Outdoor Comfort in Cold Climates
Integrating Microclimate Factors in Urban Design

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Saeed Ebrahimabadi, August 2015
Abstract

Designing urban spaces that provide outdoor comfort is an important but challenging goal in subarctic climates. An approach to urban design that is sensitive to subarctic climatic conditions is essential, but this requires effective incorporation of urban climate knowledge into urban design, which presently is impeded by several barriers. The aim of this thesis is to contribute to the knowledge of climate-sensitive urban design with a focus on outdoor comfort in cold climates.

This thesis consists of a cover essay and three papers, which together address three questions: (1) What are the barriers to integrating climate factors into urban design in subarctic climates? (2) How do urban design practitioners address outdoor comfort in design process? (3) How can wind and solar considerations be integrated into the design of urban spaces? In accordance with the broad scope and interdisciplinary nature of this research, a mixed method approach was adopted, including a literature review, two interview-based studies and microclimate analysis of an urban design proposal.

The study objectives were pursued in three stages corresponding to the research questions. The first stage consisted of interviews with local planners, which aimed to identify key barriers hindering the incorporation of climatic factors in urban planning in subarctic regions. Key findings include the identification of barriers related to design based, attitudinal, organisational, conceptual and technical issues. The design based issues relate to contextual difficulties for comfort design in cold climates, namely snow and low sun elevation. Attitudinal and organisational barriers include the neglect of opportunities for and challenges associated with urban liveability in cold climates, failure to exploit local knowledge and lack of engagement among local planners and politicians. Conceptual barriers relate to a lack of climate knowledge among practitioners and technical barriers relate to methods and the principles to be used in design, particularly wind comfort and snow in urban environments.

The second stage centred on urban design practice, by investigating the role of comfort in the development of an urban design project in a subarctic
climate. The findings of this stage showed that urban design practitioners predominantly rely on simple climate design principles and rarely use analytical tools in design. In terms of knowledge sources for urban designers, existing urban environments, work by other architects, the architects’ own experience and everyday life experiences are influential sources of understanding and inspiration. In the third stage a method to integrate outdoor comfort assessment into design is outlined and applied on a case study in a subarctic climate. The method encompasses wind comfort analysis and microclimate assessment based on solar access and wind velocity. It produces two types of result: quantitative and visual. The quantitative results include area ratios of different combinations of wind and solar conditions. Visual results are maps showing the spatial distributions of different microclimate combinations in a studied urban space, either proposed or existing. The method has proved useful for assessing relative differences in thermal comfort.

Study stages highlight issues that are crucial for improving environmental comfort in subarctic climates: (1) provision of sheltering from the wind, 2) maximising solar access and, (3) managing snow in the outdoor environment. In addressing these urban design issues, experimental design based research has the potential for creating and testing new design concepts. Practitioners’ reliance on simple climate design principles is also discussed. This research highlights that a more balanced application of climate design principles and analytical methods for addressing microclimate issues is required. Suggestions are also proposed to create a shift in the way outdoor comfort is addressed in practice, including clear goal definition, theory building and improving communications between research and practice.

Key words: urban design, urban microclimate, outdoor comfort, subarctic climate, climate-sensitive, Kiruna
Sammanfattning

Design av stadsrum med god utomhuskomfort är viktigt och utmanande, särskilt i områden med subarktiskt klimat. Ett förhållningssätt till stadsplanering som tar hänsyn till de extraordinära väderförhållanden är viktigt. Det kräver en integrering av urban klimatkunskap i stadsplaneringen, vilket dock hindras av flera barriärer. Syftet med denna avhandling är att bidra med kunskap om klimathänsyn i stadsplanering i kallt klimat med fokus på utomhuskomfort.

Avhandlingen består av en sammanfattande syntetiserande text, så kallad kappa, och tre artiklar, som tillsammans adresserar tre frågor: (1) Vilka hinder finns för att integrera klimatfaktorer i stadsplanering i subarktiskt klimat? (2) Hur hanterar stadsplanerare utomhuskomfort i designprocesser? (3) Hur kan vind- och solförhållanden integreras vid utformning av stadsrum?

Studien genomfördes i tre etapper som svarar mot forskningsfrågorna. Den första etappen bestod av intervjuer med lokala planerare och syftade till att belysa viktiga hinder som står i vägen för att integrera klimatfaktorer i stadsplaneringen i subarktiska områden. De viktigaste resultaten omfattar identifiering av hinder i samband med designbaserade, attitydmässiga, organisatoriska, konceptuella och tekniska frågor. De designbaserade frågorna rör kontextuella svårigheter för design för komfort i kallt klimat, nämligen kyla, snö och lågtstående sol. Attityder och organisatoriska hinder innefattar att möjligheter och utmaningar som förknippas med att stadens dragningskraft i kalla klimat försommnas, underlätenhet att använda lokalkunskap samt en brist på engagemang bland planerare och lokala politiker. Konceptuella och tekniska hinder är relaterade till brist på klimatkunskap bland planeringspraktiker samt brist på metoder och principer som skall användas i urban design, i synnerhet vindkomfort och snöhantering i stadsmiljöer.

Den andra etappen fokuserar på stadsplaneringspraktik genom att undersöka betydelsen av komfortproblem vid utvecklingen av projekt i subarktiskt klimat. Resultaten av denna etapp visar att stadsplanerare i praktiken främst
lutar sig mot enkla principer för klimatdesign och sällan använder analysverktyg. Befintliga stadsmiljöer, andra arkitekters projekt, arkitekters egna förslag och vardagliga livserfarenheter är viktiga kunskapskällor för lärande och inspiration.


Resultaten från dessa tre etapper belyser frågor som är avgörande för att förbättra utomhuskomfort i kallt klimat: (1) planering för att minska vindpåfrestningar 2) maximera solexponering och, (3) hantering av snö i utomhushmiljöer. En experimentellt baserad forskningsdesign har visat en potential för att skapa och testa nya koncept vid stadsplanering.

Stadsplanerares efterfrågan på enkla principer för klimatkonstruktioner har diskuterats i slutsatskapitlet. En mer balanserad tillämpning mellan klimatkonstruktionsprinciper och analysmetoder för att hantera mikroklimatfrågor behövs. En förändring av hur utomhuskomfort hanteras i praktiken föreslås, med tydlig målbild, integrering av klimataspekterna i teorier och en förbättrad kommunikation mellan forskning och praktik.
List of publications

This research is based on the following appended papers that are integrated into the thesis.

**Paper 1:**

**Paper 2:**

**Paper 3:**
Ebrahimabadi S, Johansson C, Rizzo A, and Nilsson K L (2015) “Microclimate assessment method for urban design– a case study in subarctic climate”. Received (Received with comments from Urban Design International. A revised version was submitted)

**Contributions of the author**

Paper 1 is based on literature review and interview with local planning practitioners. I prepared and drafted the paper and was responsible for the literature review and the interviews.

Paper 2 is based on review of the entries to the architecture competition for new Kiruna city centre and interview with urban design practitioners. I carried out review of the competition entries and interviews with the practitioners and was responsible for drafting and submission of the paper.

Paper 3 presents a method based on wind comfort analysis and microclimate analysis. I drafted the paper and carried out wind and microclimate simulations.
Other works by the author not included in this thesis:


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1. Introduction

1.1. Background

A comfortable microclimate in urban spaces encourages people to spend time outdoors in urban environments, which is beneficial for both physical and social well-being and the local economy. Walking and cycling are healthier than commuting with in cars and chatting with friends and neighbours foster social cohesion. Window-shopping and pleasantly strolling in town increase footfall and spending in local shops. (Hakim, Petrovitch et al. 1998, Pucher, Buehler 2010, Hass-Klau 1993, Jacobs 1962). Thus, an important aspect of urban design is to ensure that urban spaces have comfortable microclimates (as far as possible within natural and financial constraints). Clearly, this requires knowledge that allows us to understand and predict the impact of cities’ physical form on their microclimate. However, urban design usually focuses on the physical attractiveness and composition of urban spaces, and the provision of social meeting places. While such aspects affect the success of an urban space, their impact will be reduced if the urban space fails to offer pleasant and comfortable microclimates.

