctic challenges

The definition of urban morphology is the study of urban form and how it has changed and evolved over time. This theory gives Arctic architects and planners an explanation for why a settlement location was chosen and shaped. The urban environment is experiencing greater weather phenomena resulting in changed urban conditions, and accessible urban spaces. Chapman W says in his book *Planning and urban design for attractive arctic cities* that the accessible network of roads and public spaces will vary between seasons. That a city's attractiveness can be improved in winter by covering ugliness with snow, but that snow can also create contrasts with snowdrifts and gravel, etc. (Chapman et al., 2025)

Unlike some international architecturally unique cities, the best Arctic city is one that creates opportunities for everyday life in a challenging climate. In order to achieve functional everyday environments all year round, winter is seen as a resource for light and an obstacle to access and mobility, which can create unsafe situations. Soft mobilities such as pedestrian and bicycle traffic are strongly affected by the winter period with snow, however, there are other possibilities with transport in the form of snowmobiles and cross-country skiing. Winter can lead to both an increase and a decrease in outdoor activities. Depending on how a place is designed, there may be different possibilities, for example, using a square as an ice rink while others only shovel out walkways to get around. It is challenging to promote walking and cycling during the Arctic winter months. It depends on a functioning relationship between the urban network, the built environment and services (e.g. snow removal). (Chapman et al., 2025)

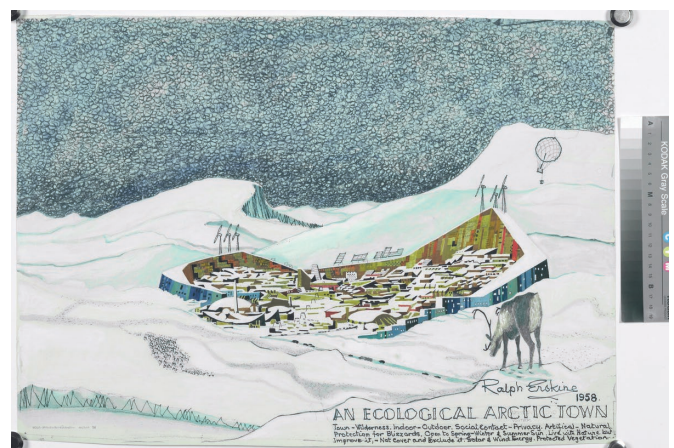
Chapman et al. (2025) says in his book *Planning and urban design for attractive arctic cities* that the available network of roads and public spaces will differ between the seasons. Every settlement that becomes a permanent city is based on urban layout principles, i.e. grids. These grids can vary in urban structure and grain. There are examples in Kiruna and Hammerfest (Norway) where they have managed to work with the typology of the place to create better wind, temperature and snow conditions for the inhabitants.



“The job of buildings is to improve human relations: architecture must ease them, not make them worse.”

Ralph Erskine (1914 -2005)

Figur 15. R. Erskine, 1958, *ArkDes*. <https://digitaltmuseum.se/021029512055/ritning>



Figur 16. An ecological Arctic Town, by R. Erskine, 1958, *ArkDes*.

Simplified microclimate methods to study in Kiruna

Ebrahimabadi et al. (2016) article Microclimate assessment method for urban design – A case study in a subarctic climate. Has investigated how climate-sensitive urban design proposals and microclimate simulations are produced. He discussed the lacking use of microclimate principles in the design process of architects and planners. By using Kiruna's new city center square as the study site, he analyzed the proposed urban project located in Kiruna, made by Whitearchitects. To better understand how the urban space reflects the climate, it is as important to understand how researchers, architects and others refer to thermal comfort. There are two main approaches. The first discusses how the amount of energy from people and their surroundings interacts. The second focuses on perceived comfort.

He highlights Brown and DeKay's (2001) proposal for an alternative microclimate mapping method, where only the climate parameters wind and sun are used to identify which urban zones had good versus unfavorable microclimate conditions. To practically simulate, calculate and map a site's wind conditions and patterns, Computational Fluid Dynamics, or CFD as it will be referred to, is used. The tools required for this often require high technical knowledge and the results rarely represent the actual wind conditions, as countless calibrations and the modeler's level of detail and materiality need to be selected. (Ebrahimabadi et al., 2016). Which often leads to simplified site typologies, models and parameters being used.

Ebrahimabadi et al. (2016) note that in the subarctic urban climate, wind speeds below 5 m/s can create a strong wind cooling effect at low temperatures. This, combined with Kiruna's lack of sunlight, long shadows and generally barren climate, underlines the subarctic challenge in urban planning that urban planners and architects in the north face. To understand the Solar conditions in Kiruna, he mapped out the solar conditions during the 21 March → Spring equinox (or Vernal equinox), 21 June → Summer solstice, and 21 December → Winter solstice. The 21 December was largely omitted in the work since there was no direct sunlight at all in Kiruna during the winter solstice. He chose to illustrate maps showing the two other dates when the site's ground was 1 never in shadow, 2 once in shadow and 3 twice or more in shadow. By combining these mapped categories, he found where the best direct solar conditions were.

The result of the articles study was a combined microclimate assessment (solar access analysis + wind analysis). The long-term goal of the study was to investigate with simple microclimate

methods how the site's sun and wind conditions. He came to the conclusion that the design proposal is acceptable for Kiruna's new square. However, it is important to draw the reader's attention to the fact that he considers the design proposal to be acceptable in a first step, where data has been obtained that wind speeds in the area are generally low and stable over the year. However, the buildings around the square, which are relatively low at 16 m but also often go up to 20 m in height, can block the sun in urban spaces in March. Which makes west-east oriented streets generally shadier. Ebrahimabadi also noted that in the subarctic urban climate, wind speeds below 5 m/s can create a strong wind cooling effect at low temperatures.

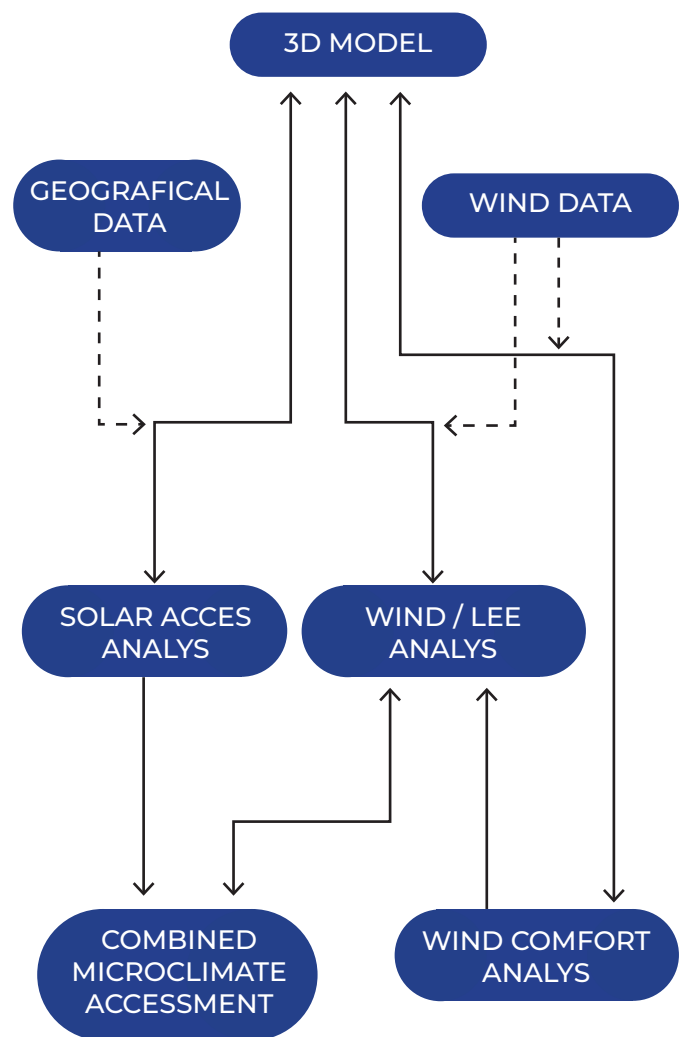


Figure 17. Ebrahimabadi workflow of the proposed method. Illustrated by thesis author, based on S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, Urban Design International, 23(2), 116–131.

Strategies, tools and their limits

The method chapter introduces the tools, methods and analyses that have been carried out. The selection of these has been based on which software and urban planning factors have proven to be relevant according to previous studies at Chalmers University of Technology, but above all the urban planning factors that are relevant for future subarctic urban planning.

This chapter mentions

- The CFD tools and their input data limitations
- Process review for the analysis and simulation work.
- Urban Selection Criteria for the selected site

The data and the Tools

To better understand how different urban morphologies affect outdoor comfort, simulation tools have been used. A comparative list of a selection of academically studied tools is presented for the different closeness and accessibility of the CFD tools to architects and urban planners. All the mentioned tools also require different basic technical, climatic and metrological knowledge. However, it is important to note that the accuracy of the CFD tools depends on their accuracy on the input data and available parameters. For Autodesk Forma and Rhino 8, an EnergyPlus Weather file (EPW file) is used as input data.

The file type is mainly used in building simulations, energy calculations and daylight analysis to predict how a building will perform in a given climate. (Ladybug Tools, n.a.) This file type consists of normalized weather data that is often collected over a 30-year period, often called a normal period or climate normals. The most commonly used for Swedish weather data is data collected from the years 1991 to 2020. Because of this, the EPW files cannot be seen as the exact truth for the weather today but as a weather and climate reference.

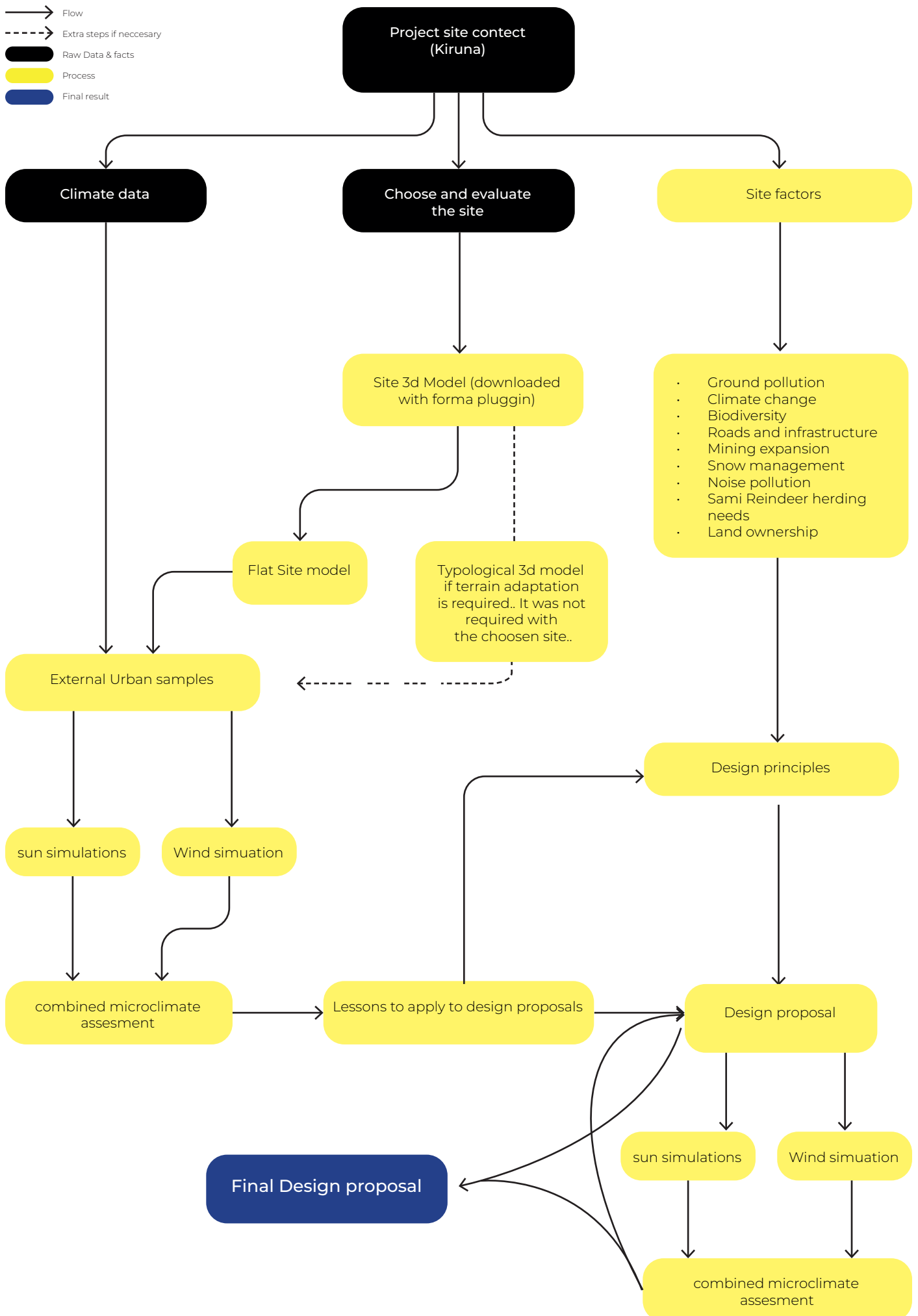
Design strategy

A combination of available tools and inspiration from the highlighted microclimate Brown and DeKay's (2001) in the Arctic by Ebrahimabadi et al. (2016) article Microclimate assessment method for urban design. The thesis design method was formed.

Urbana Selection criteria for simulations

To test a city block with respect to understanding the climatic relationship between form and site weather conditions, a boundary size of 200 x 200 m is used. The model may need to be duplicated to avoid unrealistic simulations or extreme wind effects due to the lack of surrounding buildings. The goal is to achieve a good understanding of what it is like for a person to be between the buildings. The resulting climate data is produced using Autodesk Forma.

By overlapping data for general wind comfort and solar radiation, it is possible to identify where different wind and shade situations occur in the given environment. The general wind comfort is a simplified representation of wind simulations per wind direction. The solar radiation simulation is based on a selected date. Since Kiruna is located in the subarctic climate zone of the northern hemisphere, this means that there is midnight sun; May – July, and polar night; December – January. To simplify the solar radiation simulation, the date of March 20, the vernal equinox, was chosen. To make the now green-red-toned overlapping data readable for readers with color vision impairment or color blindness, Photoshop was used for correction. The solar radiation was edited to black and white and the wind comfort color gradient was corrected.



Figur 17. Thesis method.

3D and simulation tools

Interviews about CFD tools & uses

Four interviews were conducted with the purpose to explore what CFD tools (if any) were used by the participants in their work role. Two city planners and two energy and climate engineers were interviewed. The interview was unstructured with open questions about climate adaptation, CFD tools, the participants work and related subjects. It also included their thoughts on the future of their field and what tools, technical needs and regulations might appear in the future.

There was a clear message from the participants that there is a need for technical and user-friendly tools with higher accuracy. Furthermore, the participants confirmed a lack of in-house expertise within the municipalities and architectural offices. (based on 5 interviews and general prior questioning of city planners, climate and energy engineers, architectural offices, and municipalities)

- There are challenges in getting involved actors to compromise when creating an urban plan. The urban plan is often limited by policies, standards and organizational behaviours, which does not allow for innovation or tailoring to the needs of a specific site.
- Master plans are abstracts visions of a cityscape but are sometimes used as a concrete plan, especially when it comes to roadgrids and property boundaries. There is also a risk that the master plan overtakes the detailplan, which could result in missing site-specific needs and conditions, such as wind conditions and daylight potential.
- Järfälla was mentioned as an example of a municipal with climate neutrality as a broader goal. For example, the municipality sets the requirement that building processes and detail plans must be submitted together with a wind study.

Key information and key findings from the interviews.

- The energy efficiency between buildings can become more efficient by centralizing and sharing energy, heat and sewage with neighbouring buildings. However, today's property regulations make it difficult and often impossible for property owners to share systems and resources. This is called positive energysystems.
- There should be more focus on creating a sense of responsibility and ownership in a block or neighbourhood, as mega apartment complexes often cause residents to not experience this.
- It is usually too expensive for municipalities and architect offices to use CFD tools, or order CFD simulations and analyses from consultants. When ordered, each proposal comes with a cost, making it expensive to work iteratively.
- Initiatives are taken by script and program developers to create CFD scripts that can be accurate but simple enough to be used by architects and others. The developers aim to make the software more accessible in terms of price and compatibility with already used programs, such as Rhino.

Analysing others wind analyses

In order to learn from other wind studies, 8 wind analyses have been studied. These analyses vary in the amount of information given by simulation process, its program, limit values and possible design suggestion based on the result. The compared wind studies were published during 2016 - 2023 and were carried out by either an architectural firm, a technical company or a state actor. The studies do not always state which tools were used, however, there is a pattern that *White architects* used 3D Rhino and Grasshopper with CFD scripts. In contrast to the technical consultants, *Mats Finnson*, *Filip Viira* and *AFRY* stated StarCCM+ as their tool used.

The studies have a common practice regarding wind speeds and comfort limits, which can also be called limit values and they most often mention Glaumann & Westerberg (1988) as the source for their scale, which is 5 m/s for walking/cycling, 3 m/s for squares and 1.5 m/s for sitting. One of the studies chose to use Davenport's scale instead. It is important to note that several of the studies are "limited". This means that only the 1-2 most common wind directions were simulated. These limited wind studies recommended more complete analyses. Most of the projects are under development and still in the planning phase. However, Barkarbystaden IV is being built and will be partially occupied in 2025.

Felt comfort

In Autodesk Forma, the Davenport scale is used to represent how the wind is experienced and what activities are suitable at different wind speeds (m/s) and wind frequencies (how often it blows). Davenport does not include temperature, solar radiation or humidity. This scale is often used by urban planners and can be found in Forma.

UTCI (Universal Thermal Climate Index) is an international scale that reflects the thermal comfort based on air temperature, sun radiation, wind speed and humidity.

Both the Davenport and the UTCI scales assesses how a space is experienced. It is recommended for urban planners to use both to get a broader overview of an urban space.

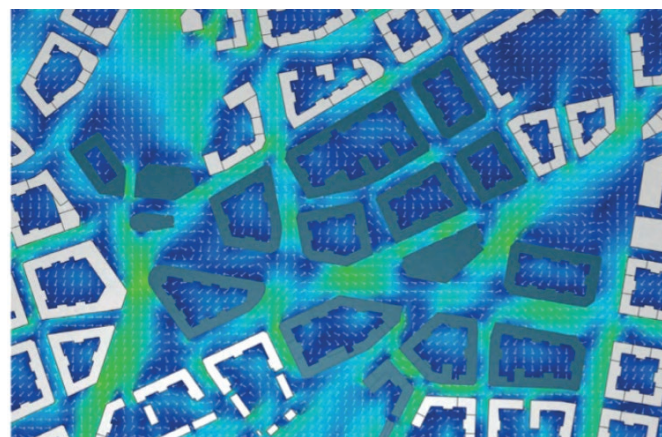


Figure 19. (s.13) Wind analysis of Barkarbystaden IV (2018), White Arkitekter. Southwest wind 5 m/s. Rhino + Grasshopper CFD script. Excerpt from p. 4. This is a better and more detailed wind simulation.

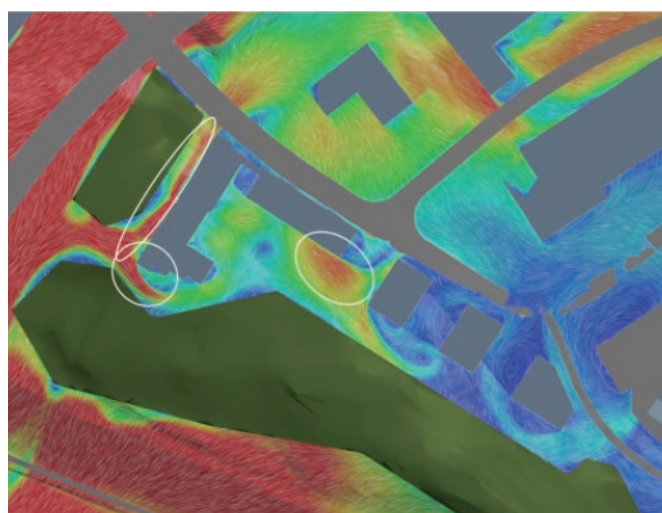


Figure 20. [vindhastighet] (s. 11), by F. Jareman & A. Jayanath Vivek, 2023, VFD Vindstudie Floretten, AFRY & Strategisk Arkitektur.

Level	Description	Windspeed
1	Calm	< 1.5 m/s
2	Light breeze	1.5–3 m/s
3	Gentle wind	3–5 m/s
4	Moderate wind	5–7 m/s
5	Fresh wind – uncomfortable	7–10 m/s
6	Strong wind – difficult to walk	10–13 m/s
7	Storm wind – dangerous	13 m/s

Figure 21. UTCI scale.

Category	Limit	Time
Sitting	3.6 m/s	1.5% of the time
Standing	5.3 m/s	1.5%
Walking Slowly	7.6 m/s	1.5%
Walking	9.8 m/s	1.5%
Uncomfortable	>9.8 m/s	1.5%

Figure 22. Davenport comfort scale.

CFD tools

Programs and their limits

To provide a clearer overview of available CFD programs and their intended users. Two articles have been used to explore 11 programs; Articles Empirical analysis of three wind simulation tools to support urban planning in early stages of design and Empirical Evaluation of Three Wind Analysis Tools for Concept Design of an Urban Wind Shelter. (Sousa et al., 2015),(Moya, 2015).

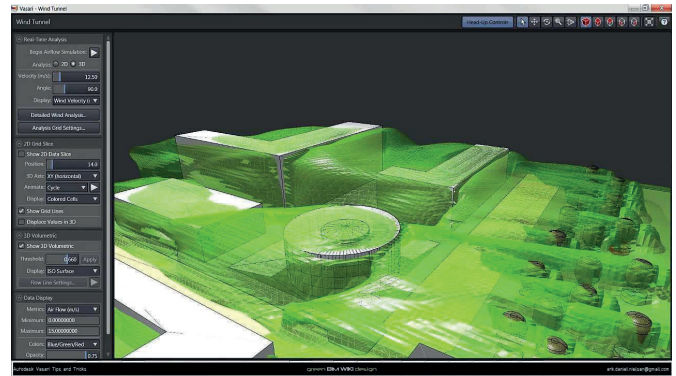


Figure 23. 3D wind simulation in Autodesk Vasari (Nielsen, 2013).

Autodesk Vasari

Vasari is a discontinued program that delivered a conceptual design, simple -CFD without ABL-modelling. Vasaris features was gradually phased into other autodesk programs, such as Revit, Formit and dynamo.

Accessibility	3/3
Accuracy	1/3
Complexity.	1/3
Available	no

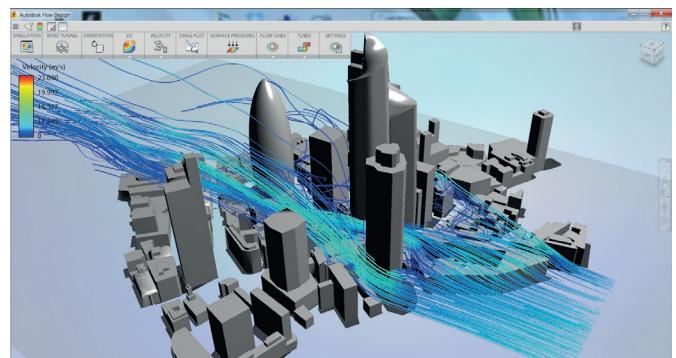


Figure 24. Autodesk Flow Design (formerly Project Falcon) simulating airflow around buildings in a virtual wind tunnel (Grimm, 2014).

Autodesk Flow Design

Flow is best suited for use in the early design stages. Flow produces results in 2D and 3D but has low precision.

Accessibility	3/3
Accuracy	1/3
Complexity.	1/3
Available	no

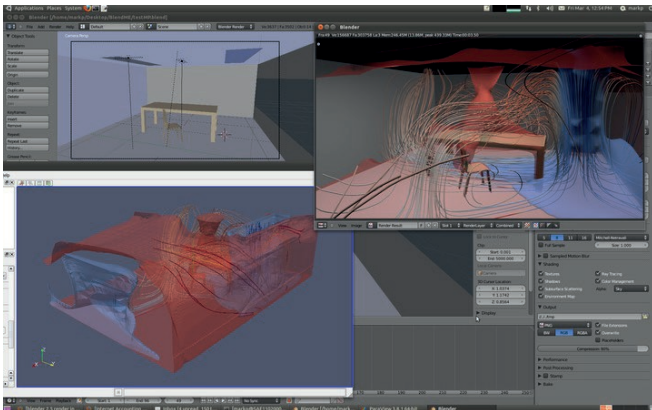


Figure 25. ODS Studio's multi-physics simulation interface (ODS Engineering, n.d.).

ODS-Studio

Is an open source that combines the programs Blender, OpenFOAM and ParaView. Creating more detailed and realistic analyses. Requires more learning and time.

Accessibility	2/3
Accuracy	2/3
Complexity.	3/3
Available	Yes

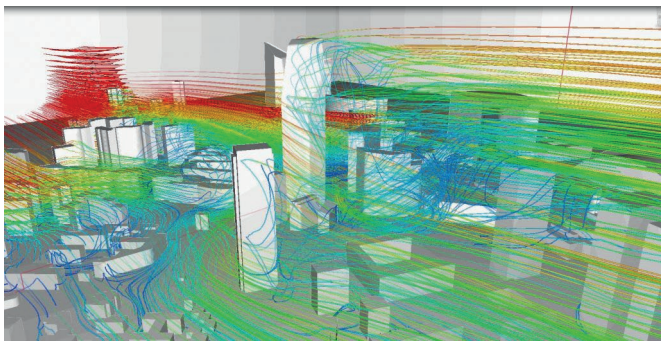


Figure 27. CFD wind flow simulation around urban buildings using ANSYS Fluent, based on a 3D city model derived from LiDAR data (Latrach, 2018).

ANSYS CFX

Creates advanced CFD for verification and supports ABL profiles and with high accuracy, but requires more technical knowledge and longer preparation time, making the program less suitable for iterative processes

Accessibility	1/3
Accuracy	3/3
Complexity.	3/3
Available	Yes

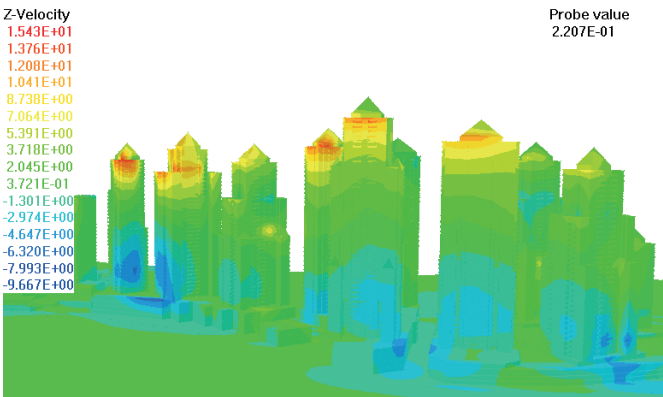


Figure 26. Overview of the PHOENICS CFD software environment, showing its Virtual-Reality Editor interface for setting up and visualising fluid flow simulations (CHAM, n.d.).

CFD Phoenix

The program contains three steps: modeling geometries (pre-processing), simulating and calculating the wind (Solver), and visualizing the result in the same program (post-processing). It is an expensive, high-accuracy program.

Accessibility	1/3
Accuracy	3/3
Complexity.	3/3
Available	Yes

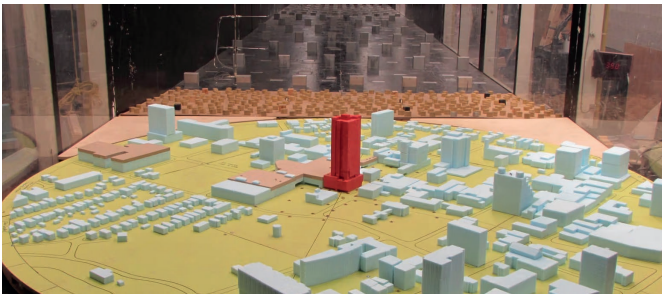


Figure 28. Pedestrian wind comfort assessment for the 24 Gaukel Street development in Kitchener, Canada, combining CFD modelling and physical wind tunnel testing at a 1:400 scale (SLR Consulting, n.d.).

Mini wind tunnel

The only physical wind analysis method mentionend so far, which includes a built-up modular wind tunnel with sensors that measure air flows near the models. This method is very realistic at close range but lacks ABL and performs worse in large-scale models and analyses

Accessibility	2/3
Accuracy	2/3
Complexity.	3/3
Available	Yes

Autodesk Forma

Autodesk Forma is one of the more user-friendly programs. Forma, as it will be referred to, is a cloud-based analysis tool and AI-driven generative design system, primarily used in the early stages of urban design, city planning and CFD studies. The program uses open-source geographic data types such as GIS, topography, EPW and can be connected to Revit, Rhino, etc. (Esri Community, 2025), (Autodesk, n.d.)

Daniel and Sood (2025) conducted a comparative analysis of Forma and other CDF tools. The authors touched on Formas technical demands, user-friendliness and described their areas of use and weaknesses. The criticism of Forma is that it is limited to the early stages and the concept phase. There are also performance problems when using large models and wanting to produce more complex results. It can be concluded that Forma produces temperature conditions, noise exposure, energy consumption and micro-, wind- and sun-analyses. Despite this, Forma is not on a “CFD level”, which means the output from Forma is not on a higher technical level. (Daniel & Sood, 2023)

Daniel and Sood (2025) consider Forma to be an excellent program to use in the early design stages, and it can greatly help architects to work more energy-efficiently and create climate-responsive architecture. Despite this Forma has its limits. During the thesis production it was discovered that Formas analyse tool Area metrics were unable to give a lower Efficiency factor than 0,9 on a test area of 200 x 200m. It is also unable to predict higher wind speed than 13.2 m/s.



Figure 29. Autodesk Forma's cloud-based early-stage design environment, enabling architects and urban designers to develop and evaluate multiple design iterations simultaneously (Symetri, 2023).

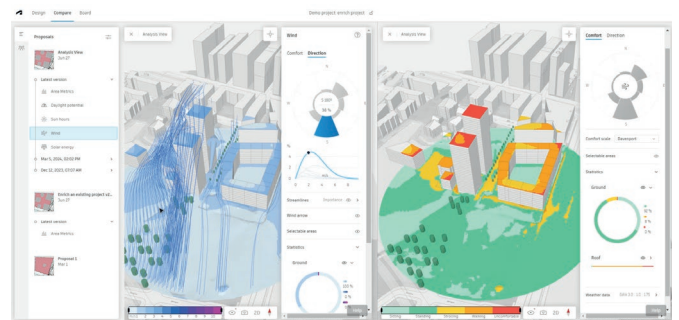


Figure 30. Autodesk Forma's compare view, displaying south wind direction simulation (left) alongside an all-direction wind comfort analysis (right) during earlystage conceptual design (Abdalla, 2024).

Autodesk forma

Accessibility	1/3	Intuitive but can be easily adjusted
Accuracy	1/3	Cannot be fully classified as a CFD simulation tool.
Complexity.	1/3	Very beginner friendly, but a short training in the program would be appreciated.
Available	Yes	

Rhinoceros 8

Rhinoceros, or Rhino 8 as it will be referred to, is a 3D program that uses NURBS mathematics and can use parametric design through its visual programming tool Grasshopper. (Robert McNeel & Associates, n.d.)

Grasshopper can run CFD simulations with the help of the right plugin, for example the Ladybug and Butterfly plugins. The program OpenFoam was also needed to simulate wind.

For this thesis, different CFD microclimate and wind scripts were tested. During these tests, it became clear that the computers needed higher capacity, as simulations could take hours to execute, depending on the input parameters. The scripts also required a higher technological knowledge, which was unavailable for the author of this thesis. Thanks to this, Rhino 8 was mainly used for downloading urban morphology models and exporting them to Forma. This was done with the help of a Forma plugin in Rhino 8.

Rhino

Accessibility	1/3	
Accuracy	1/3	Intuitive but can be easily adjusted
Complexity.	1/3	
Available	Yes	Cannot be fully classified as a CFD simulation tool.
		Very beginner friendly, but a short training in the program would be appreciated.

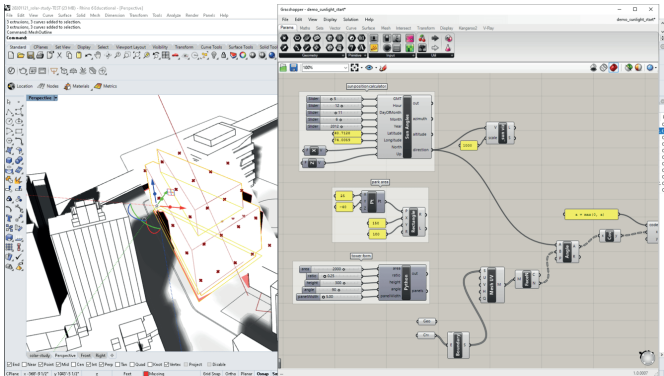


Figure 31. Solar shading and insolation analysis applied to urban building massing in Grasshopper (right) for Rhino (left)(Spencer, 2020).

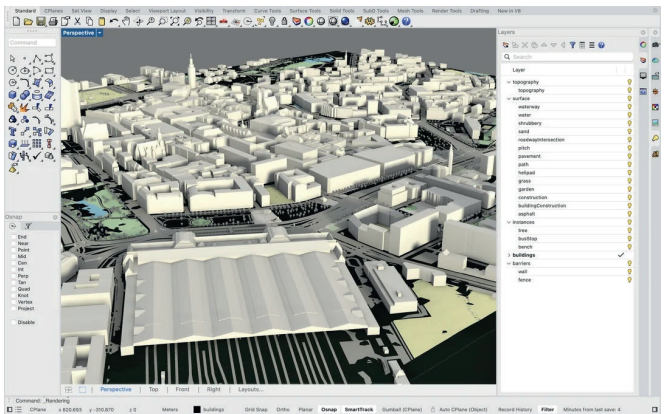


Figure 32. 3D model of central Leipzig generated via Cityweft, a platform providing downloadable real-world 3D urban models for use in CAD and BIM tools such as Rhino (u/cityweft, 2025). Both have been used in the thesis.

Design principles

Wind mitigation

A buildings morphology and site determine how the wind affects the building's surrounding urban spaces. Given wind direction, wind speed, urban shape and façade elements, it is possible to create urban areas that works with the wind. To explain the different wind concepts and effects, the Wind Design Guide by Jessica Bennet will be used.

The Wind Design Guide outlines how standalone building, and multiple buildings of different heights, shapes, volumes and distances are affected by the wind. Although the general wind speed is usually not that strong in Kiruna, the lack of protective greenery and cold temperatures make the wind feel colder than expected.

A reminder to the reader is that even when wind speeds are relatively low, the cooling effect can still be significant.

Solar maximization on the ground

In Kiruna, the sun lies between two extremes; either something you get in abundance during the summer with the midnight sun that never sets or the extremely scarce during the winter when the sun does not rise at all during the day. This may create future challenges in connection with a changing climate.

Ground materials and greenery

Although this is outside the scope of the thesis, soil materials are becoming even more important in urban spaces due to climate change. The ground needs to handle snow, water and flooding in the future, among other things.

Snow-, stormwater, and flooding management.

Due to the changing climate, unexpected heat waves can occur quickly, especially during spring. As the frost in the ground slowly warms up, it can lead to flooding of urban spaces, roads and nature. It is recommended to actively plan places to manage flooding and snow storage. For example, parks or parking lots that are paved with paving stones. This creates an increased opportunity for runoff. Even basement parking garages can be temporarily used to store excess water.

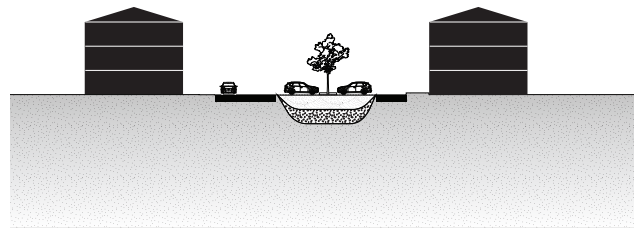


Illustration 1. During the summer, urban spaces are generally more accessible and inviting for pedestrians and visitors.

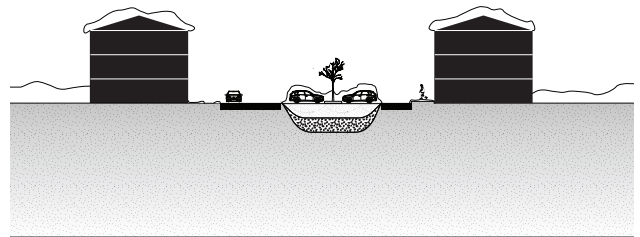


Illustration 2. During the winter, urban spaces become less accessible due to large amounts of snow

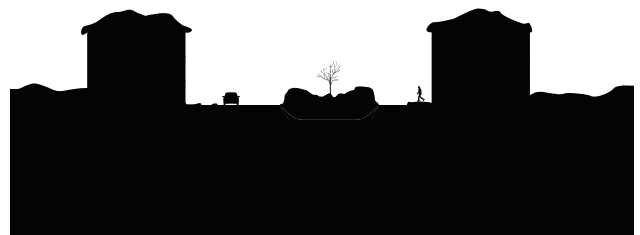
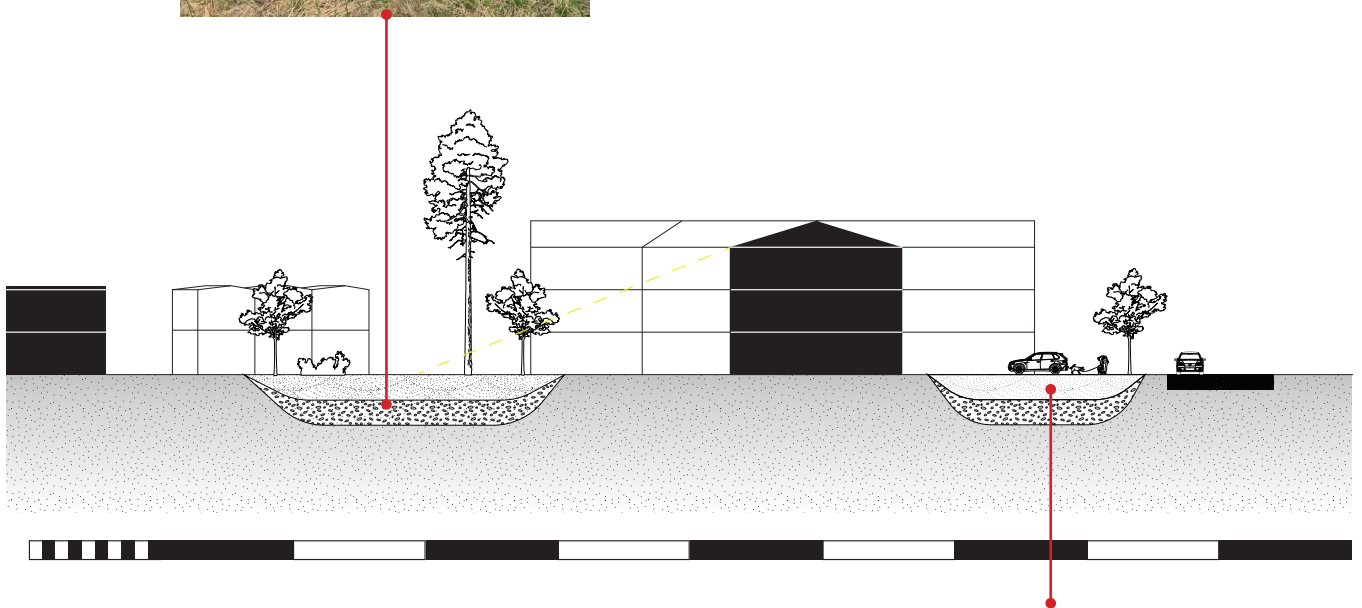


Illustration 3. A silhouette showing how the shape and accessibility of urban spaces are altered by accumulated snow.

Figure 33. The illustrations shows different experiences and accessibility during the seasons.



Figure 34. Kiruna's subarctic vegetation is characterized by short, wind-sculpted pines and birches, shaped by extreme climatic conditions including long winters, permafrost, and a severely restricted growing season. This stands in stark contrast to the denser and taller vegetation found in Sweden's coastal and temperate climate zones, posing distinct challenges for urban green space planning in northern environments. *Photo: Author.*



Parking lot surfaces and their underlying layers are designed to allow water drainage during sudden spring heatwaves, using permeable paving stones instead of asphalt, reducing hard surfaces and creating space for more greenery.



Figur 35. Shows a parkinglot with perforated ground stone and green spaces between parking lots. (BM+LA, 2011)



Figure 36. A gravel parking lot with vegetation between the spaces during summer, with a jeep visible in the background (Unknown author, n.d.).

Kiruna

Place, city, climate, architects, urban planners

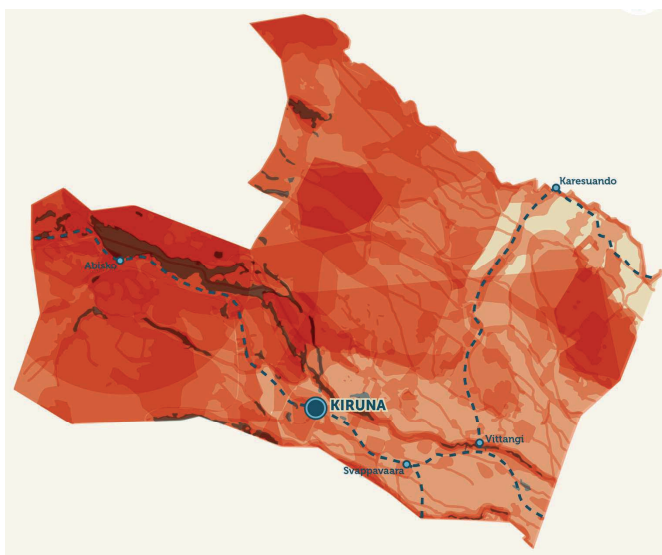
Kiruna town is in Kiruna municipality. The municipality is as large as Slovenia, surrounded by nature and land rich in natural resources of national interest. To understand the current climate challenges of the place, it is important to understand how the climate has been addressed historically.

Kiruna was founded in 1900, and a larger infrastructure system in the form of several LKAB mines, railways, and hydroelectric power grew with the community. Per Olof Hallman became Kiruna's first architect and urban planner, and the city plan was established in 1900. Hallman's design strategy was to work with the typology, conditions, and climate of the place. This was very innovative and unusual at the beginning of the 20th century, when the norm was regular grids and standardized blocks. Hallman and the architect Gustaf Wikman came to design parts of Kiruna's city plan, residential areas, workers' housing, schools, etc. Wikman's most famous work is Kiruna Church, whose design was inspired by the culture and building tradition of the Sami people. Another architect who designed several residential areas in Kiruna was Ralph Erskine. He also did research on how architectural cities are affected by the climate. (ArkDes, 2020)

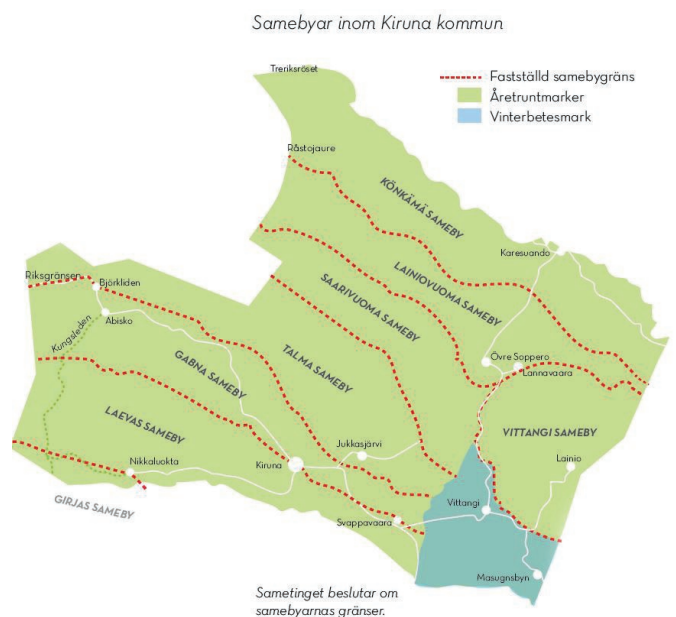
A clear difference between Wikman and Erskine is that Erskine was active much later, around 1950–1960, and had more focus on climate-adapted social architecture and preferred the style of modernism. Whereas Wikman preferred and designed buildings inspired by the Jugend, New Baroque, and American influences.

Land division and industries

Kiruna's geographical location makes it particularly suitable for space research and observations. This means that the city's expansion has historically encroached on Sami lands, and continued exploitation risks doing the same. Today, there are regulations and a generally higher respect for the Sami and their place in society and geography. Every new house or infrastructure project that needs to be built may infringe on their land, giving the Sami the right to demand a halt to exploitation, compensation, or restoration of damaged natural environments. The municipality of Kiruna is in a challenging urban planning situation, with limited land allocation that mostly goes to industries, national interests and the Sami.