The importance of creating environmental comfort in public spaces is emphasized in prominent urban design literature. Notably, Lynch (1984) discusses the climate of cities in relation to vitality, one of five basic performance dimensions of a city he defines. His definition of vitality, ’a degree to which the form of the settlement supports the vital functions, the biological requirements and capabilities for human beings …’ (Lynch 1984, p. 184) is concerned with human health and physiological well-being. The importance of comfort as a quality dimension of urban space can be understood with regard to types of activities that take place in urban space. Jan Gehl outlines a typology of urban activities based on necessary, optional and social activities (Gehl 1996). Necessary activities are so essential that they will take place regardless of the quality of urban space, e.g. travel to work or school and grocery shopping. Examples of optional activities include, among others, strolling, window-shopping and going to cafés and restaurants. Social activities - such as meeting, chatting or simply sitting and watching other people, can
only occur when others are present. Furthermore, both optional and social activities are encouraged by pleasant, environmentally comfortable urban spaces. In a similar vein, Carmona et al. (2003) highlight the importance of addressing microclimate as an inherent part of the functional dimensions of urban design. They regard comfort as a prerequisite for successful places and stress the need for “climate-sensitive urban design” that responds to both local and global climate concerns. In addition, major socio-economical shifts resulting in ‘the gradual development of industrial society’s essential city life to elective society of leisure and consumer society’ have strongly influenced uses of urban space in recent decades, according to Gehl et al. (2006, p. 8).

However, other processes, such as gentrification, de-gentrification, restriction or expansion of access and various other sociological, economic or political changes may also strongly affect both the nature and uses of public spaces.

Urban climatology is a scientific field that is highly relevant to the study of outdoor comfort; a branch of climatology that focuses on the climate of cities and the influences of aspects of urbanization on their climate. As Evyatar Erell elucidates: ‘we need to understand their microclimates [of space between buildings] so that we may manipulate the spaces to create better environments for humans’ (Erell, Pearlmutter et al. 2011, p. 1). A study of the climate in London by Luke Howard (1833), who first identified meteorological differences between town and country, is often regarded as the starting point of modern urban climatology (Hebbert 2014). However, there have been major developments in urban climate research since the mid-20th century (Mills 2008). It now covers a broad spectrum of issues such as urban heat island (UHI), the impact of street geometry on dispersal of air pollutants, pedestrian comfort, solar energy and hydrological balance of urban areas. In addition, increasing concerns about energy and environmental impacts of cities together with growing attention to public space in architecture and urban design have provided strong stimuli for applying urban climatology in urban design praxis.

Cities in high-latitude subarctic regions have extraordinary climates, with long winters and large differences between warm and cold seasons, that both impose limitations and provide unusual possibilities for urban planning and design (Mänty, Pressman 1988, Zrudlo 1988, Pressman 2004). Winters are accompanied by heavy snowfalls, short days and prolonged periods with temperatures that may be far below zero Celsius. The severity of the climate during such periods may strongly restrict activities in outdoor environments and their accessibility, with negative outcomes for urban life. People spend a great deal of their time in indoor environments, which reduces the liveliness of
urban spaces. In addition, transportation becomes highly dependent on motorized transport, and the high amounts of snow in subarctic cities have adverse consequences for pedestrian safety, road maintenance and urban storm water. Furthermore, reductions in levels of outdoor physical activities are associated with obesity and impair public health (Booth, Pinkston et al. 2005, Ewing, Meakins et al. 2014).

However, in subarctic cities the winter also provides numerous opportunities for recreation, as manifested by winter festivals, winter sports and snow-related outdoor activities (Pressman 2004). These opportunities can help subarctic cities to offer a distinctive urban life with attractions that cannot be offered by their counterparts in more temperate areas, as well as major challenges. A major problem is that such conditions strongly differ from those familiar to most urban designers, and poor climate-related design of urban spaces could exacerbate discomfort in outdoor environments, thereby adversely affecting social life and the local economy in sub-arctic cities.

Understanding the relation between urban design and urban microclimate is crucial for creating urban spaces that encourage desirable optional and social activities, as well as efficient use of energy and other resources (as broadly encapsulated in the term “sustainability”). However, despite growing interest in so-called climate-sensitive urban planning, microclimate considerations, including pedestrian comfort, have gained little ground in urban planning and design (Page 1968, Oke 1984, de Schiller, Evans 1990–1991, Erell 2008, Mills, Cleugh et al. 2010). This is partly because findings from the considerable body of research on urban microclimate is not directly applicable in urban planning practice, and practitioners still lack related knowledge.

In the Scandinavian context, environmental issues and climate are subjects of much public debate. Furthermore, many architects and planners express great interest in addressing climate issues, considering themselves as weather-wise professionals, that is, they have work experience with respect to local climates (Tøsse 2014). Nevertheless, as in other regions, there appears to be little application of urban climate knowledge in the Scandinavian countries. From interviews with Swedish planners, Eliasson (2000) identified several reasons for this, including: lack of knowledge and tools, policy issues such as unclear regulations, time constraints, other priorities in planning practices, and market orientation. As even a quick scan of publications on climate and urban design would show, a large portion of the research on urban microclimate is focused on the provision of knowledge and tools for applying findings in practice.
However, even when urban planners are provided with some principles for design and evaluation of urban projects, the institutional issues (for instance, lack of regulations and attitudes) may impede the incorporation of climate factors into design (Ryser, Halseth 2008).

On a national scale, it is noteworthy that populations of many of the sparsely populated Swedish municipalities have further declined in recent decades. These include most of the northern municipalities, except for a few hosting relatively large cities on the coast of the Gulf of Bothnia. The demographic changes are predominantly due to socio-economic trends and growth of the larger urban centres which offer more opportunities for job and education (Karlsson 2012). Urban planning and design could help by improving living environments in the declining municipalities to make them more attractive for all social groups, especially the young. Two of the northern municipalities, Kiruna and Gällivare, are particularly interesting in this respect, because their urban structures are being profoundly transformed due to expansions of mining activities that are key elements of their local economies. Additionally, in a recent interview study with inhabitants of the town towns, a large share of the participants expressed dissatisfaction about urban quality of their town centres (Jakobsson 2014). Thus, creating comfortable public spaces within the context of the local climate and surrounding landscapes is a major objective of these development schemes (Kiruna Kommun 2012).

Figure 1. Location of Kiruna in northern Sweden.
1.2. Research aims

Given the above background, designing urban spaces that provide outdoor comfort is an important but challenging goal in areas with subarctic climates such as those of Kiruna. An approach to urban design that is sensitive to the extraordinary climatic conditions is essential, but this requires effective incorporation of urban climate knowledge into urban design, which is impeded by several barriers. Thus, better application of urban climatology is needed to incorporate consideration of outdoor comfort in urban design in cold climates, but for this problem, challenges associated with incorporating urban climate knowledge in urban design must be rigorously identified and addressed.

These issues served as starting points for the research that this thesis is based upon, which was aimed at contributing to knowledge about climate-sensitive urban design in cold climates generally with focus on outdoor comfort. Thus, major issues addressed are related to the dissemination of relevant knowledge to urban design practitioners and effects of design processes on the incorporation of knowledge into practice. More specifically, as summarized in this covering essay and described in detail in the appended papers, the research addressed the following questions:

Question 1: What are the barriers to integrating climate factors into urban design in subarctic climates?

Question 2: How do urban design practitioners address outdoor comfort in design process?

Questions 3: How can wind and solar considerations be integrated into the design of urban spaces?

1.3. Thesis outline

The thesis consists of the appended scientific papers and this covering essay, which presents the background of the research, the questions addressed, the methods and theoretical perspectives applied to address them, the answers acquired and a synthesis of the main findings. It is composed of seven chapters in the following order: Introduction, Urban design and microclimate, Introduction to Kiruna and its climate, Research design, Theoretical perspectives, Summary of papers and Synthesis and conclusions.
The Introduction presents background information, the research questions, the significance of the research and its position in the field. The second chapter presents an overview of some basics about urban microclimate, outdoor comfort and thermal comfort. Chapter three introduces Kiruna and its climate. The fourth chapter presents research methods and followed by a chapter on and theoretical perspectives of the subject matter. Chapter six summarises each appended paper, describing the aims, methods and results of the studies they present. The last chapter synthesizes results presented in detail in the papers and provides concluding points.

**Table 1. Research questions addressed in the appended papers**

<table>
<thead>
<tr>
<th>Paper 1: The problem of addressing microclimate factors in urban planning practice of the subarctic regions</th>
<th>Question 1</th>
<th>Question 2</th>
<th>Question 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper 2: Microclimate considerations in urban design practice</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Paper 3: A method for microclimate assessment of urban design: a case study from northern Sweden</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

The three appended papers are associated to different research themes of this thesis. Figure 2 shows how each paper relates to the research themes.
1.4. Notes on scope and limitations

This thesis and the studies it is based upon, concern various aspects of architecture, planning, urban design, design processes, urban microclimates and pedestrian comfort related to urban design. Thus, the covering essay discusses (among other phenomena) key aspects of urban outdoor microclimates, particularly wind comfort and solar access, as they strongly influence use of urban spaces generally and pedestrian comfort particularly. Brief accounts of thermal comfort studies and how microclimate assessment relates to physiological comfort are also presented. The climate of subarctic cities (particularly Kiruna) has been a major concern throughout both the research and preparation of the thesis mainly by a case study of Kiruna urban transformation.¹

¹ Current urban developments in the town of Gällivare have been included in the investigations (interview studies and simulations) this study is based on. However, Kiruna is the main case study reported in this covering essay and the appended papers.
However, many of the aspects discussed do not exclusively affect urban environments in cold climates, and many findings should presumably have some applicability to phenomena and design processes elsewhere.
2. Urban design and microclimate

Consideration of weather and climate has been traditionally integrated in architecture and design of cities. Indeed vernacular architecture and landscaping around the world represent responses to the climate (refined by trial and error) through which building forms, choices of material and vegetation generally contribute to the creation of more comfortable microclimates (Brown 2010). Thoughts about comfort and controlling climatic elements such as wind can also be found in classical architectural texts. For example, a section of *The Ten Books on Architecture* by Vitruvius (ca. 80-70 BC to sometime after 15 BC) entitled ‘The directions of the streets; with remarks on the winds’ warns planners that winds may violently sweep streets, if they are oriented in the same directions, according to a translation by (Vitruvius, Morgan 1914).

Similarly, Palladio (1508-1580) recommended ‘broad and ample’ streets for cities with cool climates to make them ‘much wholesomer, more commodious and more beautiful’, but concluded that cities with warm climates would be healthier with narrow streets and tall buildings that generate shadow (Rykwert 1988). However, the close relationship between architecture/design of outdoor environments and their microclimates has been undermined in modern times by the emergence of automobiles and modern cooling and heating systems (Erell 2008). By the strong influence of traffic engineering on functionalist planning, streets were primarily regarded as channels for cars and street design was dictated by traffic plans (Marshall 2005), while advanced heating and cooling systems have enabled architects to create air-conditioned indoor spaces with no need to consider characteristics of the local climate in building design.

Although vernacular architectures and town urban plans represent good examples of design that is sensitive to microclimate, it should not be concluded that they were specifically designed to provide comfortable conditions, in the contemporary sense of design. Traditional architectures are results of evolutionary processes that have shaped built environments through
generations, intertwined with social needs and institutional arrangements during centuries of trial and error.

Scientific approaches to the study of city climates go back to the nineteenth century. Systematic observations conducted by Luke Howard (1833) recognised the urban heat island, which is considered as the origin of scientific investigation of urban climate, and today research into city climates (urban climatology) is regarded as a distinct sub-discipline of climatology. Today, research in this field covers diverse subjects, such as urban heat islands, energy conservation, solar radiation, air flows, and air quality. These subjects are related to diverse properties of urban environments, e.g. land-use patterns, street canyon geometry, building design and the materials selected for buildings and outdoor environments.

The city brings significant effects on its climate, including the climate within built-up areas and the atmosphere around it. The influence of urban structure on climate can be observed at different climate scales (Figure 3).

![Figure 3. Vertical sections of urban modified air showing the urban boundary layer (UBL), roughness sub-layer and urban canopy layer (UCL) (Oke 1978, Oliver 2005).](image)

The lowest part of the atmosphere in an urban area, is known as the ‘urban boundary layer’ (UBL) (Oke 1978). This layer encompasses the volume of air above the city that is influenced by the nature of the built environment and
anthropological activities in the city. It extends around 10 times the height of the buildings in the urban area, and can be divided into a number of sub-layers. The lowest is called the ‘urban canopy layer’ (UCL), and covers the volume from the ground level to the height of the buildings, trees and other objects. This layer is highly heterogeneous and strongly influenced by individual urban elements such as buildings. It is part of a ’roughness sub-layer’, extending from the ground to around two times the average buildings’ height. Air flow in this layer is affected by plumes and wakes caused by individual roughness elements. Above this there is an 'inertial sublayer', which extends to a height about four or five times the buildings’ height and is influenced by the texture of the urban fabric as a whole through the roughness properties and the heat produced in the city, but not by individual elements (Erell, Pearlmutter et al. 2011, p.16). These three sub-layers collectively form the surface layer. The upper part of the UBL is called the ‘mixing layer’, because it is influenced by both the urban terrain and non-urban upwind terrain.

2.1. Outdoor comfort

Urban microclimates have major implications on pedestrian comfort and the energy performance of buildings. Comfort has received increasing attention in recent years as a crucial quality for public space, in recognition that microclimate contributes to quality of life in cities. Comfort in outdoor environments is attributed to several objective and subjective factors, such as: feeling safe; familiarity of settings and people; acoustic, smells and visual conditions; microclimate; convenience and physical comfort (Mehta 2014, Reiter, De Herde 2003). Clearly, the focal concern is the comfort of pedestrians, because (in contrast to car users) they are in direct contact with the microclimate and experience variation in atmospheric parameters that affect their perception of the outdoor environment. Two major factors that affect pedestrians’ comfort, and thus are key foci of related research are the mechanical impact of wind and thermal sensation.

2.1.1. Wind comfort

The wind functions both as a dynamic force and a coolant. The term wind comfort is often used to refer to the mechanical impact of wind on people. Assessment of the mechanical impact of wind focuses on discomfort caused by wind, regardless of its effects on human thermal sensations. The mechanical
impact of wind is usually described in terms of its effects on people and objects, ranging from feeling a light breeze on skin through hair being disturbed and clothes flapping to people being blown over by strong gusts. Areas near high-rise buildings can become particularly exposed to uncomfortable or dangerous pedestrian-level winds if appropriate design measures have not been implemented. Wind speed is usually higher in rural areas and falls in urban environment due to blocking effect of buildings, vegetation and other objects in built environments. However, wind speeds may be higher at pedestrian level due to the 3D-volumetric properties of urban environments. This can occur when relatively high buildings deflect moving upper air layers (downwash) or by streets orientated towards the air flow, causing a channelling effect (Oke 1978, p.297).

With regard to wind comfort criteria, the Beaufort scale originally used for ship navigation has been modified for application in land regions. Table 2 shows the modified 10-level (calm to strong gale) terrestrial Beaufort scale based on pedestrian-level (h= 1.75 m) effects (Lawson, Penwarden 1977, Blocken, Carmeliet 2004).

Table 2. Effects of wind on people (after Blocken, Carmeliet 2004).

<table>
<thead>
<tr>
<th>Beaufort number</th>
<th>Description</th>
<th>Wind speed (m/s) at h=1.75 m</th>
<th>Wind effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Calm</td>
<td>0 – 0.1</td>
<td>Smoke rises vertically</td>
</tr>
<tr>
<td>1</td>
<td>Light air</td>
<td>0.2 – 1.0</td>
<td>No noticeable wind</td>
</tr>
<tr>
<td>2</td>
<td>Light breeze</td>
<td>1.1 – 2.3</td>
<td>Wind felt on face</td>
</tr>
<tr>
<td>3</td>
<td>Gentle breeze</td>
<td>2.4 – 3.8</td>
<td>Hair disturbed, clothing flaps, newspaper difficult to read</td>
</tr>
<tr>
<td>4</td>
<td>Moderate breeze</td>
<td>3.9 – 5.5</td>
<td>Raises dust and loose paper, hair disarranged</td>
</tr>
<tr>
<td>5</td>
<td>Fresh breeze</td>
<td>5.6 – 7.5</td>
<td>Force of wind felt on body, danger of stumbling when entering a windy zone, Umbrella used with difficulty, hair blown straight, difficult to walk steadily, wind noise on ears unpleasant</td>
</tr>
<tr>
<td>6</td>
<td>Strong breeze</td>
<td>7.6 – 9.7</td>
<td>Inconvenience felt when walking</td>
</tr>
<tr>
<td>7</td>
<td>Near gale</td>
<td>9.8 – 12.0</td>
<td>Generally impedes progress, great difficulty with balance in gust</td>
</tr>
<tr>
<td>8</td>
<td>Gale</td>
<td>12.1 – 14.5</td>
<td>People blown over</td>
</tr>
<tr>
<td>9</td>
<td>Strong gale</td>
<td>14.6 – 17.1</td>
<td></td>
</tr>
</tbody>
</table>
The modified land Beaufort scale describes winds’ possible effects of on people and objects, regardless of frequency. However, Bottema (2000, p. 3) notes that: ‘pedestrian discomfort occurs when wind effects become so strong and occur so frequently (say on a time scale up to 1 h) that people experiencing those winds’ effects will start to feel annoyed, and eventually will act to avoid these effects’. Thus a more appropriate way of defining wind comfort should include two parameters: a speed threshold and the probability of the threshold being exceeded. In other words, a criterion defining wind threshold speeds for specific types of pedestrian activities combined with the maximum allowable exceedance probabilities within certain durations (Holger Koss 2006, Reiter 2010). Research on wind comfort assessment has resulted in a number of such criteria. Widely known examples include those by Davenport and Isyumov (1977), Melbourne (1978), Lawson and Penwarden (1977) and Hunt et al. (1976). Some of these criteria use the hourly mean speed (steady winds) as the base parameter for evaluating wind comfort, while others are based on the gust or effective wind speed ($U_e$), which can be obtained from the following formula (Glaumann, Westerberg 1988):

$$U_e = U + k \sigma$$

Here, $U$ is the mean wind speed (say at 1.75 m height), ‘$k$’ is the peak factor and ‘$\sigma$’ is the standard deviation. It is generally accepted that pedestrians are more affected by wind gusts than by uniform winds (Hunt, Poulton et al. 1976). However, such criteria are complex to use in practice. Thus, wind comfort criteria usually applied in various countries are based on hourly wind speed (Holger Koss 2006). These include criteria used by the Building Research Establishment (BRE) in the UK, Force Technology-DMI (Denmark), the Netherlands Organization for Applied Science research (TNO, The Netherlands), the University of Bristol (England) and University of Western Ontario (Canada).