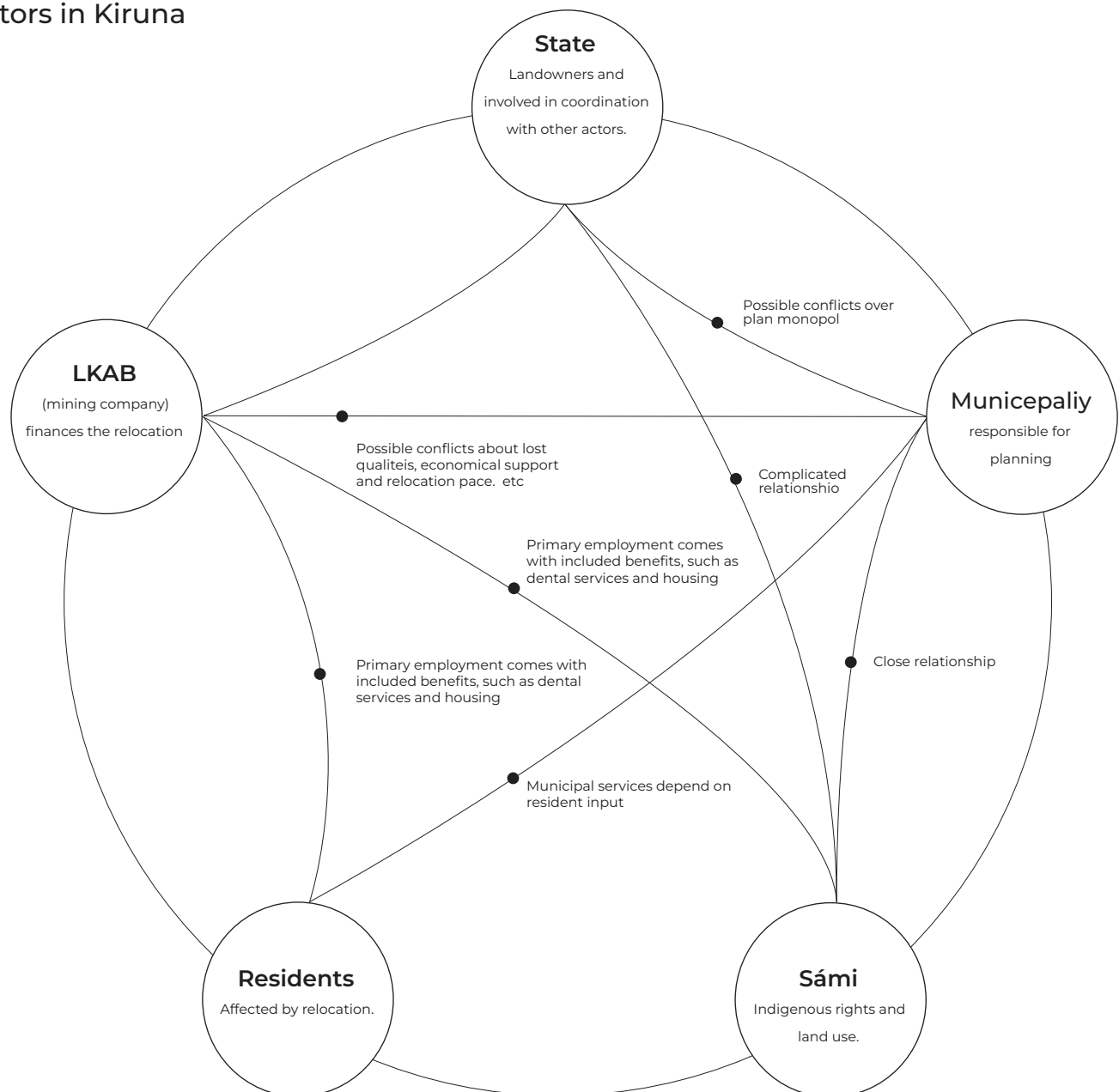


Figur 37: Red refers to areas of national interest. Kiruna Municipality. (2025). *Riksinteresse tillsammans* [PDF]. Kiruna Municipality.



Figur 38: Sami villages in Kiruna Municipality "Samebyar inom Kiruna kommun", Kiruna Lappland, n.d.

Actors in Kiruna



Figur 39. Actors relationship illustration. Illustrated by thesis author.

Extreme Climate Conditions

Arctic temperatures ranging from -45°C in winter to +30°C in summer require careful planning for thermal comfort and microclimate management.

Limited Municipal Land Ownership

Kiruna Municipality owns only 1.45% of the land, severely restricting its ability to develop new residential areas for relocated citizens.

Complex Actor Landscape

Multiple stakeholders with differing interests:

LKAB (mining company) – finances the relocation.

Municipality – responsible for planning.

State – involved in coordination.

Sámi People – Indigenous rights and land use.

Residents – affected by relocation.

Sensitive Land Use Conflicts

Expansion risks infringing on Sámi land rights, requiring legal compensation or restoration. Surrounding areas are either environmentally sensitive, occupied by minority villages, or exposed to noise pollution (ex: airport, industrial zones).

Infrastructure and Accessibility Constraints

Some areas (east along the E10) offer better infrastructure (existing plumbing/electricity), but others are wetlands, forests, or noisy zones.

Relocation Fatigue and Uncertainty

The population has already experienced one major relocation. A second phase raises concerns about long-term stability, identity, and community cohesion.

Negotiation and Land Acquisition Difficulties

The municipality must negotiate with: The state and minority groups for protected land. Numerous private landowners with small plots. All options are equally complex and politically sensitive.

Urban transformation

As part of the major urban transformation in Kiruna and the relocation of industrial functions southward, local stakeholders have developed various scenario analyzes to assess the impacts on different groups. One example is the relocation of the railway and central station, as illustrated in image X, where a new railway corridor is being investigated. Image X also shows the Swedish Transport Administration's (Trafikverket) noise impact assessment on nearby residential areas, as well as on adjacent Sámi villages and reindeer herding activities.

The Swedish Transport Administration suggests that one way to create a sense of continuity and identity in the new urban environment is to relocate selected buildings from the existing city structure. This would allow different historical layers to coexist in a kind of "dialogue." However, each such measure must be preceded by an analysis of the relocated building's impact on the future built environment and its cultural heritage value

Kiruna's western industrial area, currently located in the city center, is expected to be relocated further south along Holmajärvivägen. This move aims to place the mining-related industry outside the deformation zone while maintaining proximity to LKAB's southern access and associated infrastructure, thereby strengthening the logistical and operational connection to the mine.

The impact on reindeer herding is significant. Kiruna is surrounded by areas of national interest for reindeer herding, including core areas, migration routes, and resting pastures that are essential for the Sámi communities' ability to maintain sustainable herding practices. Infrastructure projects such as the new railway, Road 870, and industrial zones risk cutting through key migration routes, especially in narrow corridors like the one between Lombolo and the airport.

Although mitigation measures such as wildlife overpasses and fencing have been implemented, major challenges remain.

A major challenge is that Kiruna Municipality owns only 1.45% of the land within its borders. This severely limits its ability to develop new housing for relocated residents. The relocation process has already moved parts of the city centre and the church eastward. Now, discussions are underway about a second phase of relocation, raising the question:

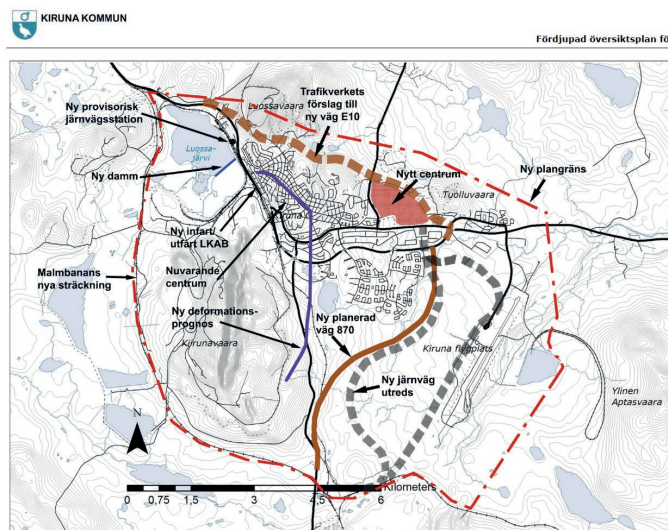
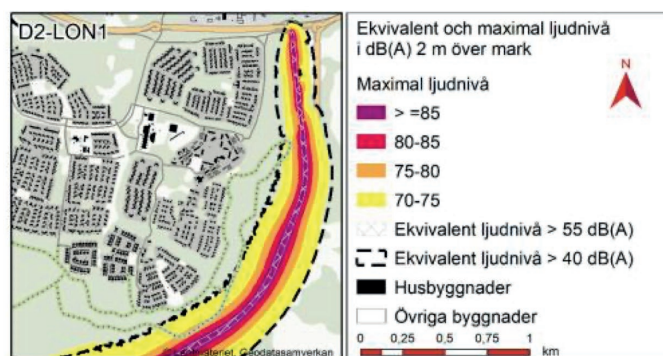


Bild 1. Större förändringar i planeringsförhållningarna, som skett efter FÖP för Kiruna C 2006.

Figur 40. Kiruna fördjupad översiktsplan (s. XX), by Trafikverket & SWECO, 2023, Samrådsredogörelse, Trafikverket & SWECO.



Figur 1. Ekvivalent och maximal ljudnivå 2 meter över mark för alternativet LON1 utan bullerskyddsåtgärder.

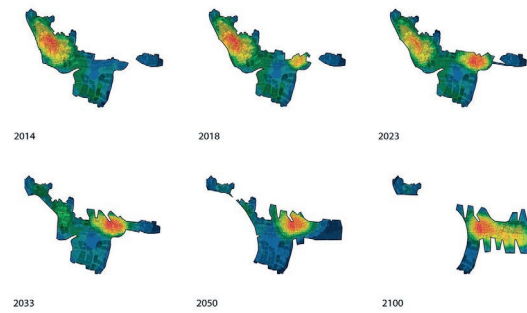
Figur 41. Kiruna fördjupad översiktsplan (s. XX), by Trafikverket & SWECO, 2023, Samrådsredogörelse, Trafikverket & SWECO.

Should Kiruna's core functions and population be moved to an entirely new site?

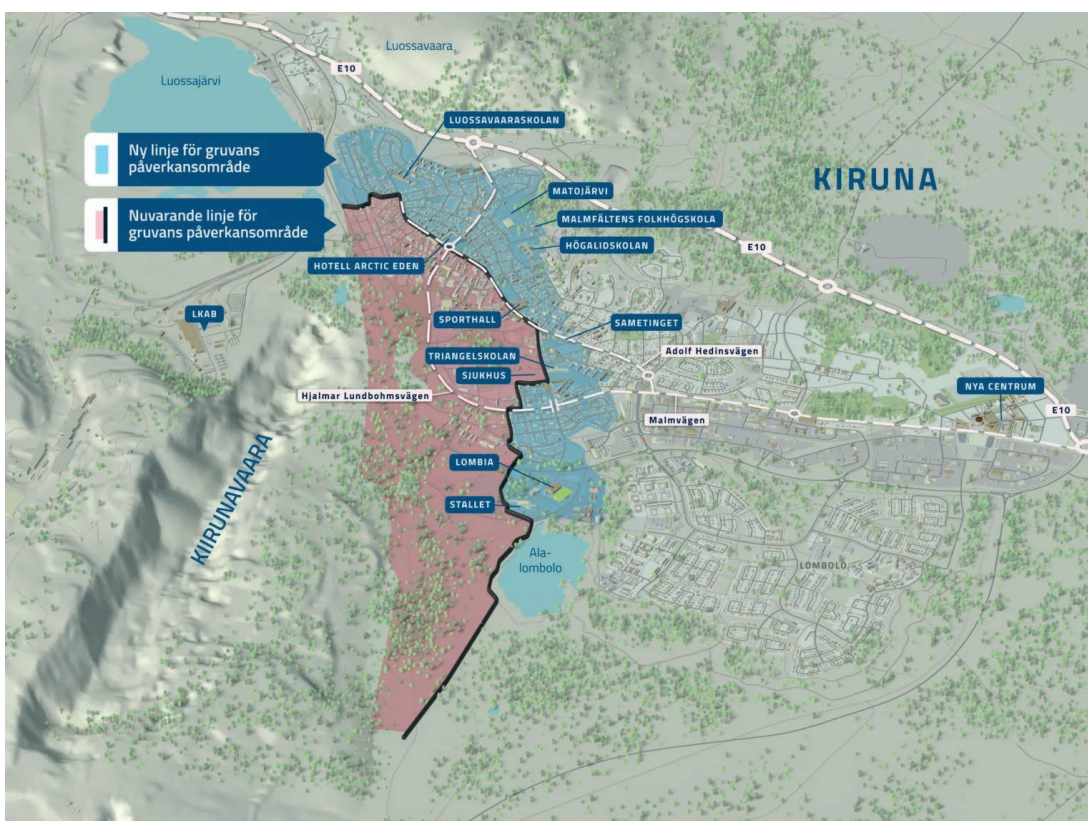
As a result of the expansion of the primary iron ore mine located west of Kiruna, ground conditions have begun to deteriorate, leading to the formation of a deformation zone that poses significant risks and is deemed unsuitable for residential and public use.

During meetings with the municipality and LKAB, it became clear that this is a massive challenge. Potential relocation sites each come with their own complications: The Sámi villages of Laevas and Gabna have previously expressed that an eastern urban expansion is preferable to

western alternatives, as it poses less disruption to reindeer herding. It is also crucial that peripheral development and increased outdoor recreation in the outskirts of Kiruna are planned with consideration for reindeer movement patterns and access to grazing land. Ultimately, the municipality must negotiate land purchases either with the state (and affected minority groups) or from many small private landowners. None of these options is easy, and all present significant challenges and costs.



Figur 42, by White Arkitekter, 2015, *The Atlantic*.



Figur 44. Kiruna urban transformation, by LKAB, 2025, *LKAB*.

In summary, Kiruna's urban transformation requires careful planning that balances cultural heritage, noise mitigation, the long-term viability of reindeer herding, and the strategic placement of industrial infrastructure.

The industrial site

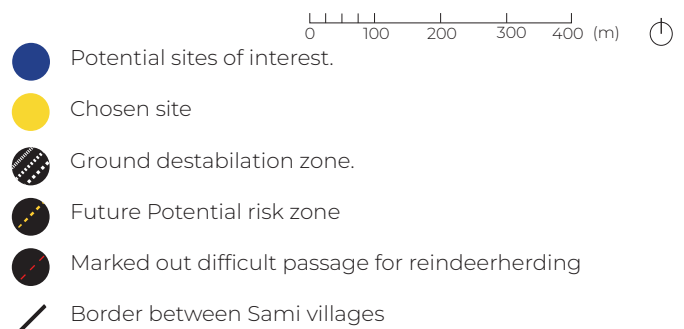


Figur 45: Geographical context of the city of Kiruna, iron mine, Sami village division, municipality land ownership border and potential sites of interest.

The Reindeer Herding Law (SFS 1971:437, 1985:919 and SKSFS 1982:2). The law establishes the Sami people's right to conduct reindeer husbandry within the traditional reindeer grazing lands. The Sami people have a marked-out difficult passage for reindeer herding, which runs through my chosen site. I have made the choice to avoid the area closest to the road west of the site in order to allow free passage for reindeer herding across the roundabout. The site is exposed to noise pollution, mainly from the airport.

This site was chosen because there are already buildings in place. Site plans have been used for relocated industries that are now located in the west industrial district (directly south of the new city centre). The industries linked to the mining industry are planned to relocate to another plot further south. In contrast, smaller industries whose services are primarily aimed at the general public are encouraged to move to the chosen site.

By choosing to build close to Kiruna's new city centre, the city centre is given centrality and context, which it does not currently have. Industrial areas and larger-scale residential buildings can be designed to protect against noise and wind.



With this and the assumption that building volumes of different scales will be built, it is also possible to accommodate new industrial premises and commercial premises on the ground floor along streets of interest.



Figur 46. Geografical context of the city of Kiruna, iron mine, Sami vilage division, municepality land ownership border and potential sites of intrest.

During the design process, I realized that the area needed more space to give the design better conditions to create good wind and climate conditions within the urban plan. The site was therefore expanded and given a more compact, rounded shape. There are two areas of interest in the design work: the edge of the urban plan, which is directly exposed to the surroundings consisting of forest, open landscape and occasional industrial buildings, and the core, the protected interior of the area. This division allowed testing of how block shapes and varied number of floors can together create a protected urban space within the plan.

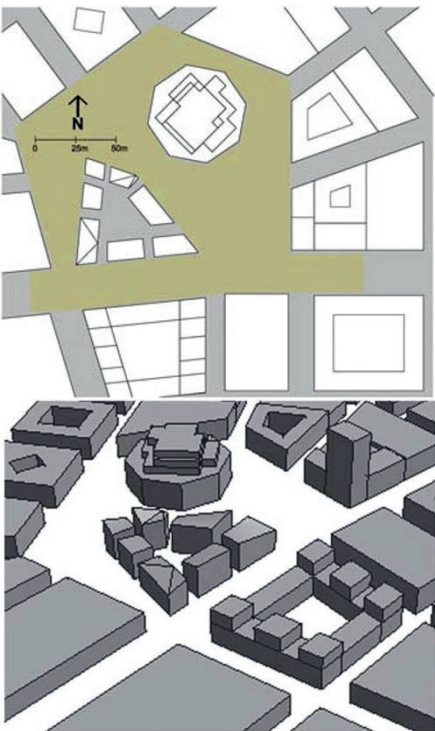
-  Chosen site
-  Marked out difficult passage for reindeerherding
-  Planed new passage for reindeerherding
-  Industrial area

New Kiruna city center

Comparison of microclimate studies

With the aim of getting a transparent overview of how accurate the Forma simulations, white architects' own simulations and Ebrahimabad's Kiruna simulations are, a simplified comparison between them has been carried out. The Autodesk Forma simulations produced do not contain the planned full-scale 3D model, nor does it include any green infrastructure used by Ebrahimabad and White Architects.

The comparison begins with a table showing the parameters and methods of the three studies. After this, selected maps from the studies are displayed and then combined. The reader is advised to observe how different detailed results are based on the level of detail of the working method and whether there are any obvious differences in the results.



Figur 47. Ebrahimabad plan and 3D model of the case study area (s. 2), by S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, *Urban Design International*, 23(2), 116–131.

Categori	Autodesk Forma comparative study (2026).	White Arkitekter & EPFL (2017)	Ebrahimabadi et al. (2016)
Main objective	Compare Autodesk Forma accuracy with professional case studies.	Improve perceived outdoor comfort at Kiruna Square with green infrastructure	Assess a simplified microclimatch method to identify sun- and shelter-favoured zones
Wind data source	SWE_Kiruna.020440_IWEC.epw	IWEC / EnergyPlus weather file	SMHI, Kiruna airport
Wind time resolution	Single-day analysis	Annual, hourly	Quarterly averages + scenarios
Annual mean wind speed	From IWEC (.epw), scaled to 1.75 m	Approx. 3.8 m/s	approx. 3.5 m/s
Tested wind speeds			6–10 m/s (comfort and safety tests)
Wind analysis height	1.75 m	~1.5 – 1.75 m	1.75 m
Surface roughness (Z ₀)	1	Not stated	0.4
Comfort evaluation framework for simulation outputs	Forma NEN 8100 & Lawson LDDC	UTCI + COMFA	NEN 8100 + simplified sun/wind scoring
Analysed urban design elements	Urban form (held constant for comparison)	Ground materials, tree density, urban form	Urban form (3D geometry by White Arkitekter)
Simulated periods	20 Mars	Full year (seasonal evaluation)	21 Dec, 21 Mar, 21 Jun
Authors & producers	By Thesis author, Jonna Pestrea	White Arkitekter + EPFL	Luleå University of Technology



Figure 48. Screenshot on Google Maps, 2024, Google Maps. Retrieved May 2, 2026, from <https://www.google.com/maps>

Explanation
Different studies have different goals, detail and technical levels, this will affect the results.
The EPW weather file is based on geographically point-based climate data, the representativeness of which is affected by the proximity of the measuring station to the location, the time period of the data, and the choice of CFD tool and evaluation method.
Will give different results, especially since longer time spans (months and years) are based on the normal and average values of the wind data.
This is not CFD-produced wind data but describes how windy the climate is on average, i.e. the average wind speed on the geographically point-based climate data from the collected weather station.
The selected wind speed in m/s
Wind analysis higher is the height at which the wind data is generated. Most often used at 1.75 - 2 m to report wind experience for pedestrians
Surface roughness refers to the friction between the wind and the material. 1 refers to an urban terrain with minimal interference to wind flow from surrounding urban structures.
Evaluation framework for simulation outputs aims to evaluate how different comfort scales. In these studies UTCI, COMFA, NEN 8100 & Lawson LDDC.
Urban design elements refer to the categories of 3D geometry included in the study.
Clarifies whether the study is annual or representative of seasons or dates.

Both case studies have used White Architects' 3D model, but it is important to note that a large part of the modeled area has not yet been built. South of the simulated square is the western industrial area, which has so far remained untouched, awaiting the industries to be divided into mining industries and non-mining industries. To then relocate mining-related industries to a new industrial area south of Kiruna. The smaller part of the industries not involved in the mine is planned to be relocated southeast, closer to the airport.



Figure 49. Annis aerial photograph, by W. Overklift/LKAB, 2023, LKAB.

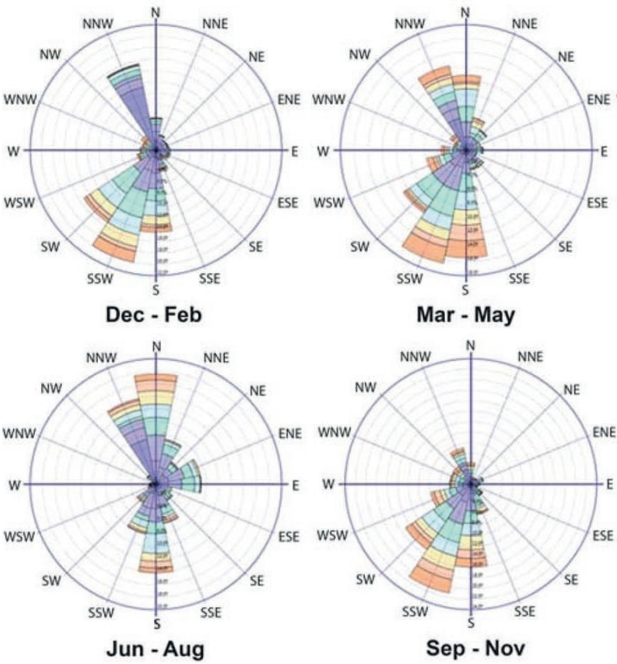


Figure 50. Ebrahimabad quarterly wind roses (s. 7), by S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, *Urban Design International*, 23(2), 116-131.

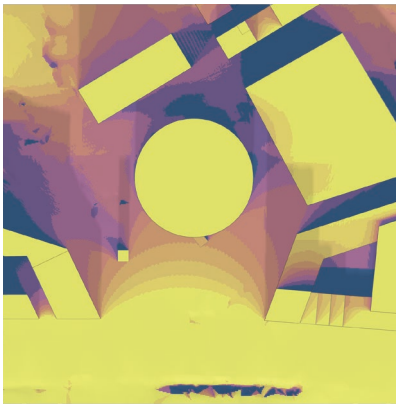


Figure 51. Analysis of sunshine hours, as of March 20. 69% of the land receives direct sun for at least 3 hours. 53% of the facade receives direct sunlight for at least 3 hours.

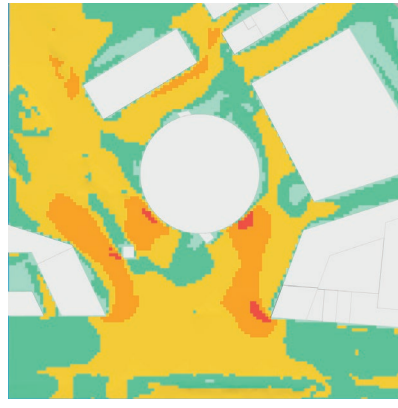


Figure 52. wind analysis showing wind comfort, Lawson LDDC as comfort scale. <statistics: Sitting 7.7%, standing 33.5%, walking 49% and walking 9.52. uncomfortable 0.5%.

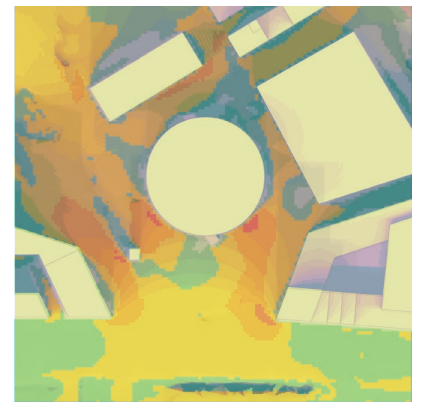


Figure 53. Combined solar and wind comfort analysis.

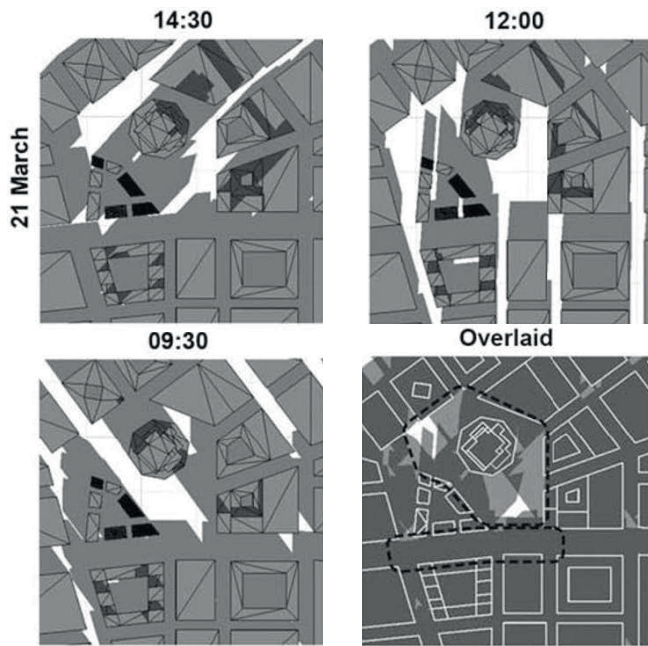


Figure 55. The solar access analyses for 21 March. The square and the east-west-directed (E-S) street are marked by the dashed line in the rightmost figures (s. 125), by S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, *Urban Design International*, 23(2), 116–131.

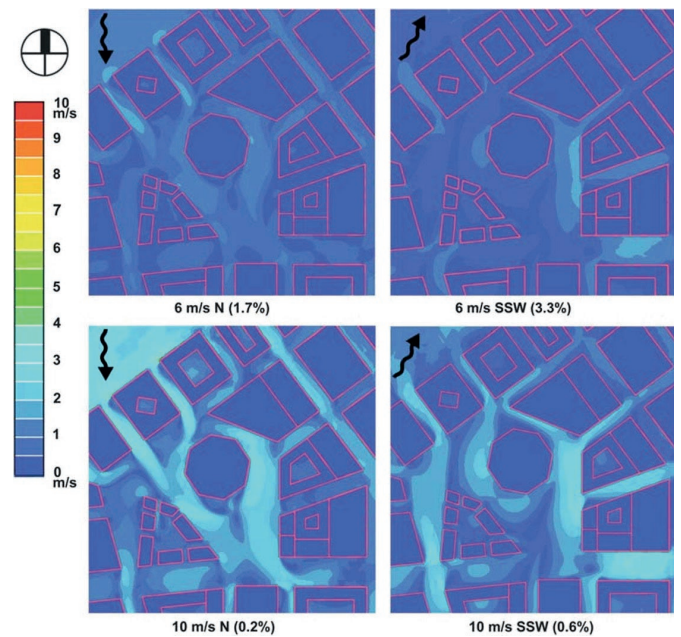


Figure 56. Simulations of pedestrian-level winds (h=1.75 m) at 10 and 6 m/s in N and SSW directions. The black arrow indicates the wind direction in each simulation (s. 124), by S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, *Urban Design International*, 23(2), 116–131.

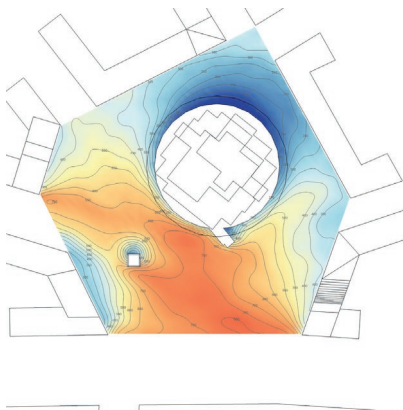


Figure 58. Shows an overlap of annual hours of direct sunlight using only clear sky without trees, by A. Pacheco Diéguez, C. Duckart, & S. Cocco, 2017, *Urban Thermal Comfort Study: Kiruna Square* (68°N 22°E), White Arkitekter & EPFL.

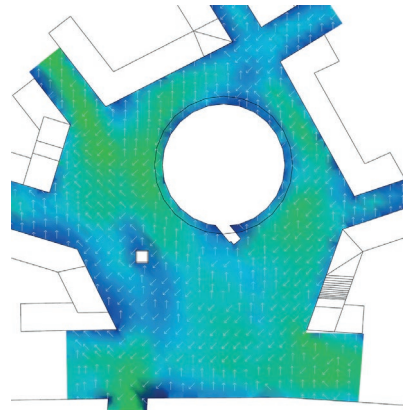


Figure 59. Annual average wind speed without trees, by A. Pacheco Diéguez, C. Duckart, & S. Cocco, 2017, *Urban Thermal Comfort Study: Kiruna Square* (68°N 22°E), White Arkitekter & EPFL.

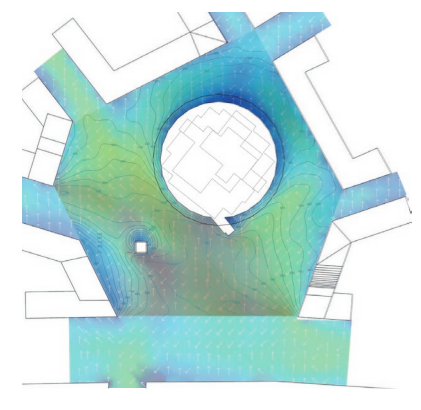


Figure 60. Shows an overlap of annual hours of direct sunlight using only clear sky without trees, and annual average wind speed, by A. Pacheco Diéguez, C. Duckart, & S. Cocco, 2017, *Urban Thermal Comfort Study: Kiruna Square* (68°N 22°E), White Arkitekter & EPFL.

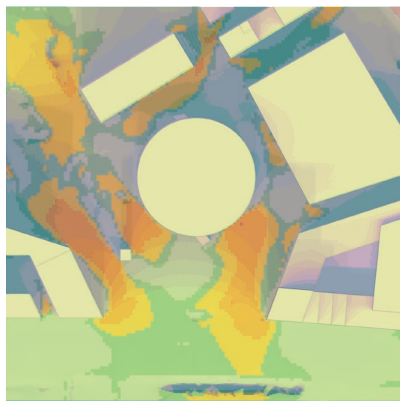


Figure 54. Combined solar and wind comfort analysis, but using NEN 8100 instead of wind comfort. Lawson LDDC.

Forma comparative simulation (2026)

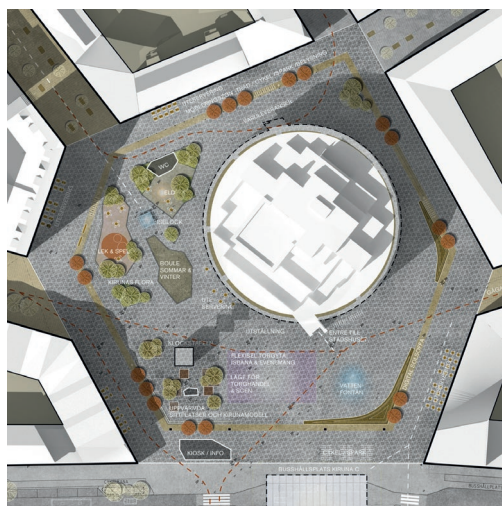
Autodesk Forma has been used to create a reference simulation of Kiruna's new square. The 3D model comes from Forma provide a Site and urban 3D model. The simulated material is based on geometrys from year 2024.



Figure 57. Maps values and microclimate assessment (wind and shadow) for 21 June at 10:00 (s. XX), by S. Ebrahimabadi, C. Johansson, A. Rizzo, & K. Nilsson, 2016, *Urban Design International*, 23(2), 116–131.

Ebrahimabadi et al. (2016)

Ebrahimabadi's article on Microclimate assessment method produces wind simulations including multiple windspeed, wind directions and solar access analyses. the solar analyzes include multiple dates and time of day with shadow studies. This study focuses on testing a simplified microclimate mapping method proposed by Brown and DeKay's (2001).



Figur 61. Plan of the square highlighting the focus areas, by A. Pacheco Diéguez, C. Duckart, & S. Coccolo, 2017, *Urban Thermal Comfort Study: Kiruna Square (68°N 22°E)*, White Arkitekter & EPFL.

White architects & EPFL simulations (2017)

White architects produced microclimate analyses in collaboration with École Polytechnique Fédérale de Lausanne (EPFL). The study was carried out with the aim of creating a basis for improving outdoor comfort in Kiruna's new town square through urban design. The study worked with the urban design elements soil materialsm tree density and urban form.

Kiruna simulations

Studies and instructions

To understand how different urban morphologies are affected by Kiruna's climate, Autodesk Forma solar and wind comfort simulations have been combined. The climate background for the simulations comes from an EPW file and the same file was used in all simulations. The file has collected data from Kiruna Airport, specificity from the weather station IVEC (International Weather for Energy Calculations). The readers should note that wind comfort studies use representative scenarios and are based on average values of the collected data. This means that the wind comfort data include all wind directions and are calibrated using normalized wind speeds derived from the EPW climate data. Forma also offers a wind direction function where wind flows and wind speeds are visualized, however, in this case the analysis is limited to wind speeds within the range of 0–13 m/s.

Kiruna's solar availability shifts dramatically between having polar nights during winter and midnight sun during summer. The solar simulations were set to March 20 during the spring equinox, when the night is as long as the day.

Each urban morphology example has been grouped with similar cases and is accompanied by a short introduction of its original site, a 3D image, a table with statistics about the study area (200 × 200 m) and observations.

To simplify and clarify the simulation results, the scales for available sunlight at ground level and wind comfort have been adjusted. The new sunlight scale indicates only when there are 1–5 hours of direct solar exposure on the ground. The wind-comfort scale has been reduced from five to four activity levels, merging the categories "strolling" and "walking" into a single activity. The four remaining categories are sitting, standing, walking, and uncomfortable.

Level	Description	Windspeed
1	Calm	< 1.5 m/s
2	Light breeze	1.5–3 m/s
3	Gentle wind	3–5 m/s
4	Moderate wind	5–7 m/s
5	Fresh wind – uncomfortable	7–10 m/s
6	Strong wind – difficult to walk	10–13 m/s
7	Storm wind – dangerous	13 m/s

Figure 62. UTCI

Category	Limit	Time
Sitting	3.6 m/s	1.5% of the time
Standing	5.3 m/s	1.5%
Walking Slowly	7.6 m/s	1.5%
Walking	9.8 m/s	1.5%
Uncomfortable	>9.8 m/s	1.5%

Figure 63. Davenport comfort scale

Category	Limit	Time
Sitting	2.5 m/s	5% of the time
Standing	4 m/s	5%
Walking Slowly	6 m/s	5%
Walking	8 m/s	5%
Uncomfortable	>8 m/s	5%

Figure 64. Lawson LDDC comfort scale was used in forma's wind comfort simulations.

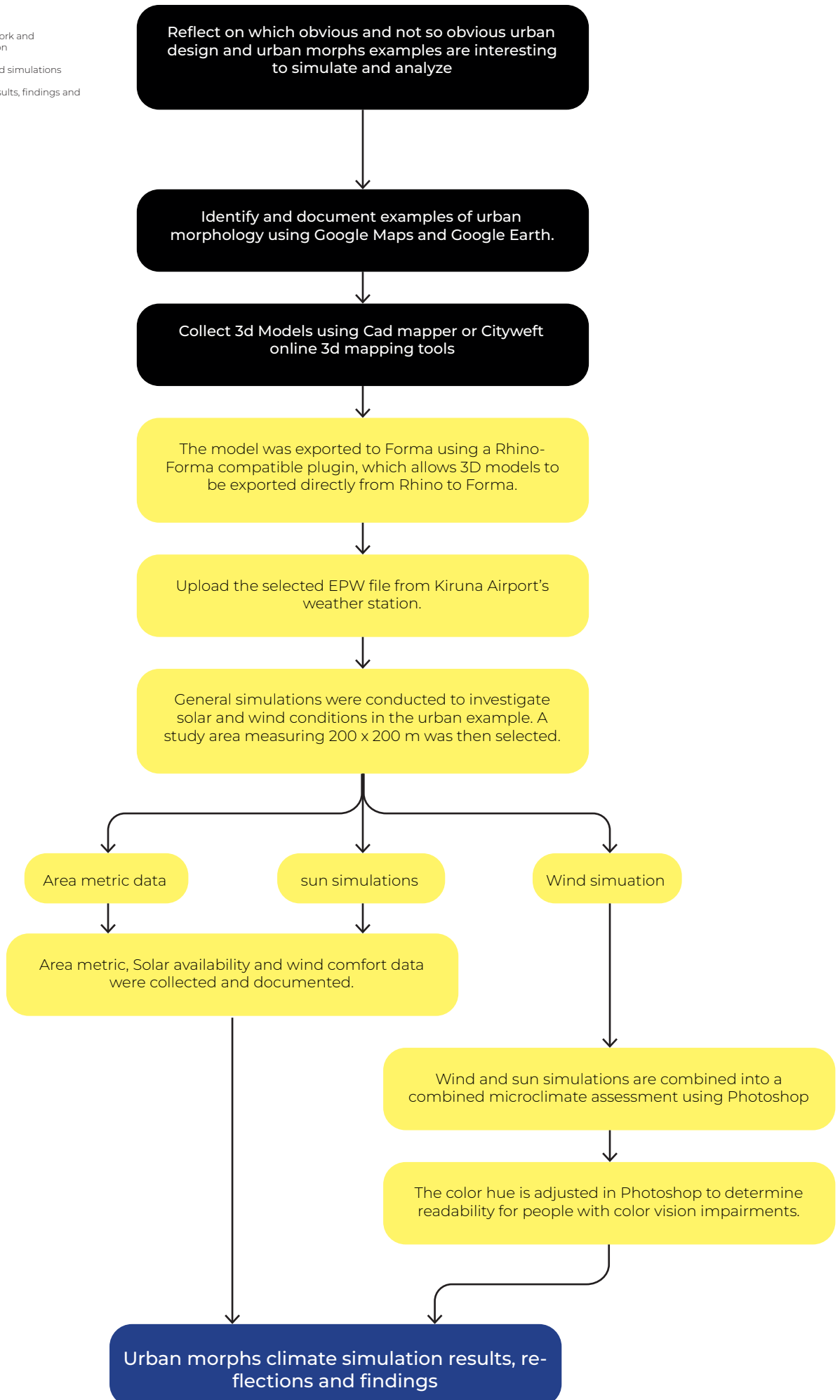
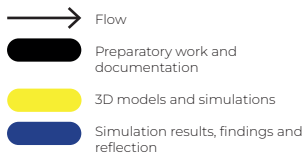
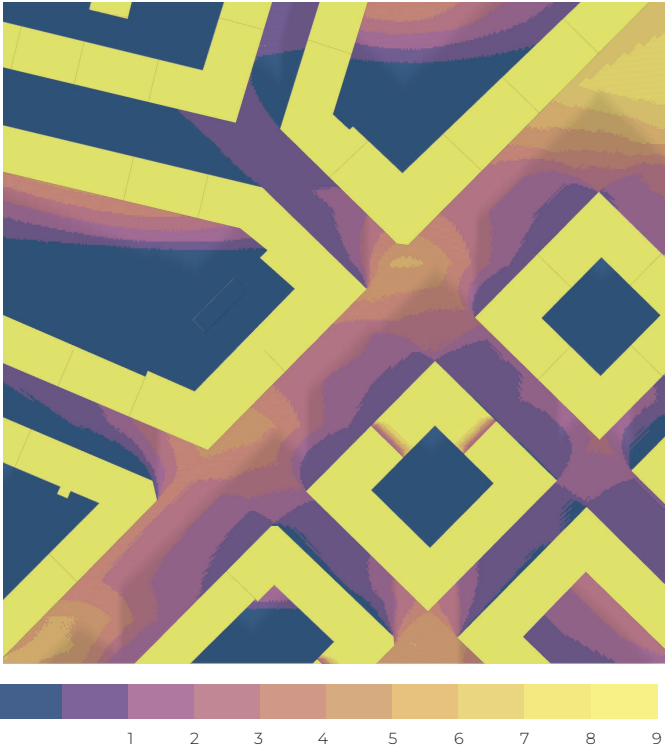


Figure 66. Simulations method and order.

Reading the simulations

In order to understand and read the following simulations. The simulations are based on overlapping sun and wind simulations.

Autodesk Forma sun hours minimum 3 hours on ground m/s



+

Autodesk Forma wind comfort Experienced wind comfort



Activity	Sitting	Standing	Slow walk	Walking	Uncomfortable
Wind speed	2,5 m/s	4 m/s	6 m/s	8 m/s	>8 m/s

Lawson LDDC comfrot scale was used in formas wind comfort simulaitons .

Combined Sun & Wind comfort study

Used photoshop to create stronger contrast

To make the wind simulation results easier to read and more inclusive for people with red-green color blindness, the presentation of the data has been adjusted with Adobe Photoshop.

The sun simulations are shown in black and white.

The wind simulations are shown using the following color scale:

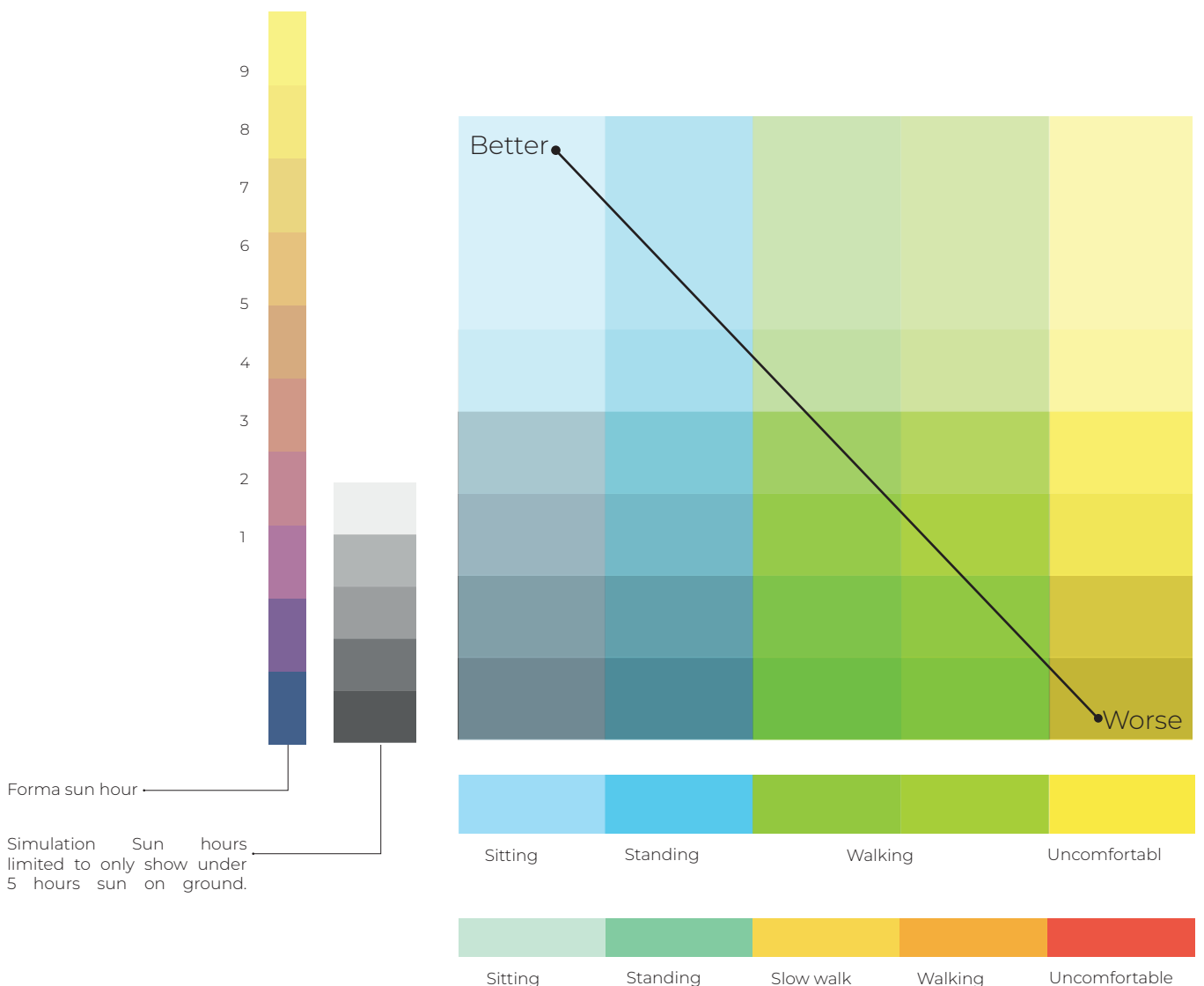
Blue light wind conditions.

Green pleasant wind conditions and windy conditions that may affect stay and activities.

Yellow unpleasant to potentially dangerous wind conditions.

By combining these two simulations, it becomes possible to simultaneously analyze both solar and wind conditions in the area.

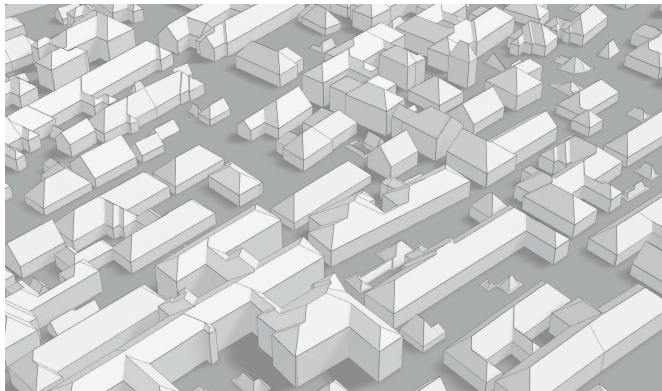
=



Historic compact low-rise urban fabric

Dragør, DNK

Dragør is a historical medieval coastal town south of Copenhagen, built on flat coastal land focused on fishing and the port. The tested area has low buildings, gable roofs, and belongs to old harbour.