One wind comfort criterion that is based on hourly wind speed is the Dutch Wind Nuisance Standard (NEN 8100), which was used for assessing wind comfort in the Kiruna case study presented in paper 3 (see Chapter six). It includes wind comfort and wind safety criteria that define acceptable probabilities and speed thresholds for various pedestrian activities, with wind speed thresholds for comfort and safety of 5 m/s and 15 m/s, respectively. The probability ($P_{max}$) is the percentage of hours per year when there are winds with a mean velocity exceeding 5 m/s at a height of 1.5 meters.
Table 3. Wind comfort and wind safety criteria according to the Dutch standard NEN 8100, adapted from (Willemsen, Wisse 2007).

<table>
<thead>
<tr>
<th>$P_{max}$ Wind comfort</th>
<th>Grade</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traversing</td>
<td>Strolling</td>
</tr>
<tr>
<td>&lt; 2.5</td>
<td>A</td>
<td>Good</td>
</tr>
<tr>
<td>2.5 – 5</td>
<td>B</td>
<td>Good</td>
</tr>
<tr>
<td>5 – 10</td>
<td>C</td>
<td>Good</td>
</tr>
<tr>
<td>10 – 20</td>
<td>D</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>E</td>
<td>Poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$P_{max}$ Wind safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.3</td>
</tr>
<tr>
<td>&gt; 0.3</td>
</tr>
</tbody>
</table>

Evaluation of wind comfort based on wind criteria such as those stated in NEN 8100 also requires statistically robust meteorological data and aerodynamic information (Blocken, Carmeliet 2004). The meteorological data usually cover several decades, frequently a “reference period” of 30 years. Wind speed is measured at a height of 10m at meteorological stations and its direction is classified in 12 sectors of 30°. Aerodynamic information is needed for converting wind data gathered at a nearby meteorological station to estimated wind speeds at a focal urban site, and consists of ‘the terrain related contribution’ and ‘design relate contribution’ (Blocken et al., 2012, p. 16). The former refers to the change in wind statistics from the meteorological site ($U_{ref}$) to a reference location close to the building site ($U_0$), and the latter represents the change in wind statistics by the built environment surrounding the building site, i.e. the change of $U_0$ to the local wind speed $U$ (Figure 4).
Simulation of wind can be conducted using scaled physical models in a wind tunnel and CFD (Computational Fluid Dynamics) techniques. Numerical modelling with CFD provides an alternative means for wind tunnel studies. CFD has several advantages to wind tunnel studies, namely, being more flexible, less costly in terms of time and expenses and the ability to generate details of wind flows at every point in the computational model. These advantages and constant advances in computing power have caused the increased application of CFD in research and practice.

2.1.2. Thermal comfort

Thermal comfort is one of the factors that influence the use and acceptance of public spaces, particularly for optional or social activities (Lenzholzer, Van 2010, Walton, Dravitzki et al. 2007, Thorsson, Honjo et al. 2007, Westerberg 2009). It has been defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE 1981). The definition highlights that human thermal comfort is characterized by both subjective (condition of mind) and objective (thermal environment) elements. The objective element can be assessed by measuring environmental parameters such as air temperature and flow velocity. However, the subjective elements are more complex; people may experience the same thermal conditions differently, due to differences in their physical, psychological, physiological and cultural state. The objective and subjective characteristics of human thermal sensation have been reflected in the approaches adopted to study and estimate thermal comfort. Accordingly, there are thermal comfort estimation models that focus on...
physiological aspects of thermal conditions, and others that focus on subjective elements, namely adaptation measures and psychological processes.

The physiological approach to thermal comfort assessment focuses on the heat balance of the human body. Human body produces heat and exchanges heat with the environment in order to maintain its internal temperature close to 37 °C. The main factors that influence the heat balance of human body include (Parsons 1993):

- Environmental parameters: air temperature, radiation, air flow velocity and relative humidity
- Personal parameters: metabolic heat generated by human activity and clothing level.

In addition to these parameters, the duration of exposure is also important. The physiological approach has led to the development of several indices to describe thermal comfort levels, mostly based on heat balance equations. The key terms in these equations describe heat generation, transfer and storage in the body, as expressed for example by the following equation (Höppe 1999, Fanger 1972):

\[ M + W + R + C + E_D + E_{Re} + E_{SW} + S = 0 \]

Here, M is the metabolic rate (internal energy production by oxidation of food), W is the physical work output, R the net radiation of the body, C the convective heat flow, \( E_D \) the latent heat flow required to evaporate water into water vapour diffusing through the skin (imperceptible perspiration), \( E_{Re} \) the sum of heat flows that heat and humidify the inspired air, \( E_{SW} \) the heat flow due to evaporation of sweat, and S the storage heat flow for heating and cooling.

The equation shows the fundamental basis for heat balance, that is, heat production should be equal to heat loss. When the body is not in thermal balance, its temperature will change, leading to thermal discomfort and physiological responses that counter the imbalance, such as changes of blood flows under the skin and sweating.
Some of the most widely known and accepted indices based on the heat balance model are the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices, both introduced by Fanger (1972); the new Effective Temperature (ET) and Standard Effective Temperature (SET*) indices based on the two-node thermal balance model presented by Gagge (1971) and the Physiological Equivalent Temperature (PET) index developed by Höppe (1999). The PMV index predicts the mean thermal vote of a large population of people, measured on the seven-point scale used by the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) (+3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, -1 = slightly cool, -2 = cool, -3 = cold). PPD is an index related to PMV that predicts the percentage of thermally dissatisfied people at each PMV value. ET and SET values (expressed in °C) are calculated using Gagge’s two-node model, in which the human body is represented by two concentric cylinders, a core cylinder and a thin skin cylinder. The heat balance between the environment and the skin cylinder is calculated through an iterative process until equilibrium is reached after a specified time (Fountain, Huizenga 1995, 2006).
PET is a steady-state model, based on the heat balance model MEMI and some of the parameters from Gagge’s two-node model (Höppe 1999). It is defined as ‘the physiological equivalent temperature at any given place (outdoor or indoor) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the condition being assessed’ (ibid., p. 73). Outdoor Standard Effective Temperature (OUT_SET*) is an extension of SET* outdoor comfort assessment that includes a model for calculating mean radiant temperature ($T_{mrt}$) in complex outdoor environments (Pickup, de Dear 2000). This index is expressed in °C and can be calculated based on given metabolic rates and clothing levels.

![Figure 6. Densities of radiation fluxes are important for determination of $T_{mrt}$, adapted from (adapted from Matzarakis et al., 2010).](image)

As previously noted, the parameters commonly used to calculate thermal comfort indices are air temperature, air velocity, relative humidity and radiation. The relative humidity and air temperature parameters can be very little affected by small-scale urban interventions as they are governed by large-scale meteorological and urban meso-scale factors. However, wind velocity and radiation parameters are affected by urban form at the micro scale. Radiation parameters can be incorporated in outdoor thermal comfort assessments by estimating mean radiant temperature, $T_{mrt}$. This is the sum of all short wave and long wave, direct and indirect radiation fluxes (Thorsson,
Lindberg et al. 2007)(Figure 6). It is defined as ‘the uniform temperature of an imaginary enclosure in which radiant energy exchange with the body equals to radiant exchange in the actual non-uniform enclosure‘ (ASHRAE 2001), and can be estimated by using a globe thermometer, or software packages such as ENVI-met® (Bruse, Fleer 1998, Huttner 2012) or Rayman (Matzarakis, Rutz et al. 2010). Sun and shadow are the parameters that influence $T_{mrt}$ most (Brown, Gillespie 1995).