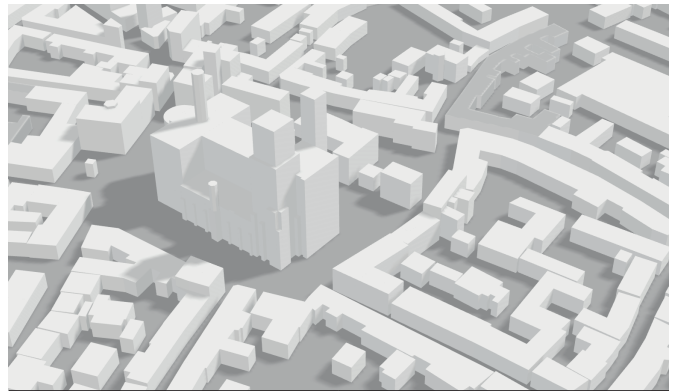
Urban type	Dense lowmedieval fabric
Number of floors	1-2
Building footprint	45%
GFA (Gross Floor Area)	90%
FAR (Floor Area Ratio)	0.9
Ground direct sun	32%
Sitting 2,5 m/s	88%
Standing 4 m/s	11.8%
Walking 8 m/s	0.2%
Uncomfortable >8 m/s	0%



The urban area at the harbor consists of dense streets with low storeys and gabled roofs. Although the streets are often oriented in a westerly direction, the urban density seems to counteract this.

Ribe, DNK

Ribe is Denmark's oldest city, founded around 700–710 AD, and it started as a trading post by the water. Ribe's urban form is organically developed and compact, with a church in the town plan.



Urban type	Dense medieval fabric
Number of floors	1-2
Building footprint	23%
GFA (Gross Floor Area)	46%
FAR (Floor Area Ratio)	0.46
Ground direct sun	29%
Sitting 2,5 m/s	57.5%
Standing 4 m/s	31.5%
Walking 8 m/s	10.8%
Uncomfortable >8 m/s	0.1%



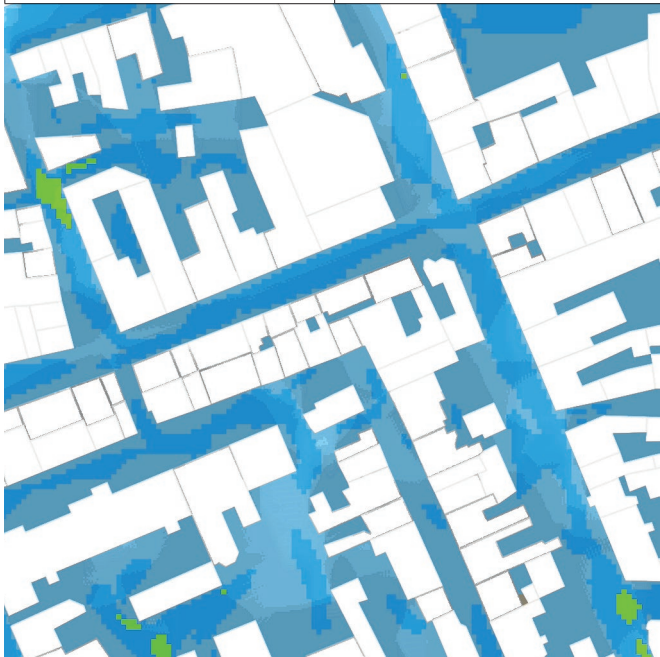
With the curved streets and organic block structure and constant ceiling height, the wind flow is often broken and does not stick as easily to facades and street corners.

Wolfenbüttel, Niedersachsen DEU

Historic city dating back to the 16th century and has been the residence of the Dukes of Braunschweig-Lüneburg.



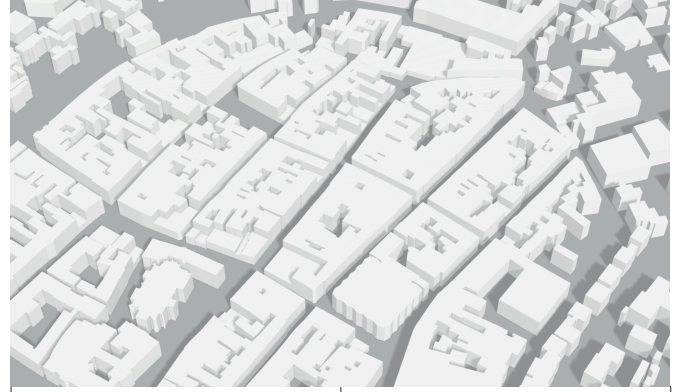
Urban type	Historical urban from
Number of floors	2-4
Building footprint	52%
GFA (Gross Floor Area)	207%
FAR (Floor Area Ratio)	2.07
Ground direct sun	2%
Sitting 2,5 m/s	63.4%
Standing 4 m/s	35.3%
Walking 8 m/s	1.3%
Uncomfortable >8 m/s	0%



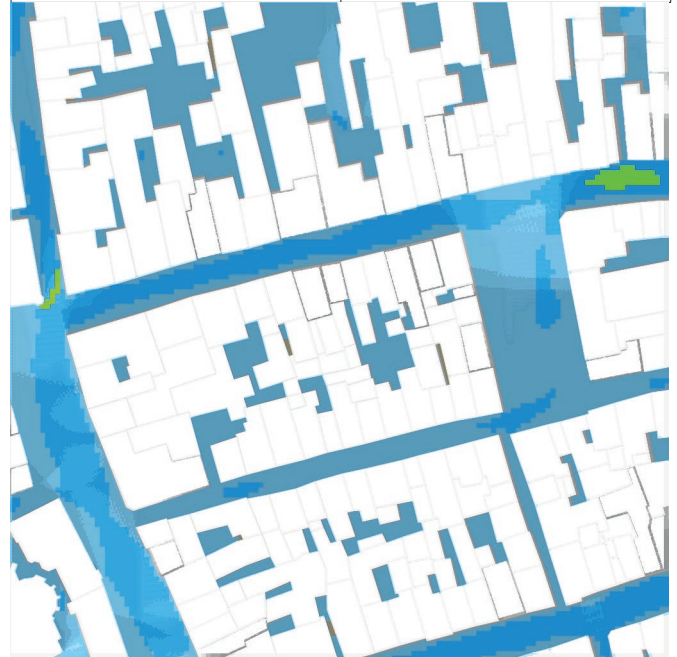
The dense urban structure creates a more wind-protected climate, but it results in many of the streets are in the shade.

Celle, Altstadt, DEU

Celle is a compact historic town with a medieval and early modern urban fabric. The historic core developed in the 13th century.



Urban type	Historic timber-framed town
Number of floors	2-6
Building footprint	66%
GFA (Gross Floor Area)	305%
FAR (Floor Area Ratio)	3.05
Ground direct sun	1%
Sitting 2,5 m/s	71.1%
Standing 4 m/s	27.9%
Walking 8 m/s	0.9%
Uncomfortable >8 m/s	0%



The dense urban form creates calmer wind conditions, however, the buildings shade a large part of the streets.

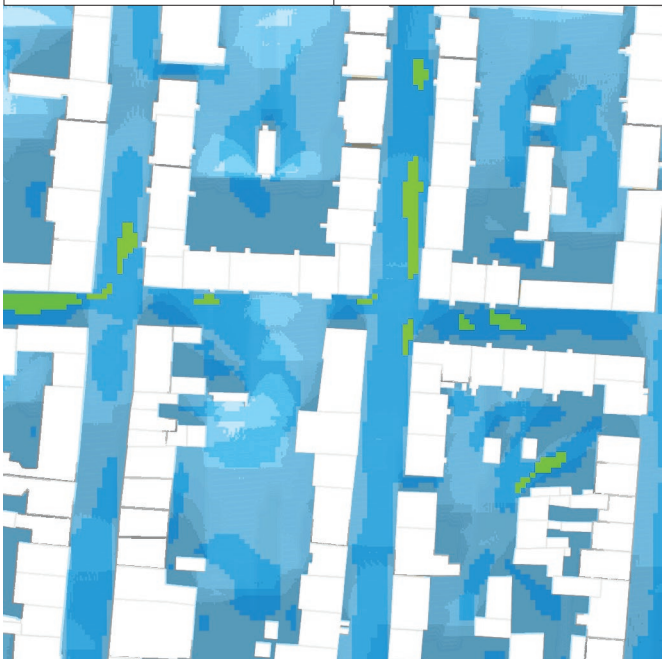
Open urban fabric

Greifswald, GER

Greifswald is a German Hanseatic city with a long history and a relatively regular street network. The city has a compact urban structure shaped by its medieval development.



Urban type	Hanseatic city
Number of floors	2-4
Building footprint	44%
GFA (Gross Floor Area)	138%
FAR (Floor Area Ratio)	1.38
Ground direct sun	19%
Sitting 2,5 m/s	63.2%
Standing 4 m/s	34.5%
Walking 8 m/s	2.4%
Uncomfortable >8 m/s	0%



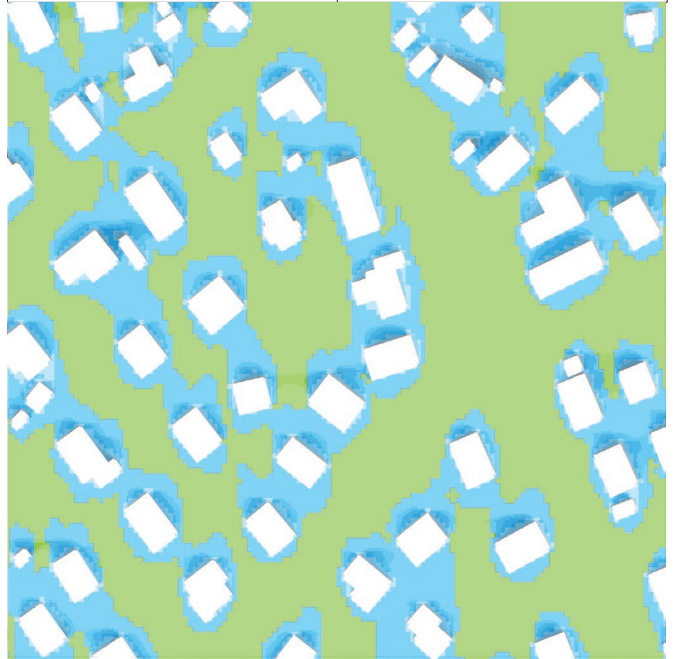
The street network creates a mix of lee, light and shade, and wind tends to follow the edges of the blocks.

Älvsjö, Stockholm, SWE

A residential area northeast of Långsjön in southwest Stockholm.



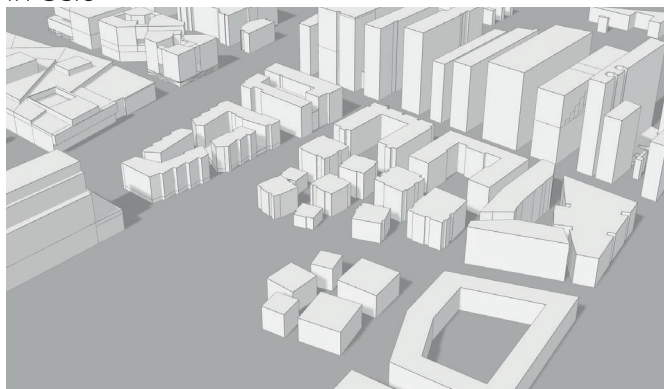
Urban type	Single family house area
Number of floors	1
Building footprint	16%
GFA (Gross Floor Area)	16%
FAR (Floor Area Ratio)	0.16
Ground direct sun	96%
Sitting 2,5 m/s	7.9%
Standing 4 m/s	33.8%
Walking 8 m/s	58.3%
Uncomfortable >8 m/s	0%



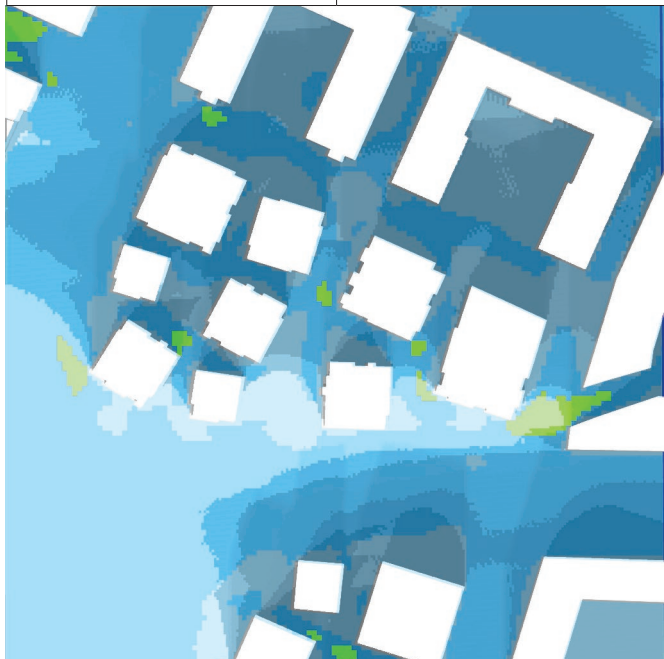
The low density villa structure allows wind to move freely through streets and garden spaces.

Vannkunsten, Oslo, NOR

Vannkunsten is a modern residential area by the Oslofjord in the Bjørvika district. It consists of several point houses directly on the water. Built in 2020-2021 as part of the Fjordbyen development in Oslo



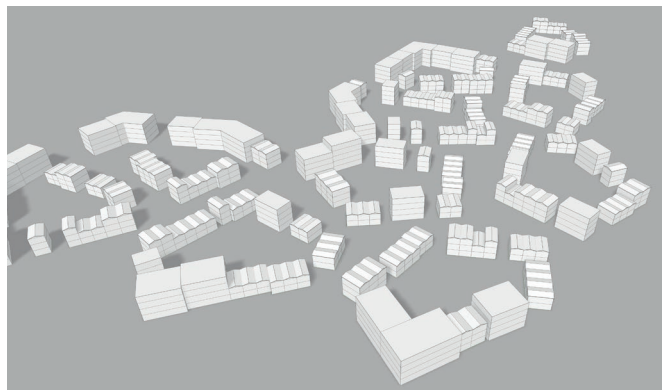
Urban type	Dense waterfront mixed urbantypologi
Number of floors	4-8
Building footprint	27%
GFA (Gross Floor Area)	185%
FAR (Floor Area Ratio)	1.85
Ground direct sun	79%
Sitting 2,5 m/s	25.8%
Standing 4 m/s	63.3%
Walking 8 m/s	11.9%
Uncomfortable >8 m/s	0%



Despite the exposed location, the wind-tight construction results in fewer uncomfortable wind conditions, largely due to the building density. However, this density also leads to poorer solar access.

Billund, DNK

The Danish architecture firm Gehl developed a site in Billund, also known as Legoland. This site is not yet built, so assumptions have been made in recreating the Gehl example.



Urban type	Conceptual urban design
Number of floors	2-5
Building footprint	18%
GFA (Gross Floor Area)	58%
FAR (Floor Area Ratio)	0,58
Ground direct sun	95%
Sitting 2,5 m/s	43.1%
Standing 4 m/s	41.6%
Walking 8 m/s	15.3
Uncomfortable >8 m/s	0.0%

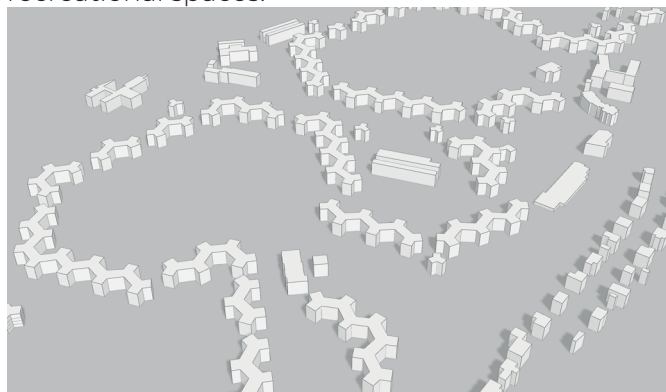


This project manages to balance human scale urban planning and the use of broken street networks. This, combined with the floor height, prevents the gusty uncomfortable winds from occurring.

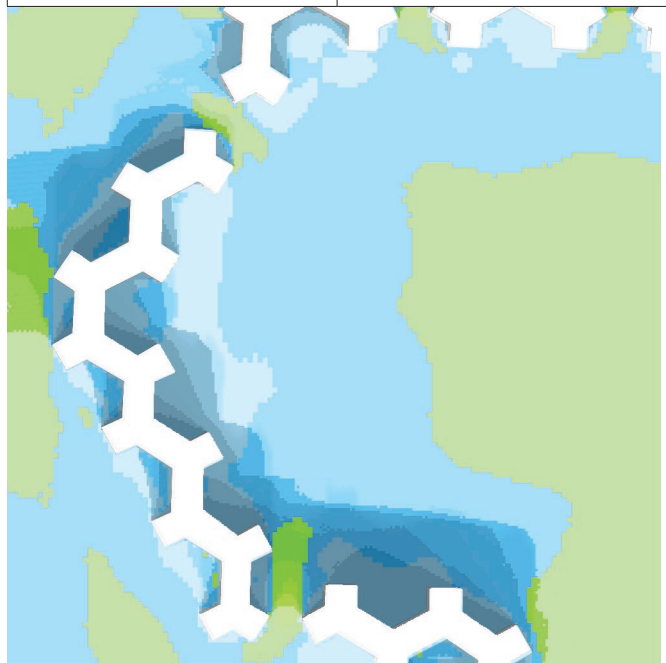
Open urban fabric

Västra Rostaparken, Örebro, SWE

Västra Rostaparken, Örebro Municipality, is a residential area built with the building-in-park concept and Swedish functionalist planning principles, separating housing, traffic, and recreational spaces.



Urban type	Open slab landscape urbanism
Number of floors	4
Building footprint	9%
GFA (Gross Floor Area)	37%
FAR (Floor Area Ratio)	0.37
Ground direct sun	91%
Sitting 2,5 m/s	15.7%
Standing 4 m/s	42.7%
Walking 8 m/s	41.4
Uncomfortable >8 m/s	0%



The open block structure allows plenty of light into the park and surrounding residential areas. The building's hexagon-like shape creates places for shelter and comfort. Openings between these wide blocks create more uncomfortable places in increased wind conditions.

Mellanheden, Malmö, SWE

Mellanheden in Malmö consists of an elongated, slightly crooked residential structure that borders a residential area and multiple schools.



Urban type	Open residential block
Number of floors	3
Building footprint	20%
GFA (Gross Floor Area)	60%
FAR (Floor Area Ratio)	0.60
Ground direct sun	87%
Sitting 2,5 m/s	35.6%
Standing 4 m/s	43.6%
Walking 8 m/s	20.7%
Uncomfortable >8 m/s	0%

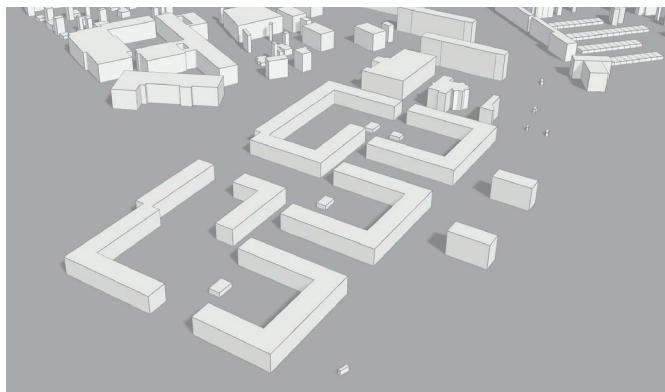


The hexagonal courtyards create sheltered spaces and lee. The protruding house bodies break up the wind flow.

Half open blocks

Brunnsbo, Gothenburg, SWE

Brunnsbo is a modernist residential area with large, broken-up blocks in northern Gothenburg.



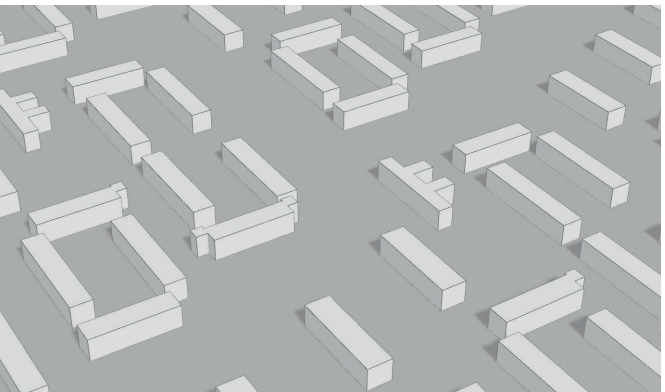
Urban type	Open block urbanism
Number of floors	4
Building footprint	29%
GFA (Gross Floor Area)	116%
FAR (Floor Area Ratio)	1.16
Ground direct sun	70%
Sitting 2,5 m/s	26.6%
Standing 4 m/s	59.1%
Walking 8 m/s	14.3%
Uncomfortable >8 m/s	0%



The semi-open blocks show that U-shapes create dark corners and small courtyards. The loose block structure allows more sun on the ground. Wind gets stuck at openings and along façade corners. L- and U-shapes create lee areas regardless of wind direction.

Fosie, Malmö, SWE

Fosie is a modernist residential area in Malmö. The area is divided into functional areas with semi-open blocks.



Urban type	Half open block
Number of floors	2-4
Building footprint	16%
GFA (Gross Floor Area)	66%
FAR (Floor Area Ratio)	0.66
Ground direct sun	76%
Sitting 2,5 m/s	16.4%
Standing 4 m/s	52.3%
Walking 8 m/s	31%
Uncomfortable >8 m/s	0%

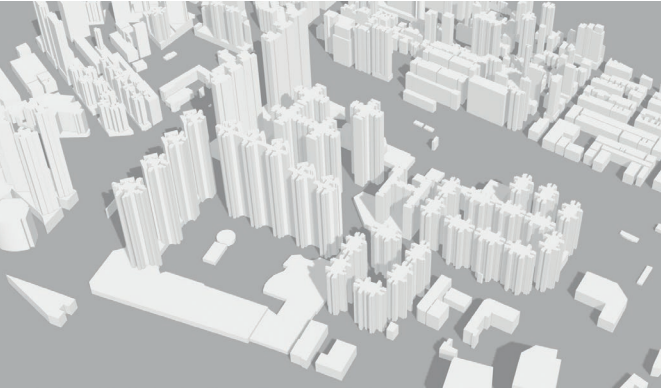


The blocks are too narrow and the angle hides some of the sun, which creates darker courtyards. The openings between the houses catch the wind and create windier places between the blocks.

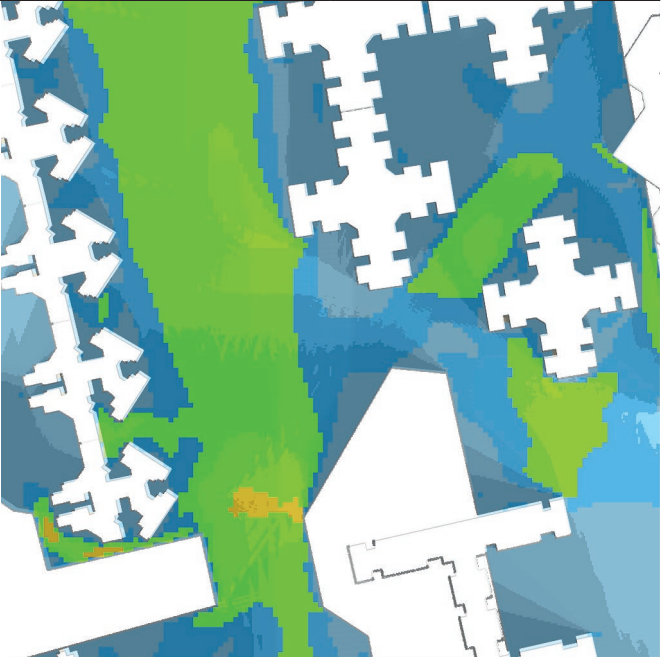
Half open blocks

Mong Kok, Hong Kong, CHN

In central Hongkong lies the Mong kok area. with extreme highrisebuildings. the area consists of apartments, offices and stores.



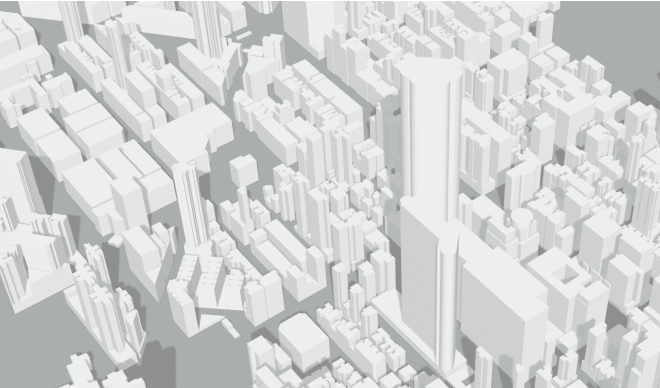
Urban type	Dense highrise
Number of floors	3-46
Building footprint	32%
GFA (Gross Floor Area)	929%
FAR (Floor Area Ratio)	9.3
Ground direct sun	14%
Sitting 2,5 m/s	36.9%
Standing 4 m/s	31.5%
Walking 8 m/s	30.5%
Uncomfortable >8 m/s	1.1%



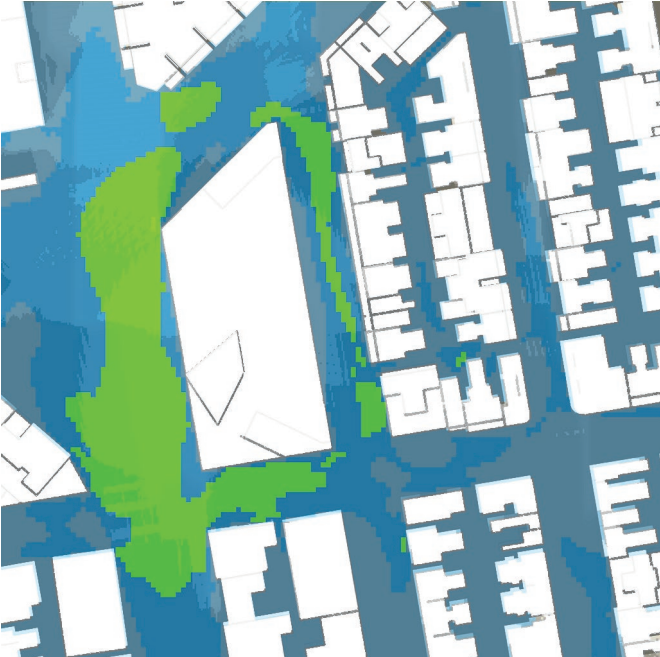
The wide street creates a wind corridor through the urban fabric. Combined with air pressure around the high-rise towers, wind is forced downward at ground level. The towers also create extensive shadows and uncomfortable wind conditions.

Mong Kok, Hong Kong, CHN

In central Hongkong,north of the Mong Koks subway station lies the Mong Kok area. with extreme highrisebuildings. the area consists of apartments, offices and stores and tramlines.



Urban type	Dense highrise
Number of floors	2-24
Building footprint	36%
GFA (Gross Floor Area)	361%
FAR (Floor Area Ratio)	3,61
Ground direct sun	0%
Sitting 2,5 m/s	52%
Standing 4 m/s	27.1%
Walking 8 m/s	17.4%
Uncomfortable >8 m/s	0%

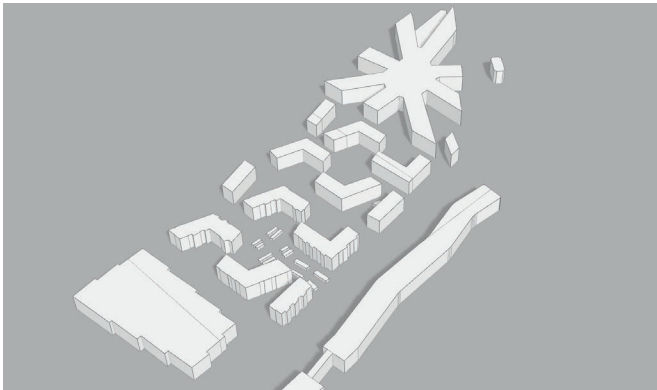


The extremely dense high-rise construction limits sunlight at ground level. However, the compact urban form reduces wind in smaller streets. Air pressure around the tallest buildings pushes wind downward, creating windier conditions at ground level.

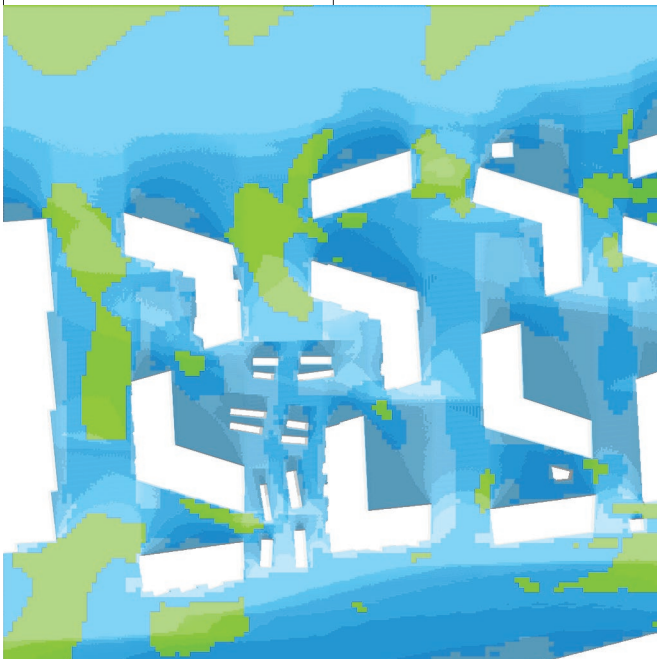
Closed blocks

Marmorbyen, Copenhagen, DNK

Marmorbyen is part of the Nordhavn redevelopment project in Copenhagen, featuring open block structures, residential courtyards, and a pedestrian-oriented waterfront urban fabric.



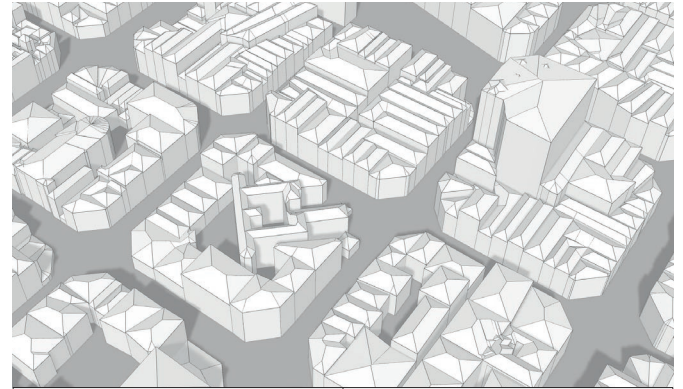
Urban type	Open waterfront blocks
Number of floors	4-6
Building footprint	18%
GFA (Gross Floor Area)	81%
FAR (Floor Area Ratio)	0.81
Ground direct sun	60%
Sitting 2,5 m/s	13%
Standing 4 m/s	46.2%
Walking 8 m/s	40.8%
Uncomfortable >8 m/s	0%



The regular building geometry results in varying weather conditions, creating sheltered interior areas as well as windy street corridors.

Eixample, Barcelona, ESP

Barcelona's grid form of orthogonal streets in Spain. With a standardized block size with space for both residents and businesses. Built from 1860 to 1900.



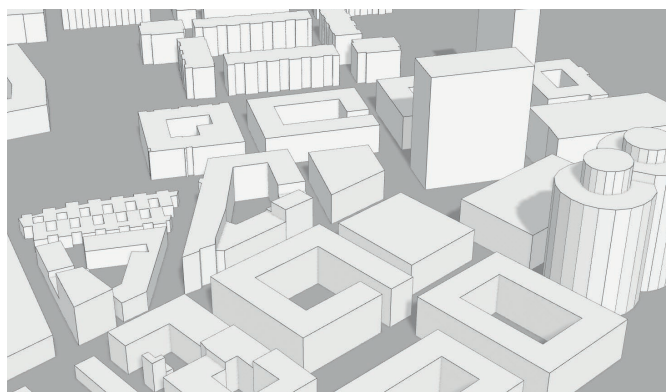
Urban type	Octagonal city block (
Number of floors	2-8
Building footprint	66%
GFA (Gross Floor Area)	486%
FAR (Floor Area Ratio)	4.9
Ground direct sun	1%
Sitting 2,5 m/s	29.4%
Standing 4 m/s	42.1
Walking 8 m/s	28.4
Uncomfortable >8 m/s	0%



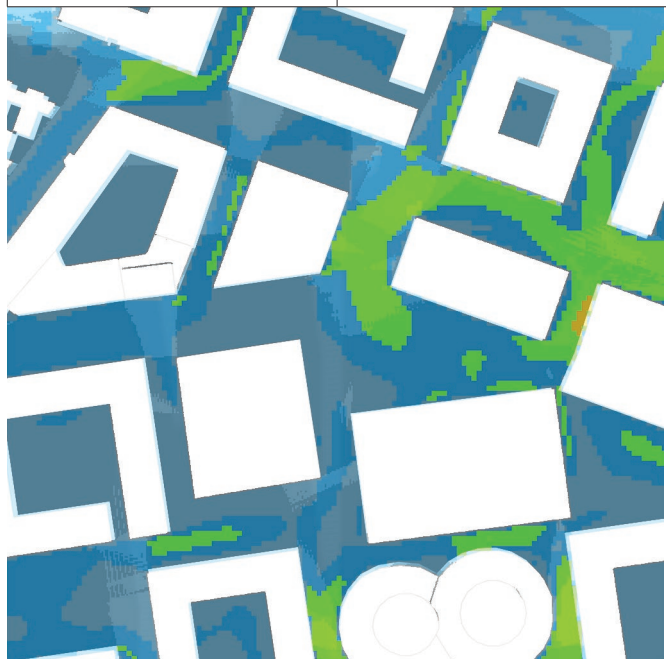
The wind catches on the edges of the buildings and creates windy neighborhood corners. The streets are too narrow and the buildings too tall to allow the sun to reach the ground.

Nordhavn, Copenhagen, DNK

Nordhavn is a transformation project in Copenhagen, reusing and restructuring the harbor. It's a dense mixed-use district focused on street life, prioritizing pedestrians and cyclists.



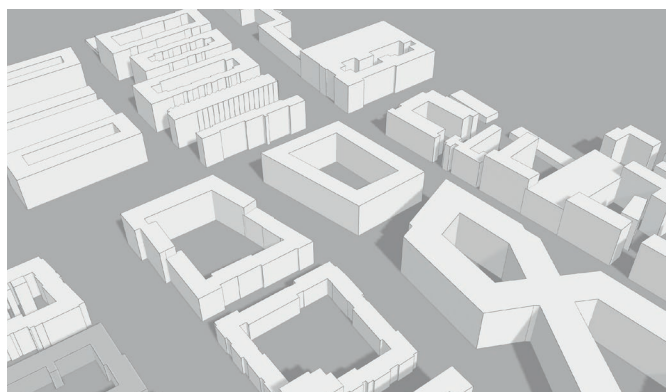
Urban type	Contemporary block
Number of floors	2-15
Building footprint	45%
GFA (Gross Floor Area)	323%
FAR (Floor Area Ratio)	3.23
Ground direct sun	1%
Sitting 2,5 m/s	44.1%
Standing 4 m/s	38.4%
Walking 8 m/s	17.3%
Uncomfortable >8 m/s	0.2%



The city structure is dense but with a high number of floors, which results in shaded streets. The varying building heights also create wind conditions where the wind is pushed down in a downwash effect, leading to windier places.

Tårnby, DNK

Ørestad Syd is an area in southwest Copenhagen in Denmark on the island of Amager. It is a modern, architecturally designed area with large courtyards and a mixed program.



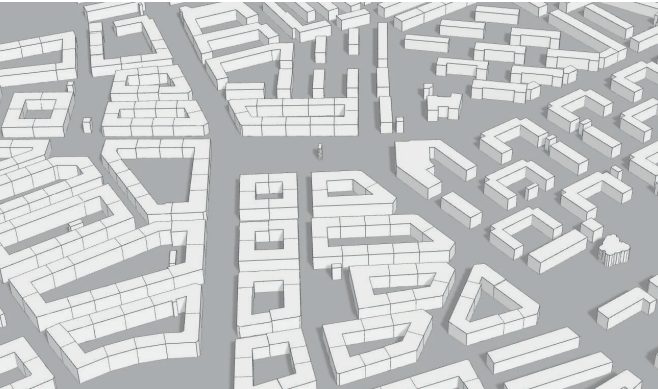
Urban type	Modern Large blocks
Number of floors	5 - 10
Building footprint	81%
GFA (Gross Floor Area)	704%
FAR (Floor Area Ratio)	0.9
Ground direct sun	48%
Sitting 2,5 m/s	32.7%
Standing 4 m/s	43.7%
Walking 8 m/s	23.7%
Uncomfortable >8 m/s	



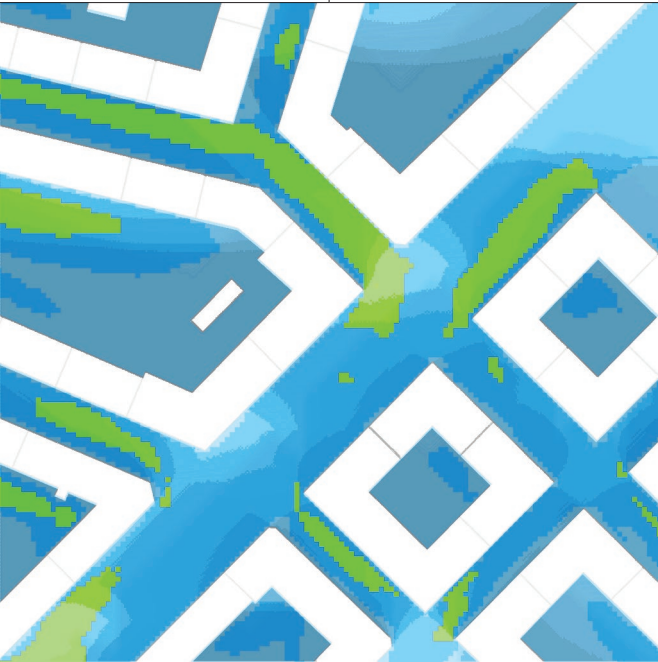
Building height and wide open street spaces create the opportunity for increased wind speed, which often makes the locations less suitable for rest and programming such as unprotected outdoor restaurants.

Kungsladugård, Gothenburg, SWE

Kungsladugård is an area west of central Gothenburg. The area contains both semi-open and closed neighborhoods.



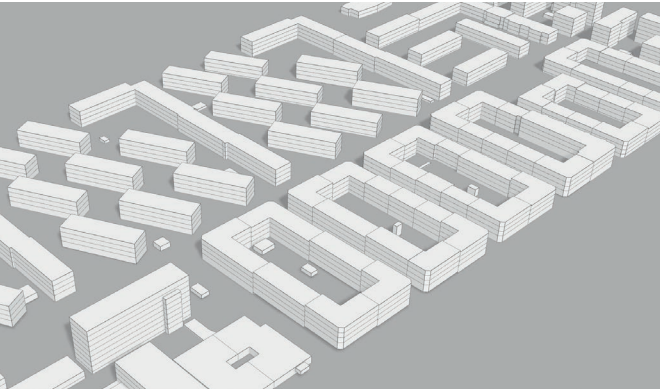
Urban type	Closed blocked
Number of floors	4-5
Building footprint	38%
GFA (Gross Floor Area)	17.1%
FAR (Floor Area Ratio)	1.71
Ground direct sun	29%
Sitting 2,5 m/s	36.7%
Standing 4 m/s	47.4%
Walking 8 m/s	15.8%
Uncomfortable >8 m/s	0%



The area's closed courtyards create shelter in the smaller but darker courtyards. The larger courtyards are largely shaded by the height of the floors in the south. This height often causes the air pressure to be pushed down in the courtyards, making the larger courtyards windier.

Kvillebäcken, Gothenburg, SWE

Kvillebäcken is a modern, dense mixed-use city that replaces a former industrial area with a new, dense neighborhood.



Urban type	Modern neighborhood city
Number of floors	3-5
Building footprint	34%
GFA (Gross Floor Area)	110%
FAR (Floor Area Ratio)	1.01
Ground direct sun	29%
Sitting 2,5 m/s	42.2%
Standing 4 m/s	44.4%
Walking 8 m/s	12.8%
Uncomfortable >8 m/s	0%



The elongated courtyards create sheltered conditions, but also a wind tunnel effect in the streets between the closed blocks. Wind becomes trapped in the corners of the buildings, especially on angled façades.

Observations and design choices

Based on the content of previous chapters and lessons learned in the form of simulations, a list of observations has been created.

1. Long roads need to be broken up into shorter sections, so the wind is prevented from forming wind behaviors such as wind tunnels.
2. Narrow roads create better wind conditions and a human scale, but the disadvantage is that the sun is limited.
3. The sun is mostly limited to the west-to-east-oriented streets.
4. Mixed floor heights have a side effect where floor differences generally contribute to an increased wind situation at the ground. At the ground, there is lower air pressure and the higher you go up the floors, the pressure increases. This causes the high air pressure to be pressed down towards the ground.
5. Based on the observation in point four, the conclusion is drawn that a dense low urban form suits Kiruna best. Social places and places that are intended to be planned to spend time in should have lower construction in the south and prioritize protection from the wind.
6. Low-rise structures should face south to make maximum use of the sun.
7. If you have a neighborhood with a typical grid street network, you need to plan to break up the street shape after a few blocks.

Of the simulations that have been carried out, four examples have been selected to form the basis for my own design.

Västra Rostaparken Örebro prevents the wind from getting stuck in the facade and creating air bubbles, especially in the protruding parts. They are absolutely crucial in dampening the wind.

Dragör has an urban density and has a human-adapted scale that allows for both sun on the ground and many places with shelter.

Billund by Ghel architecture office has not yet been built, but it still gave one of the best results by creating loose residential neighborhoods with irregular street networks. I interpreted that, like Erskin's concept project Arctic Town, they used the idea of a wall, where the apartment buildings on the outer edges embrace other buildings as protection.

I think Greifswald, from Germany, had a good proportion of how big a block could be in Kiruna.

With this in mind, my design proposal is a repetition of block patterns that resemble fish scales in shape with the aim of preventing long straight streets. The height of the apartment buildings varies between 1–3 floors because I want to allow the sun to reach the ground. My result is more densely packed than Ghel's, but I am inspired by its example with common spaces within the loose blocks.

Places that become shadier are used for parking. There is always a social area in the blocks that is placed closest to the row of apartments with the spikes.

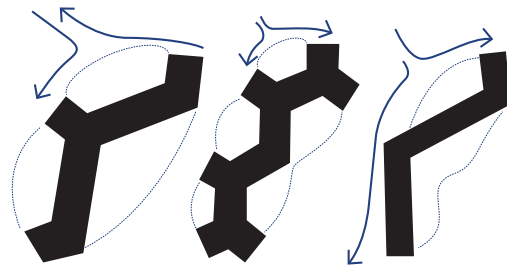


Figure 67. Shapes inspired by Västra Rosta parken. Illustrations made by author. The crooked flow of the buildings redirects, slows down the wind. The V and U shape creates an air bubble effect, which creates conditions for lee. See next page.

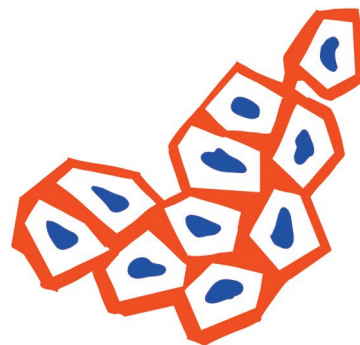
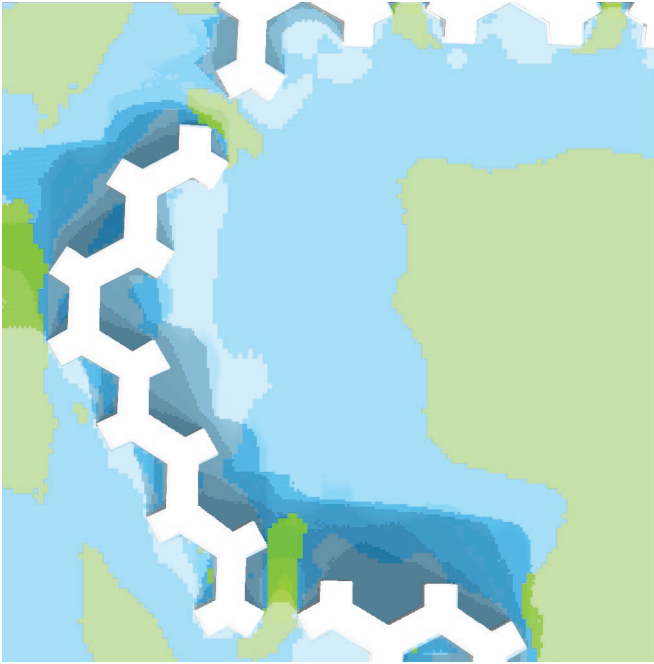


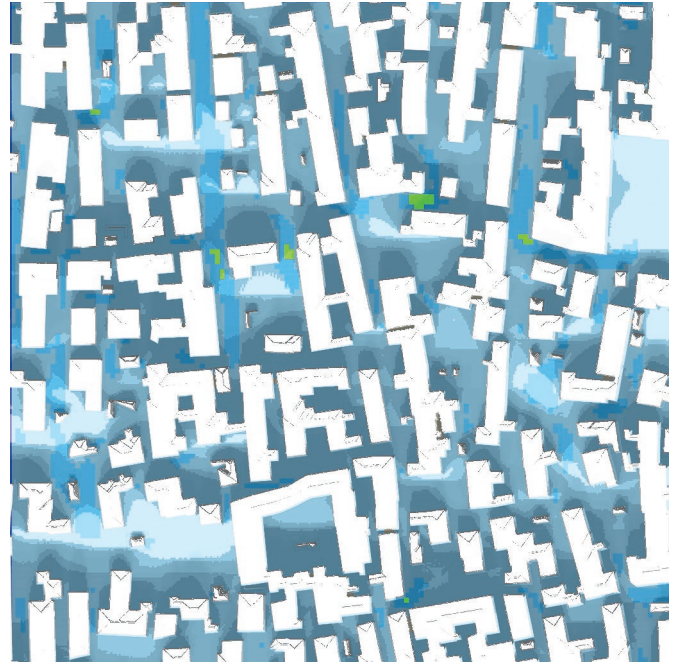
Figure 68. Illustration of Ghel Billund proposal made by author
● Red represents the streets shape. Here you can clearly see that the blocks are 5-sided.
● Blue is the planned water features. The blue function is an inspiration for areas programmed for green space, flood control and snow mitigation.