The indices described above are based on steady-state heat conditions. Except for PET and OUT_SET∗ they were all originally developed for indoor settings, although they could theoretically be used for evaluating outdoor climates. Climate parameters that affect thermal comfort are similar in indoor and outdoor environments, but they are more variable and less controllable in outdoor environments. Thorsson et al. (2004) found a discrepancy between PMV estimates of thermal sensation and responses of interviewed pedestrians in a park in Gothenburg Sweden, which indicated that PMV may not be appropriate for assessing short-term outdoor thermal comfort. This is because it cannot represent transient exposure and psychological aspects that play important role in the subjective assessment of the out environment. Similarly, Nikolopoulou et al. (2001) found substantial discrepancies between theoretical PPD values and actual sensation votes (ASV) of the users. Consequently, a major criticism of steady-state models is that they do not accurately predict thermal sensations in outdoor environments, where the thermal conditions are highly dynamic and often outside the human comfort zone (Höppe 2002).

However, users of outdoor urban environments often show high tolerance and acceptance of microclimate conditions that lie outside the established comfort range, mediated by various adjustments that can bridge gaps between thermal conditions and people’s thermal requirements. The adaptive approach to thermal comfort analysis explores effects of such adjustments on human thermal sensation, which include “physical” adjustments, such as changes in clothing and activities, “physiological” adjustments and “psychological” adaptations, related to factors such as expectation, preferences and perceived control (Nikolopoulou, Lykoudis 2006, Reiter, De Herde 2003). Studies in multiple countries have demonstrated that psychological factors play major roles in comfort assessment, including: naturalness, expectations, duration of exposure, perceived control over sources of discomfort, environmental stimulation (Nikolopoulou, Steemers 2003, Thorsson, Lindqvist et al. 2004, Spagnolo, de Dear 2003, de Dear, Brager et al. 1997) and historical and
cultural factors (Knez, Thorsson 2006). In extreme climates where microclimate conditions are often far from thermally optimal, adaptive factors influence thermal perception particularly strongly.
3. Introduction to Kiruna and its climate

Kiruna and its climate provided case material for much of the research presented here and in the appended papers. Kiruna is Sweden’s northernmost town with a population of slightly more than 18000 people (Statistics Sweden 2013). The urban area of the town covers approximately 19 square kilometres. Kiruna is a notable town at a national and international level due to a number of reasons, namely its location in Swedish Lapland, indigenous Sami people, Kiruna Church, the Ice Hotel, iron ore mine, and of course its climate. The mine is operated by Luossavaara–Kirunavaara AB (LKAB) – a corporate group owned by Swedish government – and is the world’s largest sublevel iron ore mine.

![Figure 7. Arial photo of Kiruna (Lantmäteriet, licence: I2014/00602).](image)

LKAB was founded in 1890. The mining activity and establishment of Kiruna began some years later when construction of a railway between Luleå, Kiruna and Narvik on the Norwegian coast was finished in 1902. Hjalmar Lundbohm, LKAB’s first managing director and the founder of Kiruna, had lofty
aspirations to build a model city. He employed Per Olof Hallman, a renowned Swedish city planner at the time to prepare a town plan for Kiruna

Hallman designed a staggered street network to reduce wind forces. The street network was adapted to the ground topography and made mountain Kirunavaara - where mining activity began- visible from many points in the town (Figure 8).

Kiruna and the mine have been evolving together since their foundation. Kiruna is less dependent on mining activities today as compared to its early years, as other businesses have developed. However, due to the strong ties between the mine and many of these businesses, the economy of the Kiruna is affected by the business conditions of LKAB. In 2004, LKAB announced that the extraction of iron ore would be proceeding towards the central areas of Kiruna and would cause land subsidence in the central areas of the town situated near the mine (Kiruna Kommun 2012, p.12). The land subsidence has led to an on-going extraordinary urban transformation process involving relocation and rebuilding of large parts of Kiruna. The municipality embarked on a new comprehensive plan for Kiruna shortly after the LKAB announcement about the continuation of ore extraction beneath the central areas. The central concern in this transformation process is how to safeguard

Figure 8. The first time plan prepared by Hallman in 1900 (Kiruna Kommun, 2012).
development and viability of the city as whole. An architecture competition was held in 2012 and 2013 regarding design of a new city centre for Kiruna. The competition objectives involved preparation of a vision and a strategy for the development of Kiruna towards east and design of a new city centre.

Kiruna is located near latitude 67° N and about 140 Km north of the Arctic Circle. It has an inland subarctic climate (SMHI 2012), of sub-category Dfc (D, cold; f, without dry season; c, cool summers) according to the Köppen-Geiger classification of world climates, which covers large parts of northern Canada, Norway, northern Sweden, Finland and Russia (Figure 9). Features of this climate include long and very cold winters, and short, cool to mild summers. The low temperatures during long parts of the year result in permafrost, which strongly affects vegetation. At the local scale, Kiruna’s climate is influenced by the city’s stark topography, which affects temperature and wind patterns. Topographical shadows cause inhomogeneous warming of the land, which generates thermal winds (SMHI 2012). Snow cover period extents from October to May. Some key information about Kiruna and its climate can be summarized as follows (Kiruna Kommun 2012):

- Geographical location: 67°51’ N 020°13’ E
- Population: approximately 23000 in the entire municipality and 18200 in the city of Kiruna
- Climate: inland subarctic
- Mean temperatures in January and July: -14.3 °C and +12 °C, respectively
- Annual precipitation: approximately 488 mm
- Days of midnight sun and polar night per annum: 50 and 20, respectively.
Temperatures in Kiruna vary widely between seasons (mean monthly temperatures at 15.00, UTC, range from -12.7 °C to 15.3 °C). However, during the coldest and darkest months (December, January and February) the temperature varies very little diurnally (Table 4).

**Table 4.** Mean temperatures (°C) at indicated times of day and month, blue represents cold and red/orange represents hot (SMHI 2012).

<table>
<thead>
<tr>
<th>Time in UTC</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>-12.8</td>
<td>-12.6</td>
<td>-9.4</td>
<td>-4.1</td>
<td>2.5</td>
<td>8.7</td>
<td>11.2</td>
<td>8.7</td>
<td>3.8</td>
<td>-1.9</td>
<td>-7.8</td>
<td>-11.0</td>
</tr>
<tr>
<td>18</td>
<td>-12.7</td>
<td>-12.3</td>
<td>-8.2</td>
<td>-1.7</td>
<td>5.1</td>
<td>11.3</td>
<td>14.1</td>
<td>11.5</td>
<td>5.2</td>
<td>-1.5</td>
<td>-7.7</td>
<td>-11.1</td>
</tr>
<tr>
<td>15</td>
<td>-12.7</td>
<td>-11.4</td>
<td>-5.3</td>
<td>0.1</td>
<td>6.2</td>
<td>12.6</td>
<td>15.3</td>
<td>13.1</td>
<td>7.6</td>
<td>-0.2</td>
<td>-7.6</td>
<td>-11.6</td>
</tr>
<tr>
<td>12</td>
<td>-12.4</td>
<td>-10.4</td>
<td>-5.2</td>
<td>0.1</td>
<td>6.1</td>
<td>12.4</td>
<td>15.1</td>
<td>13.0</td>
<td>7.8</td>
<td>0.6</td>
<td>-7.1</td>
<td>-10.9</td>
</tr>
<tr>
<td>9</td>
<td>-12.6</td>
<td>-12.2</td>
<td>-7.6</td>
<td>-1.5</td>
<td>4.9</td>
<td>11.1</td>
<td>13.8</td>
<td>11.6</td>
<td>6.3</td>
<td>-0.7</td>
<td>-7.6</td>
<td>-10.9</td>
</tr>
<tr>
<td>6</td>
<td>-12.7</td>
<td>-13.0</td>
<td>-10.5</td>
<td>-4.2</td>
<td>2.8</td>
<td>9.0</td>
<td>11.6</td>
<td>9.1</td>
<td>3.6</td>
<td>-2.2</td>
<td>-7.8</td>
<td>-11.0</td>
</tr>
<tr>
<td>3</td>
<td>-12.6</td>
<td>-13.0</td>
<td>-10.7</td>
<td>-6.1</td>
<td>0.6</td>
<td>6.8</td>
<td>9.2</td>
<td>6.9</td>
<td>2.7</td>
<td>-2.1</td>
<td>-7.8</td>
<td>-11.0</td>
</tr>
<tr>
<td>0</td>
<td>-12.7</td>
<td>-12.9</td>
<td>-10.1</td>
<td>-5.4</td>
<td>0.5</td>
<td>6.1</td>
<td>9.0</td>
<td>7.4</td>
<td>3.2</td>
<td>-1.9</td>
<td>-7.7</td>
<td>-11.0</td>
</tr>
</tbody>
</table>

**Figure 9.** Köppen Geiger map of world climates (Adapted from Peel. et. al. 2007)
Prevailing wind directions in Kiruna are South, South West and North. South to South West winds account for approximately 39%, and north winds 10%, of annual winds. As shown in the temperature wind rose in Figure 10 (left panel) winds from the South West are strongest, and relatively cold. The winds from the West have similar speed, but are significantly warmer. The Swedish Meteorological and Hydrological Institute advised entrants to the urban design competition described in detail below that wind climates would be more comfortable in outdoor areas opening towards the West than in those facing South.