Västra Rostaparken, Örebro, SWE



Building shapes and protruding forms inspired by Västra Rosta Park. The curved arrangement redirects and slows down the wind, while the V and U shaped forms create an air bubble effect that generates sheltered lee conditions. See illustration below.

Dragør, DNK



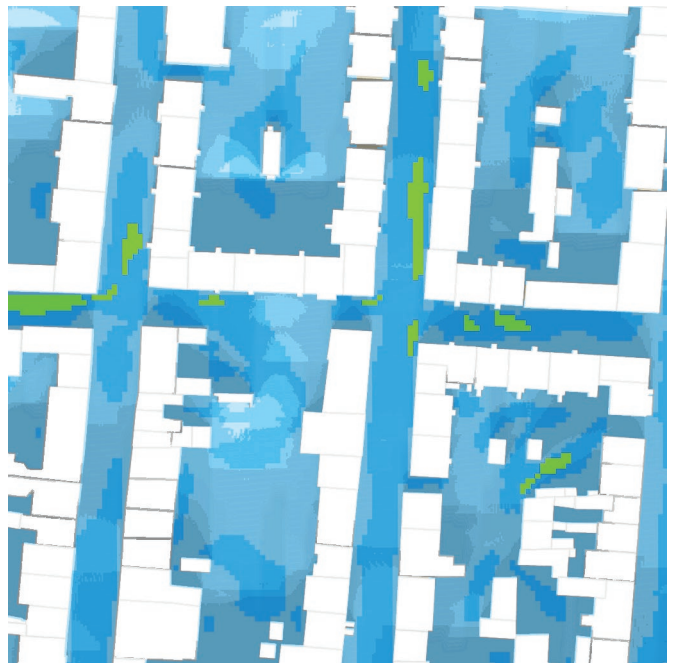
Dragør's morphological example shows a medieval city whose density creates favorable wind conditions. A density designed for people and goods, not for cars.

Ghel Billund proposal, DNK



The Billund case is based on a tourist area where the urban design breaks up the block structure and divides long streets into shorter sections, which successfully avoids wind tunnel effects. This creates spaces both between the blocks and in their inner courtyards, making it a clear example of broken street networks.

Greifswald, GER



Greifswald is yet another example of medieval urban morphology, providing good references for the size of inner courtyards. However, the city plan shows that straight streets create windier spaces.

Design and mitigation

The design work is based on the simulation results and the previously presented findings, and focuses on implementing the developed design principles within my site. The design does not prioritize architectural qualities, but street networks, block structures, building heights and building forms have been weighed against each other to create an outdoor climate adapted to Kiruna's climatic conditions, with a varied number of floors between 1 and 4.

The street network is primarily based on Billundsfallet, with broken roads of 8 m width, unlike Billund which will primarily be a low-speed and pedestrian area. In the design, 8 m is sufficient for two oncoming cars. During the design, supplementary simulation tests of 200 x 200 m were carried out to investigate wind and solar conditions.

The block structure contains common gardens, parks and parking areas that have been planned as areas for stormwater management and storage of plowed snow. Through permeable soil materials and perforated ground surfaces, conditions are created for collecting and delaying stormwater

in a controlled manner. This is very important during the spring when large amounts of snow have accumulated during the winter and sudden spring heat waves can create a risk of flooding, as there is still ground frost.

The overall design shows that a combination of broken street networks, dense low-rise buildings and conscious building placement can effectively dampen wind impacts and create protected urban spaces. The finished design has then been simulated and tested at a number of selected locations within the area to verify that the principles hold up in practice. It should be emphasized that typical architectural values, such as aesthetics, spatial quality and design, have not been prioritized. The focus has been consistently on climate adaptation and wind reduction, which means that the design should be seen as a functional planning basis rather than an architectural proposal.

Lastly the design weaknesses have been explored in extremer wind speeds, 13 m/s.

Section A - A

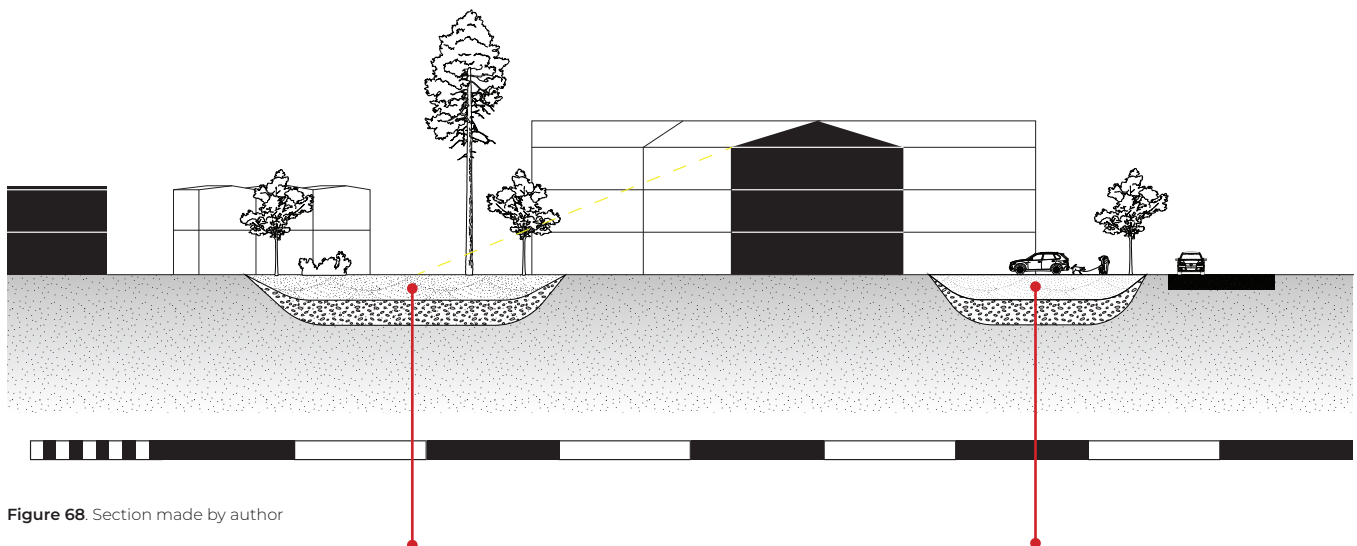


Figure 68. Section made by author



Figure 69. Kiruna's subarctic vegetation is characterized by short, wind-sculpted pines and birches, shaped by extreme climatic conditions including long winters, permafrost, and a severely restricted growing season. This stands in stark contrast to the denser and taller vegetation found in Sweden's coastal and temperate climate zones, posing distinct challenges for urban green space planning in northern environments. *Photo: Author.*



Figure 70. A gravel parking lot with vegetation between the spaces during summer, with a jeep visible in the background (Unknown author, n.d.).



Figure 71. Illustrated plan with planned mitigation



Figure 72. Illustrated plan with planned mitigation



Wind walls

The marked out buildings have most of the time a higher floor number, ex 3-4 floors, compared to surrounding buildings that are limited to 1-3 floors



Snow mitigation

During the winter half of the year the plogade snow needs to have planned areas that can be reserved for snow storage.



Water mitigation

Sudden flooding die to increased rain fall and sudden warm weather during early spring, the risk of flooding have increased. To plan for urban water mitigation, the blocks commun gardens parks, parkingareas have the added function of collecting and absorbing the water. Thic could be done through soil material and perferated ground stone.

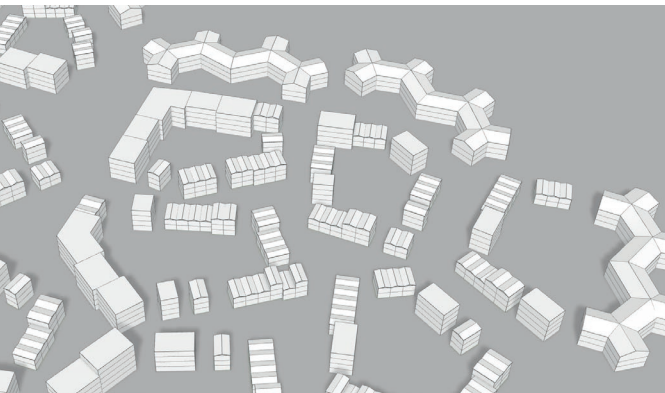


Simulation

To evaluate the design's wind and solar conditions, four areas of the design have been simulated. The results are shown on the next page.

Design simulations

1. North-east site edge

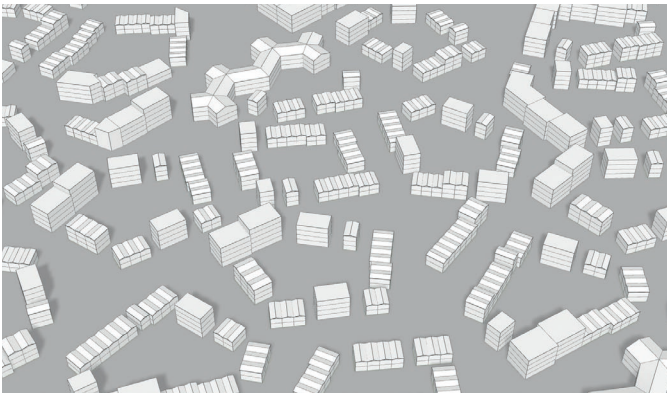


Ground direct sun	65%
Sitting 2,5 m/s	63.4%
Standing 4 m/s	31.5%
Walking 8 m/s	5%
Uncomfortable >8 m/s	0%

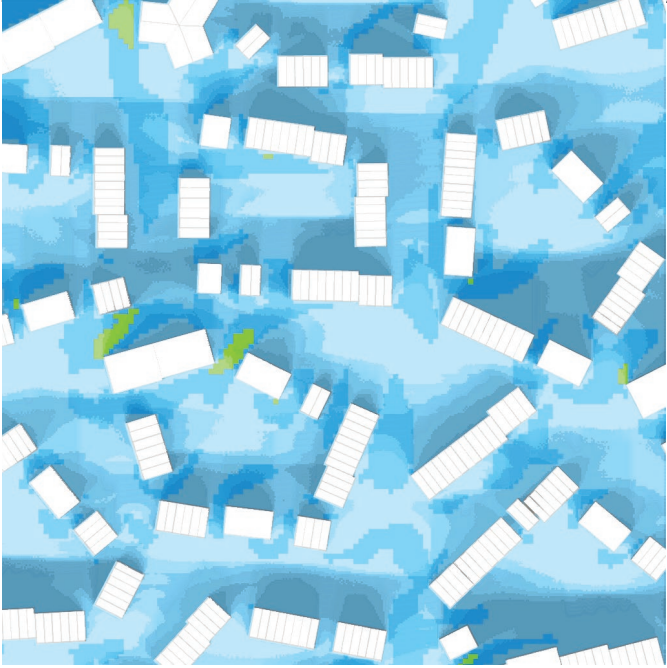


Here, the protruding irregular building shapes are used as wind walls. It is also visible how west to east oriented buildings cast more shadow than buildings placed along an angled street.

2. Dense urban block in urban context

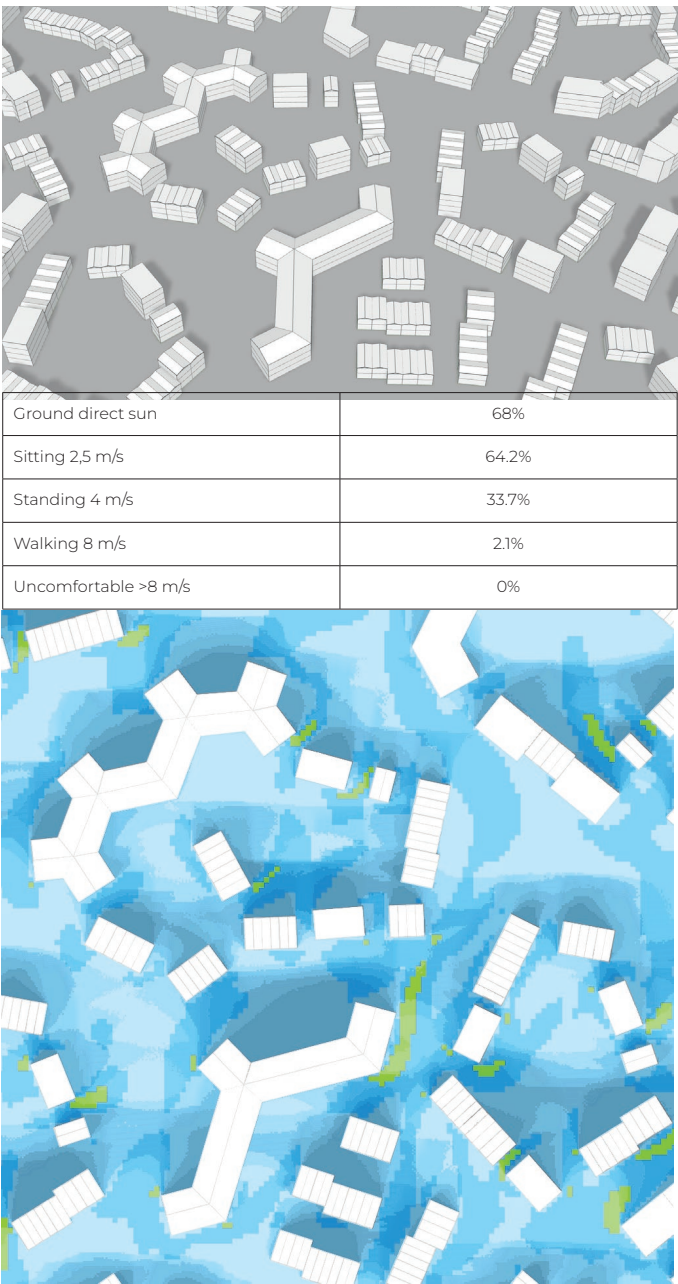


Ground direct sun	61%
Sitting 2,5 m/s	75.9%
Standing 4 m/s	23.3%
Walking 8 m/s	0.8%
Uncomfortable >8 m/s	0%



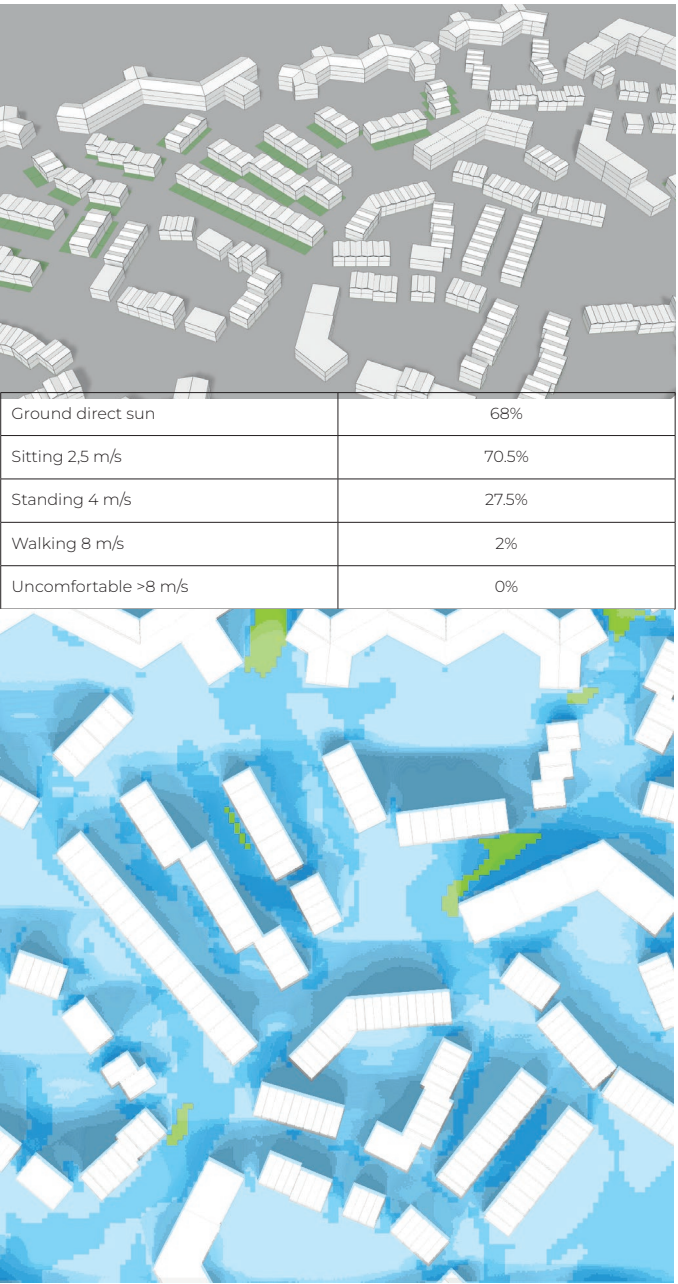
This simulation example is strongly inspired by the Billund case, but placed deeper within an urban environment. This resulted in even calmer streets and inner courtyards with favorable lee and solar conditions. However, it is directly visible how buildings with 3-4 floors create more wind (see green), compared to the surrounding 1-2 storey buildings.

3. Wind walls in urban context



This morphological example features elongated apartment buildings positioned within a larger urban area, functioning as wind walls. However, the north-facing side of these buildings receives very little sunlight, making it more suitable for parking rather than active urban spaces.

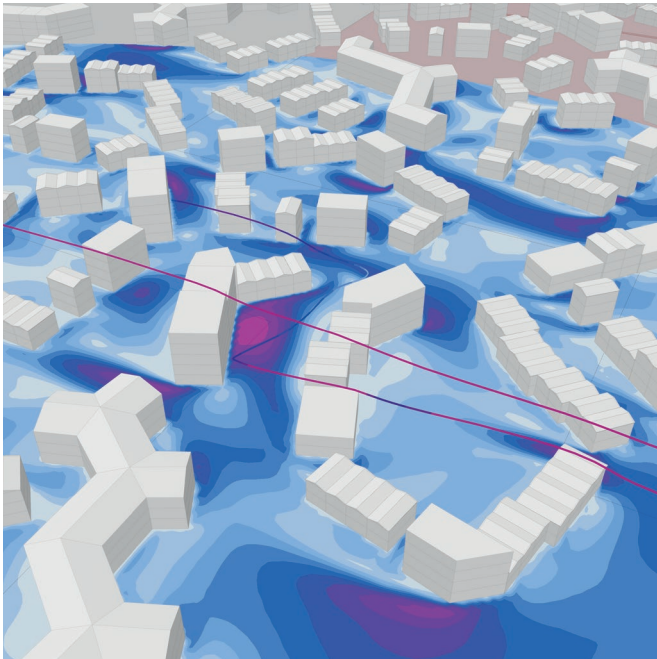
4. Wind walls in urban context



This morphological example features a denser urban design, inspired by DragØr. This area features mainly rowhoused with 1-2 storeys. The areas with increased wind situations are mainly at the wind wall buildings.

Exposing design weaknesses in extreme wind

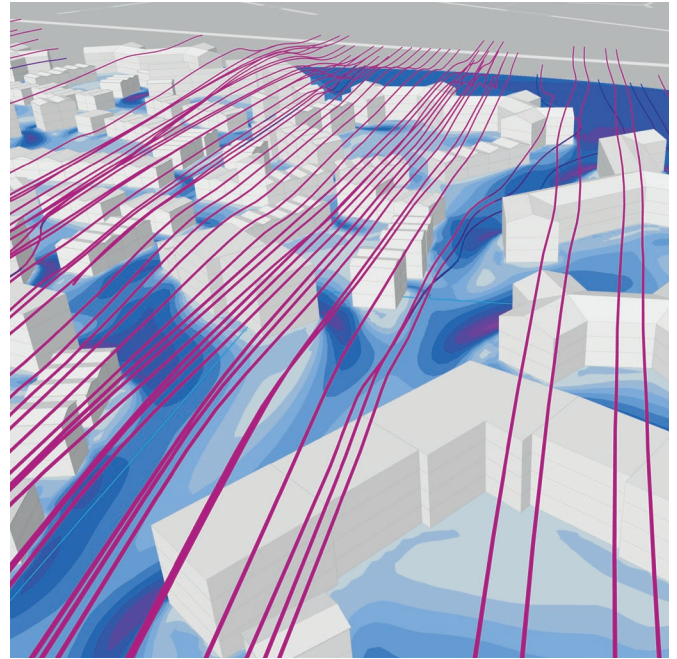
Wind Downdraft at Street Level



In the northerly wind simulation, a clear downdraft effect can be observed. The height of the building creates elevated air pressure on the windward side of the facade, forcing air masses from higher altitudes down toward street level.

This results in increased wind speeds at pedestrian level, creating uncomfortable wind conditions in the immediate vicinity of the building. Wind situations like this is important to avoid when planning outdoor social spaces.

Planning for Openings in the Urban Layout



The northerly wind analysis shows that certain combinations of wind direction and wind speed generate strongly exposed and uncomfortable outdoor spaces. In these identified zones, wind mitigation measures should be integrated as a complement to the urban design. For example vegetation in the form of trees, shrubs, or built up earth terrain.