![Temperature Wind Rose](image1.png)

**Figure 10.** Annual temperature wind rose (left) and wind rose for Kiruna Airport (SMHI, 2012).

Due to its location close to latitude 67°N Kiruna has a “polar night” lasting about 20 days in December, and a “midnight sun” period lasting about 50 days.
in summer (when northern facades get sunlight during the early morning and late evening hours). However, although the daylight hours are very long during the warmest months, sun elevations are relatively low (maximum elevations range from $0^\circ$ in December to $45^\circ$ in June), which makes solar design of outdoor spaces challenging, especially for the late winter months March and April (Figure 12).

**Figure 12.** Orthographic projection of the sun’s path at Kiruna.
4. Research design

4.1. Implementation

In accordance with the broad scope and interdisciplinary nature of the research, a mixed method approach was adopted, including case study, literature review, semi-structured interviews and microclimate analysis of an urban design proposal.

Two main objectives were formulated to meet the aim of the research this thesis is based upon, i.e. to extend knowledge about climate-sensitive urban design. These were: to identify particular challenges associated with integrating consideration of the subarctic climate in urban design; and to extend understanding of the relationship between urban design practice and knowledge of urban microclimates, particularly for cities with subarctic climates. These objectives were pursued by successively addressing the following topics, which shaped the contents of the appended papers (Figure 13):

1) Problems of addressing climate in urban planning of cold regions according to the local planning practitioners.
2) Integration of microclimate factors into urban design practice
3) Microclimate assessment of urban design projects based on solar access and wind velocity

The research began by identifying challenges, difficulties and opportunities associated with addressing microclimate-related factors in urban planning in subarctic climates. This was done through interviews with local planning practitioners based in municipalities in northern Sweden in conjunction with a thorough review of literature on urban design in cold climates. In a second stage, urban design practitioners’ approaches to addressing outdoor comfort in the Swedish subarctic climate were examined in a case study. This involved interviews with urban designers and an analysis of entries for a competition held for designing a new urban plan for the entire city of Kiruna. Investigations in the third and final stage focused on assessment of outdoor
comfort. This stage included a review of thermal comfort studies and an outline of a method for assessing wind comfort and microclimate performance in urban design projects.

Paper 1 and paper 2 are qualitative studies and paper 3 is primarily quantitative. Overall, this combination emphasises the qualitative nature of this thesis. In paper 3, wind speed and thermal comfort indices are simulated using computer aided tools and are based on data from Kiruna Airport meteorological station. The analysis is limited to the urban canopy layer, i.e. analysis of the microclimate at street level, in the space between the ground and roof tops. The investigation into the relationship between urban form and microclimate is focused on pedestrian comfort. The influence of urban form on the energy performance of buildings and indoor microclimates is not included in this thesis.

4.2. Case study

Case studies are useful for answering ‘how’ or ‘why’ questions in situations involving a contemporary set of events where the researcher has little control (Yin 2003), and through use of varied sources of information, they allow researchers to acquire judicious understanding from real life situations. Scepticism has been expressed about reliability of case studies in terms of scientific generalizations (Stake 1995). However, this study is based on the view that while statistical generalization from a single case study is clearly impossible, analytical generalization may be feasible (Johansson 2000), through
combined or separate use of several modes of reasoning (including deductive, inductive and abductive) and triangulation.

Abductive reasoning was found to be most relevant for generalization in stage 2, in which generalization was performed through synthesis of findings and relevant aspects of design theories. According to Locke (2010, p.1): ’abduction is the process of forming a possible explanation involving an imaginative effort to understand on the part of beings acting and learning in a world. It is a practical reasoning mode whose purpose is to invent and propose ideas and explanations that account for surprises and unmet expectations. Within the context of scientific endeavours, abduction is the basis for the inventive construction of new ideas, explanatory propositions, and theoretical elements.

Triangulation is a key feature of the case study that reinforces the validity of a research. It involves use of multiple methods and sources for studying a subject in order to “reduce bias” and develop “converging lines of inquiry” (Yin 2003, p.98, Wolfram Cox, Hassard 2010). It often entails: ‘direct observation’ by the investigator(s) within the case environment, probing by asking case participants for clarification and elucidation, and analyses of written documents (Woodside 2010). In this study triangulation was achieved by reviewing publications about urban design in cold climates, scrutinizing the posters and proposals submitted by the 10 competing teams and the semi-structured interviews with key members of the teams.

4.3. Literature review

The starting point was to identify special aspects of urban design related to cold climates and acquire knowledge about requirements and difficulties, paying attention to the experience of the local planners. The exploratory nature of the study at this stage was the chief reason to begin with a literature review, which examined literature with the following foci:

- urban design in cold climates (particularly outdoor environments)
- application of urban climate knowledge in urban design
- active transport modes in cold climates.

The themes were selected through meetings with an advisory group for this stage, composed of three planners working in the chosen Swedish municipalities. The aim of the literature review was to identify the relevant research in order to gain literature awareness, internalizing the literature (Groat,
Wang 2013), and frame the problem at the outset of the study (Creswell 2009, p.27). Hence, the review was conducted selectively in relation to the research questions (addressed in paper 1) and the previously mentioned focal areas. Relevant journal articles and books were searched for in Scopus, Web of Science and and Libris databases using single key-words or in combined forms. The main sets of keywords included outdoor comfort, wind, microclimate, climate-sensitive, thermal comfort, urban microclimate, urban climatology, subarctic climate, pedestrian comfort, pedestrian and cycling. The results from the literature review at this stage helped to frame contours of the research and informed all of the subsequent stages. The theme “active transport mode in cold climate” related to the impact of climate on walking and cycling, and possible contributions of urban design to facilitate and promote walking and cycling. This was a central theme in the first parts of the project this thesis is based upon, as presented in my licentiate thesis and paper 1. In later stages, papers and the thesis overall, outdoor comfort became the major concern. The focal themes and related publications are mapped in Figure 14.

**Figure 14.** The literature map of the research showing major research subjects and the related publications.
4.4. Interview studies

Interview investigations were applied in stages 1 and 2 of the research. Due to the qualitative nature of these stages, the interviews were semi-structured and focused, including a set of open-ended questions that emerged from the case study (Creswell 2009, Yin 2013, p.27). The purpose of the interviews in stage 1 was to identify problems, opportunities and needs related to addressing seasonal climate factors in planning in cold climates. In stage 2, the interviews focused on the designers and their approaches for addressing microclimate. In both stages, an interview protocol was used to present the aim of the study, procedure for processing interview transcripts and ethical concerns before asking the questions. When wording the questions, attempts were made to minimize potential bias while following a line of inquiry corresponding to the focal subject (Yin 2013, p. 110). In stage 2, the interviews shaped part of the qualitative case study that was the main element of the research during this stage. In this stage, the first interviews centred on ‘design for comfort’, while questions regarding design processes were incorporated into later interviews. In both stages most interviews were conducted through telephone meetings, but in a few cases there were face-to-face meetings. More details about the interviews are provided in the respective papers.

The selection of municipalities and the individuals was considered as a means to gather data with increased variability rather than aiming to find correlation between experiences among the participants (Trost 2005). In this respect, a limited number of interviews can inform with depth, which is not usually possible in much larger sample of participants. In qualitative studies, the selection of individuals does not entail statistical merit. Because the aim is to discover patterns regardless of the number of respondents who demonstrate the patterns, patterns can be discovered as long as the interviews answer the question of interest. In stage 1 that focused on the local planners, a sample group of four northern Swedish municipalities was selected, which led to seven participants in total. The participants worked in different planning positions that were composed of three architects, three planners and one with traffic planning education. This approach has also been the basis for the stage 2 interviews, in which interviews with participating urban design practitioners shape an important part of the qualitative case study method used in that stage. In stage 2, ten interviews were conducted, lasting between 45 to 75 minutes.

The interview transcriptions from both stages were scrutinized through a qualitative data analysis, started by reading through all data and then moving
towards a more detailed analysis of the texts through several steps including: generation of initial codes, categorizing codes, search for themes within the codes, positing themes in relation to theoretical perspectives and interpretation of the themes in relation to question of study (Braun, Clarke 2006, Creswell 2009). Following these steps involved making balance between proximity and distance with the data (Widerberg 2002). Proximity with data can be easier achieved than holding distance from them. In both stages 1 and 2, the initial steps of analysing data (reading through and codifying) led to themes that resembled the previous publications about the subject i.e. challenges of climate sensitive urban design. However, the way researchers observe and understand data is influenced by their background, experiences and initial perception about the examined data. In order to lessen the bias from the preconceptions and thus maintaining distance from the data, codes and themes were critically reviewed and revised in order to offer an interpretation of data which truly corresponds to the original data and what the interview participants expressed. The results were validated by working closely with the data by listening to the audiotaped interviews and reviewing the interview transcriptions to include other dimensions of the data which were not considered in the beginning.

4.5. Microclimate assessment

In the study reported in paper 3 a microclimate assessment method was developed and applied to a design project located in Kiruna. The data used included climatic parameters derived from simulations to assess outdoor comfort based on two factors: solar access and wind speed. Solar access is related to patterns of direct sun radiation and shadow in outdoor environments, which were simulated using the computer-assisted design (CAD) program Autodesk® Ecotect Analysis. Wind speeds were simulated using the computational fluid dynamics (CFD) package Autodesk® Simulation® CFD 2015. CFD tools use numerical techniques to solve equations related to flows of fluids. CFD has been increasingly used for simulating wind flows around buildings and it has several advantages over use of full-scale models and wind tunnel tests. Notably, it does not require a physical model and thus allows more flexible tests of different design alternatives in terms of both study objects and test conditions. Furthermore, while wind tunnel tests provide information about wind conditions at some spots in the study area, one can obtain information regarding all of the areas from a CFD model. Autodesk® Simulation® CFD 2015 has been validated with a suite of test models with known models (Autodesk 2014). More details
of the CFD model including parameters such as mesh size, the turbulence model, wind vertical profile, size of computational domain are presented in paper 3.

The microclimate simulation tool ENVI-met® was used to simulate microclimate parameters required for estimating values of the thermal comfort index OUT_SET* reported in paper 3. ENVI-met® has been chosen because the software can simulate all parameters influencing thermal comfort. It is defined as a ‘three dimensional microclimate model designed to simulate the surface-plant-air interactions in an urban environment with a typical resolution of 0.5 to 10 m in space and 10 sec in time’(Bruse 2015). The model simulates the main atmospheric processes and variables that influence urban microclimates, including radiation fluxes, temperature, humidity, air flows and turbulence.
5. Theoretical perspectives

The focus of this thesis and underlying research, on outdoor comfort in urban design represents a theory-practice bond, perceived in accordance with two frameworks. One posits comfort as a quality feature of urban design. In this respect, the framework is situated within the urban design discipline, where the theory-practice relationship corresponds to the relation between normative theory of urban form and the realized urban form. In the other framework, the theory-practice bond corresponds to a relationship between urban climate knowledge, as an instrumental knowledge (theory) and urban design as practice, which is synthetic and interdisciplinary (Khan, Vandevyvere et al. 2013). Both of these frameworks were applied throughout the research, and while writing the appended papers and thesis, but the climate-related framework is most important in this context. How the theory (urban climate knowledge) is being integrated as instrumental knowledge in practice depends on both internal processes in design and external factors that influence this relationship. Theories that explain aspects of relationships between urban climatology and urban planning and design aid understanding of the external factors. On the other hand, theories about design processes are helpful for comprehending the internal processes of urban design, with regard to the role of analysis in design, which in turn influences how outcomes from the instrumental knowledge are integrated in urban design.

5.1. Application of urban climate climatology in urban planning and design

Approximately 54 percent of the world’s population resided in urban areas in 2014, corresponding to a population of circa 3.9 billion. This proportion is projected to increase to 66 percent by 2050 (United Nations, Department of Economic and Social Affairs 2014). The growing global urbanization influences the climate at multiple scales, through effects of urban form (cities’ three-dimensional geometry and material composition) and functions of cities, including everyday activities that result in emissions of waste heat and materials into the atmosphere (Mills, Cleugh et al. 2010). The application of urban
climatology in urban planning and design pertain to numerous subjects at spatial scales ranging from building and street (micro) through neighbourhood (local) to city and region (macro), and temporal scales ranging from seconds (e.g. for some urban meteorological processes such as chemical dispersion) through centuries (some buildings’ lifetimes) to 1000 years (city-scale planning) (Grimmond, Roth et al. 2010, p.258).

Urban planners are generally aware of benefits related to use of urban climatology in urban planning for addressing sustainability issues, but diverse barriers impede its application in their practice. This discrepancy has been researched and debated in the field of urban climatology for several decades (Hebbert 2014). For example, in a document entitled Urban Climatology and Its relevance to Urban Design published by the World Meteorological Organization (WMO) in 1976, Chandler noted that:

‘Optimization of the indoor climate is a most important and long recognized role of the architect. In contrast, although not entirely neglectful of climatic considerations, urban planners have, until comparatively recently, only rarely considered climate among the several constraints upon urban design. The layout of cities has in most cases been dictated, or almost accidentally created, by a series of mainly political, social and economic decision-making processes, often over many centuries. The reason for the neglect of climatic consideration has been partly the relative youthfulness of the science of urban climatology, and partly the relatively weak communication links that presently exist between climatology and planning. But faced with the exponential growth of the world's population and the accelerating pace of urbanization, it is clear that our cities must, where appropriate, be purposefully planned in order to optimize the environment of urban areas and avoid a series of structural and functional design failures. Climate is an essential element in this planning.’ (Chandler 1976, p. xiv)

In attempts to elucidate barriers hindering application of climate knowledge in planning, the differences between the two disciplines should be taken into account. Although urban climatologists and urban planners share interest in urban climates, there are important differences in their research interests, methodologies and means of presenting results (Mills 1999). Urban climate research covers a broad range of subjects, some of which have little applicability in planning and design. Notably, the aim of much research by urban climatologists is to elucidate processes responsible for climatic phenomena, while architects’ work and research are largely concerned with
practical applications. In addition, climate models sometime involve high
degrees of simplification in order to focus on specific issues. Such
simplification can limit practical applications of results, as seems to be the case
for findings of some studies on street canyon geometry (Erell 2008).

Despite continuous progress in the field of urban climatology in recent
decades, and growing awareness of the impact of urbanization on climate, the
application of urban climatology research has remained limited in practice
2008, Mills, Cleugh et al. 2010). Page (1968) noted three reasons why urban
planning practitioners’ may ignore urban climate research results: they may
consider them irrelevant, difficult to apply in presented forms, and/or
incomprehensible. In addition, through interviews with Swedish planning
practitioners, Eliasson (2000) identified five classes of explanatory variables.
Two of the classes (conceptual: lack of knowledge; and technical: a lack of
user-friendly tools) are associated with urban climatology, whereas the other
three (policy, organizational and market issues) are more connected to
planning practice. On this basis, she suggests that urban climatologist should
actively strive to:

1) improve awareness about urban climate,
2) enhance means of communication and argumentation
3) develop suitable tools and education for urban planners.

A pioneer of bioclimatic architecture, Olgyay (1963), who was also an
architect, contended that climate should be a core consideration in design,
proposing that the first and second stages in design should be ‘a survey of
climatic elements at a given location’ and evaluation of ‘each climate impact in
physiological terms’. However, publications by urban climatologists often
emphasize that urban planning is a highly complex and primarily political
activity, which is not necessarily informed by results of scientific research
(Eliasson 2000, Mills, Cleugh et al. 2010). Furthermore, Erell et al. note (2011,
p. 10) note that using climatic tools is not advisable for every urban design
project; their application should be limited to projects with clear goals,
validated knowledge support and a cost-benefit assessment in relation to
climate approaches. They further outline the following conditions to be
considered for more effective integration of microclimate in urban design:

- **Subsidiarity**: The final results of an urban planning and design process
  are outcomes of a multiple-level optimization process. It is highly
valuable if benefits of a particular approach are not necessarily limited to a unique policy required to achieve the desired goal. Subsidiarity is about finding solutions for a particular issue at the lowest possible planning level. If several approaches could be used to address a goal, those that could be applied in later phases of planning are preferable.

- **Economic viability:** recommendations by urban climatologists related to city planning are likely to have unknown financial consequences. Urban planning and design are driven largely by market preferences and economic constraints. For instance, the geometry of street canyon affects traffic capacity and the value of land lots along the streets. As noted by Reference, “any explanation for the relative lack of success in implementing climate related strategies in urban planning must therefore consider the lack of a practical framework to access their economic effects too.

- **Clear and immediate benefits:** Without quantitative measures that clearly show the effect of a proposed design in terms of urban microclimate, decision-makers may overlook climatic considerations. Thus, there is a need to develop adequately reliable predictive tools for evaluating climate-related objectives and solutions.