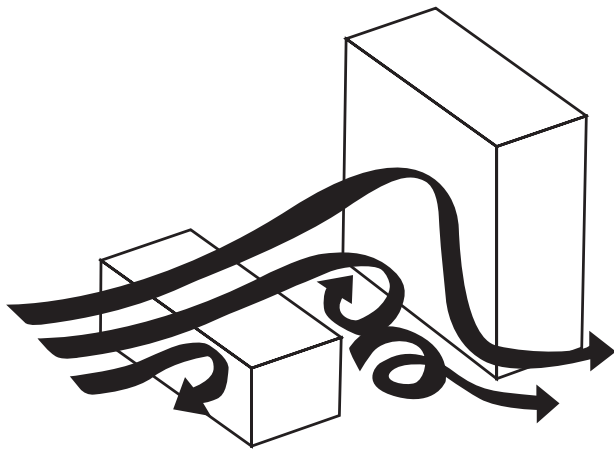


Figure 71. Illustrated wind path in urban setting, made by author

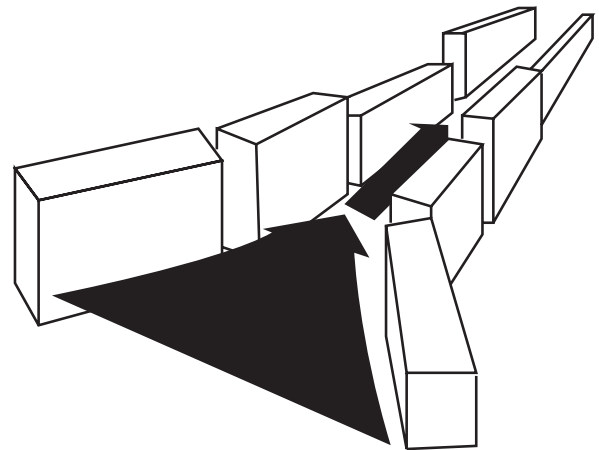
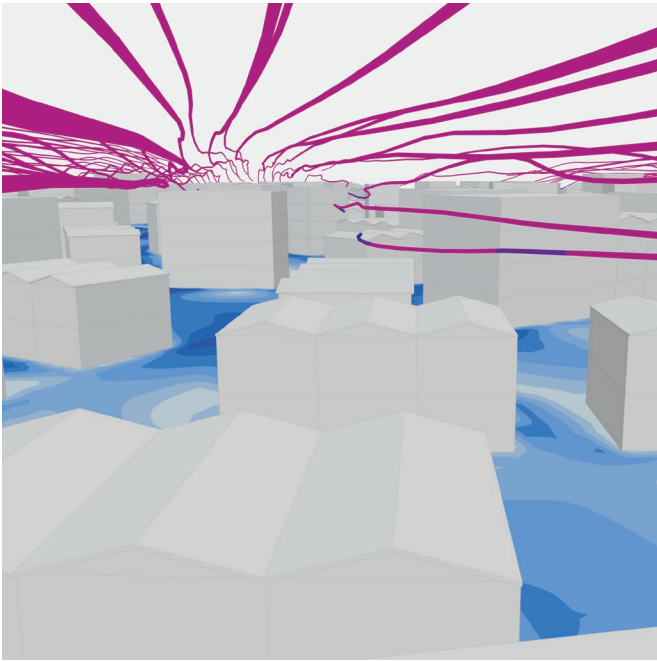


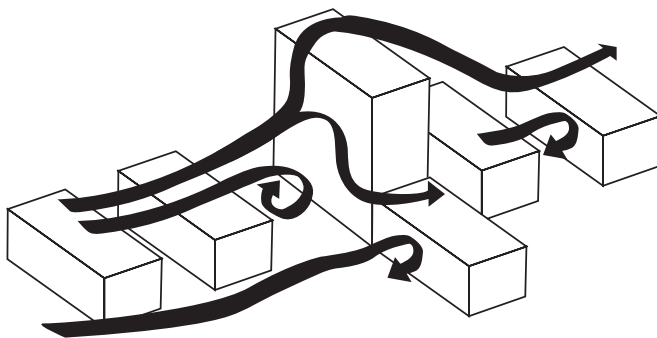
Figure 72. Illustrated wind path in urban setting, made by author

The Mixed-City Problematic



The “mixed city” is a common ideal in urban planning, combining varied building heights and typologies. The northerly wind simulation of this 1–4 storey structure shows that even modest height differences allow wind to channel actively between buildings and down toward ground level.

The wind analysis also reveals a often overlooked consequence, that this type of urban structure generates strongly exposed balconies. Over time, uncomfortable wind conditions may lead residents to enclose them, affecting both the streetscape and the original design intent.



By running wind simulations at 13 m/s with a northerly wind direction, I deliberately used an elevated wind speed to expose potential weaknesses in the urban design.

Autodesk Forma proved to be a quick and effective tool for testing extreme scenarios, showing how building volumes, orientation, and the spaces between them directly affect wind comfort at pedestrian level.

in other words..

These findings highlight the value of integrating wind analysis early in the design process, to identify where wind mitigation measures are needed.

Figure 73. Illustrated wind path in urban setting, made by author

Discussion

Agenda 2030 and the teachers at Chalmers University of Technology's architecture program have one thing in common: they highlight how important it is to work sustainably and to develop different solutions. This is to reduce the amount of CO₂ that the construction industry produces. In parallel, municipalities and authorities have a focus and assignment on planning based on a more extreme climate. This means choosing everything from local and recycled materials with a lower CO₂ impact, but also creating design proposals that can handle extreme weather. Municipalities are also invested in producing less CO₂ and becoming more climate neutral.

Some municipalities are also facing the challenge of growing and needing more housing, but have limited access to land. In many cases, this leads to drastically increasing development and densifying the city. Building projects are usually shaped based on the project's budget, choice of plot, etc. My experience is that the role of the architect has been minimized and historically pushed into the production stage to a more assembly line role where the architect's role, knowledge and value are no longer taken into account.

My experience is that it is more of a general encouragement to work sustainably, and climate studies, in addition to solar studies, are often overlooked. In Sweden, there is no requirement to document climate studies, which means that there is no uniform database with collected studies from, for example, municipalities and construction projects. These would be good examples that can help spread knowledge about the conditions and impact of the climate.

It is worth noting that the CFD simulations conducted are based on wind values and seasons that span several years. These represent the collected data from the selected EPW file, which can be produced with various parameters and levels of detail. The parameters are corrected to create a credible replica of the surrounding topology and the design of the surrounding environment.

When I delved deeper into the wind and microclimate studies, it became clear that the wind simulations are limited to the most problematic wind directions and only in a few studies were different wind speeds tested. In addition, the professional simulations were done on simplified geometries, no facade elements, balcony railings or canopies. The focus was also on pedestrian height, that is, 1.75-2 meters above ground level. Here, I saw a few wind simulations that had investigated the impact of the wind on balconies.

I was even more surprised by the lack of recommendations. The experience was a limited result where the wind study was presented as relevant facts and nothing more. Through reading up on the subject and through the interviews that were conducted, it became clear that these studies are very rarely done.

Some of the reasons may be that CFD tools have historically required high technical knowledge and have been relatively expensive, meaning they were rarely implemented beyond the early stages of a project. However, with enthusiastic and innovative script developers and more accessible programs on the market, such as Autodesk Forma, climate simulations and especially wind simulations have become more accessible and user-friendly for architects and urban planning offices alike.

By collecting CFD simulations and data, architects and urban planners can learn what works and which urban morphologies do not fit. This is especially important for making good urban planning. In other words, it does not matter if the municipality has planned a street to have outdoor cafes, if the urban morphology creates a downwash effect on the place where people want to sit and enjoy the sun on an early spring day.

When I focused my work on the subarctic environment, some assumptions had to be made. One of the biggest assumptions was that greenery would not be included in my studies, even though the chosen urban morphology examples had a lot of greenery, since greenery was not a reliable factor in Kiruna.

I feel that architects have historically worked based on strong design principles and ideologies that all ultimately result in what Hemmerson called "architectural generations". These generations simplified and summarized how architects had worked for a specific period.

I believe and hope we will move from building general international copy-paste grids in cities without a clear local architectural identity. New city districts could have fit in regardless of whether it was in Västerås, Frankfurt, or New York.

I have observed that architecture is becoming more and more about creating places with sustainable materials and representing local identities and cultures. I hope that CFD climate studies can become a natural part of the design process of the next generation of architects and, consequently, reinstate the local architectural dialects created by local climate and materials.

Conclusion

Research question:

How can architects use urban morphologies and CFD simulations, to design microclimates and outdoor comfort, in a subarctic urban climate?

Today, there is little focus on the design of microclimate and outdoor comfort when planning and building. Instead, the focus is often on the CO₂ production of materials and transport, energy efficiency and exploitation of the building project. There is a lack of knowledge about the outdoor comfort topic in related industries and it is important that it becomes a natural part of the construction and planning process.

My research shows that architects have access to CFD tools (Rhinosorus 8 and Autodesk Forma) that are useful for urban planning, including microclimate and outdoor comfort. The tools are at an accessible technical level and are accurate enough to be used for climate studies and microclimate investigations. These investigations should be included in the early stages of the design and become a natural part of the iterative design work of architects and planners. In more complex and larger projects, I believe that a deeper and more advanced CFD simulation with higher quality should be carried out in the later stages.

I experience that many municipalities do not have clear guidelines when it comes to approving construction projects, which includes solar and wind studies, in the building permit process. In addition, there is a lack of legislation that places demands on the municipality and the construction industry.

Municipalities often do the right thing on paper by producing policy documents on climate issues and how to respond to climate impact. However, the arguments remain on paper, and concrete factors such as development needs and economics are what govern the actual construction process.

The interviews with urban planners and energy and climate engineers confirm that it is a challenge to apply changes to processes and go beyond already established practice. A major challenge for municipalities is the limited resources.

In order to provide architects with site-specific information, municipal planners need to have the

right conditions to be able to draw detailed plans, which are based on the conditions of the local climate. My opinion is that municipalities need more support, from a regional or national level, to be able to design urban environments with outdoor comfort in mind. In order for municipalities to be able to carry out climate studies and use CFD tools, broader expertise is required, which most municipalities do not have today. Instead, municipalities become dependent on ordering CFD wind and solar simulations, which are costly.

It is not a given that an architecture firm should automatically use CFD tools; instead, that responsibility should primarily lie with the municipalities, who are responsible for both the comprehensive plan and the detailed development plan. It should be in the interest of municipalities to conduct measurements for wind and solar impact, in the same way that studies are carried out for landslide risks and flooding. This may not be relevant for a single residential build, but it should be a matter of course when establishing a larger high-rise or block development.

Based on the municipality's ownership of urban planning, municipalities should take greater responsibility for both increasing their own knowledge and ensuring it among all relevant parties. Through increased understanding of what CFD measurements contribute, a shared knowledge base can grow between municipal planning offices, architects, and developers.

Bibliography

ArkDes. (2020). *Kiruna forever*. Arkitektur och designcentrum.

Abdalla, A. (2024, July). *The state of Autodesk Forma* – June 2024 edition. IMAGINIT Technologies. <https://resources.imaginit.com/building-solutions-blog/the-state-of-autodesk-forma-june-2024-edition>

Autodesk. (n.d.). *Forma site design product details*. Autodesk. Collected 7 maj 2026, från <https://www.autodesk.com/products/forma-site-design/product-details>

Bark, H. (2025, June 28). Klimatzoner i Sverige: En guide till Sveriges olika klimatområden. *Agenda 2030 delegationen*. <https://agenda2030delegationen.se/klimatzoner-sverige-en-guide-till-sveriges-olika-klimatomraden/>

Bendroth, L. (2020). Turning Torso [Photograph]. *Malmö stads mediabank*. https://mediabank.malmo.se/sv?term=turning&sort=-created_at

Bengtsson, S., & Holmér, I. (2016). *Outdoor thermal comfort under subarctic climate of north Sweden – A pilot study in Umeå*. Umeå University. Retrieved September 24, 2025, from <https://umu.diva-portal.org/smash/record.jsf?pid=diva2%3A1046941>

BM+LA. (2011). *HDI Gerling*. Retrieved May 20, 2026, from <https://www.bm-la.com/projects/hdi-gerling>

CHAM (Concentration Heat and Momentum Ltd). (n.d.). *CHAM technical report TR 001: What PHOENICS is*. https://www.cham.co.uk/phoenics/d_polis/d_docs/tr001/tr001.htm

Chapman, D., Nilsson, K. L., & Sjöholm, J. (2024). *Planning and urban design for attractive Arctic cities* (1st ed.). Routledge. <https://doi.org/10.4324/9781003336136>

u/cityweft. (2025). *Interest in direct site context plugin for Rhinograsshopper* [Reddit post]. https://www.reddit.com/r/rhino/comments/1n7arty/interest_in_direct_site_context_plugin_for/

Ebrahimabadi, S., Johansson, C., Rizzo, A., & Nilsson, K. (2016). *Microclimate assessment method for urban design – A case study in subarctic climate*. *Urban Design International*, 23(2), 116–131. <https://doi.org/10.1057/udi.2015.26>

EnergyPlus. (n.d.). *IWEC weather file: Kiruna, Sweden* [Data set]. Retrieved May 5, 2026, from https://energyplus-weather.s3.amazonaws.com/europe_wmo_region_6/SWE/SWE_Kiruna.020440_IWEC/SWE_Kiruna.020440_IWEC.zip

Erskine, R. (1958). *An ecological Arctic Town* [Illustration]. ArkDes. <https://digitaltmuseum.se/021029512055/ritning>

Esri Community. (2025, October 12). *Existing & historical limitations*. <https://community.esri.com/t5/arcgis-for-autodesk-forma-documents/existing-and-historical-limitations/ta-p/1625533>

Fink Shapiro, G. (2020). Kiruna, forever changing. *Places Journal*. <https://placesjournal.org/article/kiruna-forever-changing>

Grimm, T. (2014, January 24). *Project Falcon, for airflow simulation, graduates to Autodesk Flow Design*. Revit Add-Ons. <http://revitaddons.blogspot.com/2014/01/project-falcon-for-airflow-simulation.html>

Hausladen, G., Liedl, P., & Saldanha, M. (2012). *Building to suit the climate: A handbook*. Birkhäuser.

Hemmersam, P. (2021). *Making the arctic city: The history and future of urbanism in the circumpolar North*. Bloomsbury Visual Arts.

Jareman, F., & Jayanath Vivek, A. (2023). *VFD Vindstudie Floretten* [PDF]. AFRY & Strategisk Arkitektur.

Kiruna kommun. (2014). *Fördjupad översiktsplan för Kiruna C: Antagen 2014 06 16, laga kraft 2014 07 18*. https://www.kiruna.se/download/18.1c6f2b1c14a5f3f9b1e1e/1406039477083/fop-kiruna-c2014_laga-kraft-2.pdf

Kiruna kommun. (2020). *Riksintressen*. <https://kiruna.se/download/18.16278324175640811245e8a/1603895441404/riksintressen.pdf>

Kiruna Lappland. (2024, January 5). Cold record in Vittangi. *Kiruna Lappland*. Retrieved September 24, 2025, from <https://kirunalappland.se/en/news/cold-record-vittangi/>

Kiruna Lappland. (n.d.). *Samebyar inom Kiruna kommun* [Image]. Retrieved October 21, 2025, from <https://kirunalappland.se/om-renar-och-renskotsel/>

Ladybug Tools. (n.d.-a). Climate analysis. *Ladybug Tools Academy*. Retrieved February 2, 2026, from <https://docs.ladybug.tools/ladybug-tools-academy/climate-analysis>

Ladybug Tools. (n.d.-b). *EPWmap*. Retrieved February 2, 2026, from <https://www.ladybug.tools/epwmap/>

Latrach, W. (2018, November 21). *Urban simulation with ANSYS: From LiDAR file to 3D city model*. Mechead.com. <https://www.mechead.com/urban-simulation-with-ansys-from-lidar-file-to-3d-city-model/>

LKAB. (2025). *Kiruna urban transformation* [Photograph]. https://lkab.com/wp-content/uploads/2025/09/b4c227f0096163_org-scaled.webp

LKAB & Kiruna kommun. (2025, September 12). *Kiruna kommun och LKAB presenterar väg framåt för fortsatt stadsomvandling*. LKAB. Retrieved September 24, 2025, from <https://lkab.com/press/kiruna-kommun-och-lkab-presenterar-vag-framat-for-fortsatt-stadsomvandling/>

Marsh, A. (2018). *Psychrometric chart* [Web app]. AndrewMarsh.com. <https://andrewmarsh.com/software/psychro-chart-web/>

Moya, R. (2015). *Empirical evaluation of three wind analysis tools for concept design of an urban wind shelter*. In Y. Ikeda, C. M. Herr, D. Holzer, S. Kajima, M. J. Kim, & A. Schnabel (Eds.), *Emerging experience in past, present and future of digital architecture: Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia* (CAADRIA 2015) (pp. 313–322). The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA).

Nielsen, D. (2013, August 15). *Autodesk Vasari WA - Tips and tricks about 3D wind simulation functionalities* [Video]. YouTube. https://www.youtube.com/watch?v=FdoKJsL_bA

Newsworthy. (2025, January 2). *Globalt värmerekord 2024 – så var vädåret i Norrbotten*. Newsworthy. Retrieved September 24, 2025, from <https://www.newsworthy.se/artikel/296380/globalt-vaermerekord-2024---sa-var-vaedaet-i-norrbotten>

ODS Engineering. (n.d.). *ODS Studio: Building simulation framework*. <https://www.ods-engineering.com/tools/ods-studio/>

O'Sullivan, F. (2015, June). *A town on the move*. *The Atlantic*. <https://www.theatlantic.com/magazine/archive/2015/06/a-town-on-the-move/392078/>

Olofsson, A. (2024, September 8). *Fotografi av Örebro kommun i samband med uppdatering av invånarantal* [Photograph]. Örebronyheter. <https://www.orebronyheter.com/fredag-6-september-blev-vi-160000-invanare-i-orebro-kommun/>

Pacheco Diéguez, A., Duckart, C., & Cocco, S. (2017). *Urban thermal comfort study: Kiruna square* (68°N 22°E) [Report]. White Arkitekter & EPFL.

Pelsmakers, S., Donovan, E., Hoggard, A., & Koźmińska, U. (2022). *Designing for the climate emergency: A guide for architecture students*. RIBA Publishing.

Robert McNeel & Associates. (n.d.). *What are NURBS?* Rhino3D. <https://www.rhino3d.com/features/nurbs/>

Sametinget. (n.d.). *Sápmi – the land of the Sámi*. Retrieved October 9, 2025, from <https://www.sametinget.se/samer>

SLR Consulting. (n.d.). 24 Gaukel: *Pedestrian wind assessment*. <https://www.slrconsulting.com/projects/24-gaukel-pedestrian-wind-assessment/>

SLU. (2025, June 16). *Klimat* (Markinfo – ståndort). *Sveriges lantbruksuniversitet*. <https://www.slu.se/om-slu/organisation/institutioner/mark-miljo/miljoanalys/markinfo/standort/klimat/>

Spencer. (2020, November 23). *Adapting solar analysis script to existing Rhino geometry* [Forum post]. McNeel Forum. <https://discourse.mcneel.com/t/adapting-solar-analysis-script-to-existing-rhino-geometry/112919>

Statistics Sweden. (2025, February 6). *Economy-wide material flow accounts 1998–2023*. <https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/system-of-environmental-and-economic-accounts/pong/statistical-news/economy-wide-material-flow-accounts-19982023/>

Sveriges geologiska undersökning (SGU). (2025). *Bergverksstatistik 2024* (Periodiska publikationer 2025:1). <https://resource.sgu.se/dokument/publikation/pp/pp202501rapport/pp2025-1-rapport.pdf>

Symetri. (2023, May 9). *Autodesk Forma is here!* <https://www.symetri.co.uk/news-events/news/autodesk-forma-is-here/>

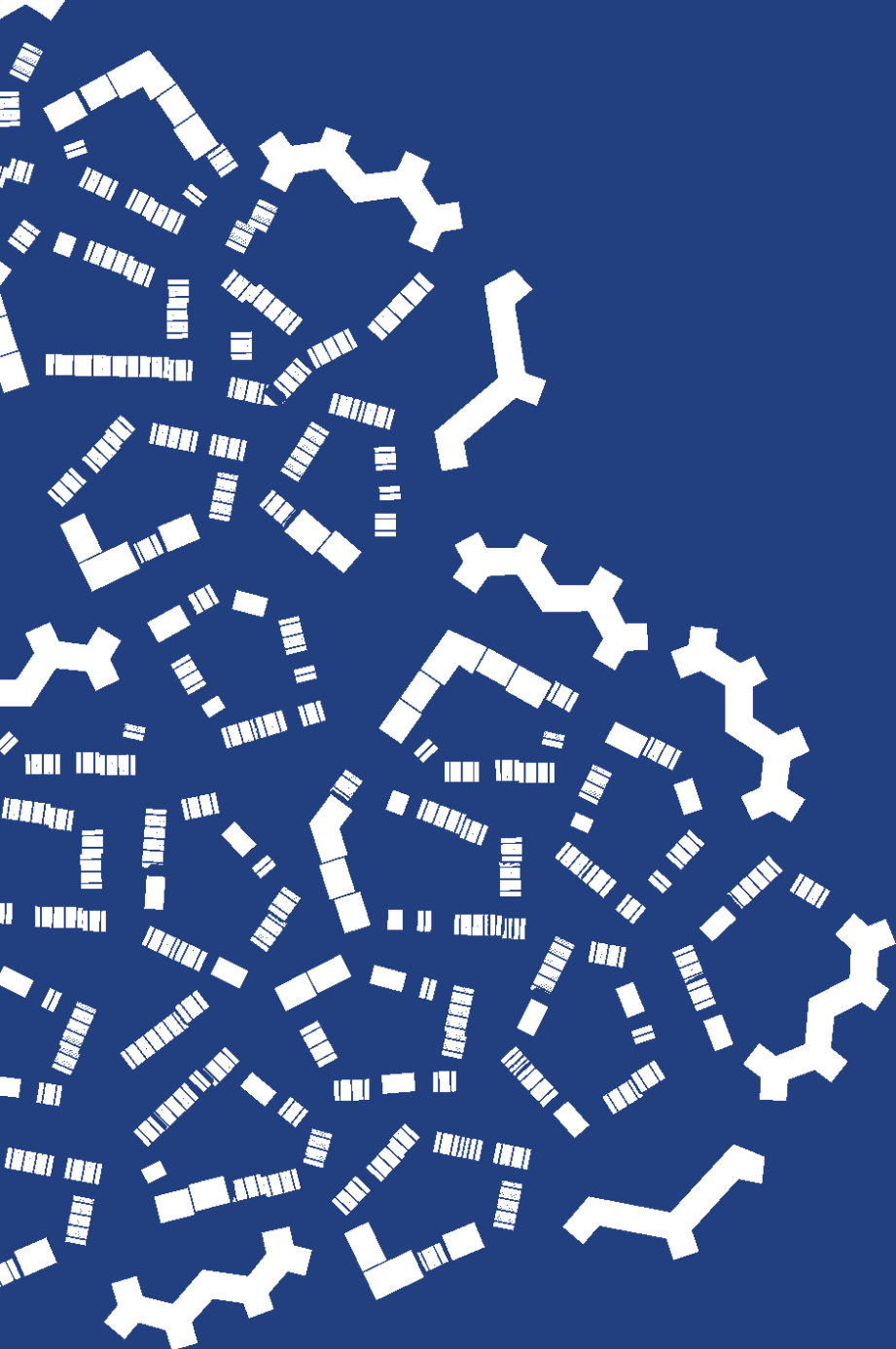
Trafikverket & SWECO. (2023). *Samrådsredogörelse* [PDF]. https://bransch.trafikverket.se/contentassets/bca320983d7b4a86925085c3e29312ab/samrad-maj-2023/jp_kiruna_samradsredogorelse_2023-03-09.pdf

United Nations. (n.d.). The 17 goals. *United Nations Sustainable Development Goals*. Retrieved September 17, 2025, from <https://sdgs.un.org/goals>

Unknown author. (n.d.). *Gravel parking lot with greenery between the parking spaces and a jeep in the background* [Photograph]. Pinterest. <https://se.pinterest.com/pin/337136722129861490/>

White Arkitekter. (n.d.). *Relocating an entire Swedish city*. World Landscape Architect. Retrieved September 29, 2025, from <https://worldlandscapearchitect.com/relocating-entire-swedish-city-white-arkitekter/?v=efad7abb323e>

White Arkitekter. (2018). *Wind analysis of Barkarbystaden IV*.



CHALMERS
UNIVERSITY OF TECHNOLOGY

Author: Jonna Pestrea
Examiner: Nils Björling | Supervisor: John Hemfridssons
Department of Architecture and Civil Engineering | MPARC
Urban Architecture | 2026