### 5.2. Design and the role of analysis

The previous subsection briefly described barriers to the application of urban climatology in urban planning and design (mainly from an urban climatologist’s perspective). Major highlighted barriers include differences between urban climatologists’ and urban planners’ research interests, methodologies and means of presenting results. Thus, one main recommendation to address the limited practical application of urban climatology is to provide relevant climatic information and guidelines in early stages of planning or design. However, a question this raises is whether availability of information on urban microclimate will ensure that a design proposal will meet climate-related goals such as provision of comfortable outdoor environments. Exploring characteristics of design and design disciplines is helpful for addressing this question, especially with regard to the role of analysis in design. Thus, while attempting to avoid excessive discussion of design theories, this section briefly introduces design methodology.

Design emerges from our need to change the environment we live in through physical changes. In other words, ‘design exists because the world around us
does not suit us’ (Gero 1990). Creativity is a core value for design and art. However, unlike art, design produces artefacts such as objects or buildings that must meet functional requirements, within certain frameworks of functional, socio-cultural and economic constraints.

Design differs from most other disciplines, in often having to address ill-defined or “wicked” problems (Buchanan 1992). An ill-defined problem is one for which there is insufficient information for a designer to perceive requirements clearly (Archer 1979). The concept of wicked problems was first introduced by Rittel and Webber (1973), who pointed out the societal nature of planning problems, in contrast to the usually ‘definable’, ‘separable’ and ‘tame’ characteristics of natural science problems (ibid, p. 160). Wicked problems have been described as: ‘ill formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values and where the ramifications in the whole system are thoroughly confusing’ (Buchanan 1992, p. 15). In the absence of adequate information, exhaustive analysis is difficult and finding a correct solution cannot be guaranteed. In coping with ill-defined problems, an important task for designers is to define and redefine them with regard to solutions that might emerge in their minds during initial phases of the design process.

The problem-solving strategies employed by designers also differ from those used in other fields, both natural sciences and humanities. These distinctions are illustrated by observations presented by Lawson (2005, p. 42) of psychology and architecture students who participated in design-like problem-solving activities under laboratory conditions. The task was to design a single-story building block using rectangular wooden pieces with faces coloured red or blue. Lawson observed clear differences between the strategies used by the two groups of students. He concludes that designers focus on producing satisfactory solutions rather than optimised solutions based on analysis (i.e. they are solution-focused rather than problem-focused). The problem-solving approach in design disciplines tends to be based on synthesis and aims at inventing new values that do not exist, whereas problem solving in science is more analytical, aiming at learning about what exists (‘how things ought to be’ and ‘how things are’, respectively, as noted by Simon (1996)). Further, time and cost constraints are more decisive in design disciplines: ‘the designer is constrained to produce a practicable result within a specific time limit, whereas the scientists and scholars are both able, and often required to suspend their judgments and decisions until more is known’ (Cross 2007a, p. 7). Thus,
experienced designers are skilled in producing satisfactory solutions in relatively short times, rather than employing prolonged problem analysis for optimization of results.

Other important elements of design processes are self-reflection and iteration. In a design process, self-reflection refers to designers “conversing” with the design concept, which may be in the form of a drawing or a model. The production of such a representation is not merely a way of communicating with others, but also a method for pursuing a line of thought, which enables the designers to discover problems and solutions. Self-reflection may take either of two forms in design ‘reflection in action’, that is the designer’s continuous reflection on the current understanding of the design problem and the soundness of emerging solutions, and ‘reflection on action’ in which the designer monitors the process rather than design subject (Lawson 2005, p. 299).

Analysis in design

‘…after a while one knows and accepts that the research into what makes good places to live will be endless, often without conclusion, and always value-laden. There comes a time when one says, “Well, I must take a leap. All of the experience has taught me something. It may be unprovable, but I think I know what a good place is”’ (Jacobs, Appleyard 1987, p. 112).

An early theorization of the role of analysis in urban planning can be attributed to the biologist and planner Patrik Geddes, who advocated comprehensive observation of city life as the basis for planning, as expressed by the notion ‘survey before plan’ (Geddes 1915, Çalışkan 2012). A key principle underlying his method was that planning must emerge from a diagnostic survey. In the 1960s, the design process became conceptualized under the influence of system thinking, which gave rise to the synthesis-analysis model of design methodology, which it portrays as sequences of activities starting from analysis. For instance, in an approach advocated by (Asimow 1962), the design process involves three phases: a feasibility study, preliminary design and detailed design. Each of these phases is composed of cyclic steps of analysis, synthesis and evaluation. In a similar vein, Markus (1969) and Maver (1970) mapped the design process in architecture, and suggested it consists of “analysis”, “synthesis”, “appraisal” and “decision” sequences at multiple levels (Figure 15) (Lawson 1997).
Levin (1966) proposed a similar map for urban design and town planning, defining the design process by a long series of sequences. His proposed model maintains the idea of design as a sequential process, in which an optimal solution is generated from a detailed procedure of information processing. With regard to the sequential conceptions of design, Lawson (2005, p.40) argues that ‘they seem to have been derived more by thinking about design than by experimentally observing it, and characteristically they are logical and systematic.’

It seems reasonable to state that design processes always include all or some of these sequences. Designers need to gather a design brief, make some preliminary analyses, generating one or more solutions, which are assessed in accordance with some implicit or explicit criteria, and communicate the design results with their clients. However, the idea that these activities take place sequentially and separately is much less convincing. In contrast to analysis–synthesis models of design processes, Hillier et al. (1972) emphasized the role of conjecture in design and proposed a conjecture–synthesis model. According to these authors, two activities are crucial for design: variety reduction and conjecture. When a design activity starts there is usually a number of solutions. These solutions will be then reduced by external limitations and the designer’s own cognitive map. Conjecture is conceptualization of possible solutions in

Figure 15. Map of the design process proposed by Markus and Maver (adapted from Lawson, 1997).
early design phases, which helps designers to understand problems in relation to relevant solutions (Cross 2007a). A development of the conjecture-synthesis model based on case studies and interviews with architects, the ‘primary generator’, has been proposed by Darke (1979), who identified a primary phase before conjecture, in which an idea or group of idea served as a starting point for design. Lawson also refers to an analysis of a series of architectural drawings by Rowe (1987), in which he detected ‘lines of reasoning which are based on some synthetic and highly formative design idea rather than on analysis of the problem.’

An overview of theories regarding design processes reveals a shift from analysis-led approaches to modelling design processes, articulated in works by Asimow (1962), Simon (1996) and Markus and Maver, towards solution-led models (Lawson 1997, Cross 2007a). In recent conceptualizations on design, problem definition and solution-finding are regarded as interactive activities, i.e. analysis, synthesis and evaluation occur in design processes, but not necessarily in sequences. Rather they occur through iterative feed-back loops that occur between different design activities until a satisfactory solution is reached that meets the initial design criteria. In this respect, analysis has an intermediary role in efforts to reach the final solution, which is significant to composing and articulating design patterns, but it is not the primary step or activity from which the entire design will emerge (Çalışkan 2012).
6. Summary of the papers

Paper 1: The problems of addressing microclimate factors in urban planning of the subarctic regions

Paper 1 offers an overview of challenges of climate-sensitive planning in subarctic cities. The paper is based on a literature review and interviews with planning practitioners working in the Boden, Gällivare, and Kiruna municipalities of northern Sweden. The literature review highlights problems associated with three focal aspects of urban planning in cold climates: urban design in cold climates, non-motorized transportation in cold climates and the impact of climate knowledge in planning.

Interviews with planning and design practitioners identified the following aspects specifically related to urban planning in cold climates:

- Design for Snow: Snow poses both challenges and opportunities in cold climates.
- Lack of basis for systematically working with climate aspects in planning.
- Little attention to climate factors in large-scale planning instruments, e.g. master plans.
- Little engagement in seeking and exploiting opportunities associated with cold climates in planning.
- Lack of awareness among local politicians about climate factors.

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2 Ebrahimabadi, S, Nilsson K L and Johansson C (2015) "The problems of addressing microclimate factors in urban planning of the subarctic regions" Environment and Planning B: Planning and Design 42(3) 415 – 430
The interviewees expressed widely varying ideas regarding what should be done and the achievable climate objectives at each urban level. Thus, to foster climate-sensitive urban planning, it is important to improve understanding of the climatic outcomes of planning decisions at various scales. Tools that can be used to address this issue are urban climate maps (UCMaps). UCMaps can be of analytical or recommendation type, presenting various kinds of climatic information, such as air flow, thermal and air pollution patterns. Examples of UCMaps that are particularly relevant for sites with cold climates include maps of temperature patterns, sunny and shady slopes and prevailing cold winds.

The difficulty of carrying out microclimate analysis in planning or design processes was highlighted in both the interviews and reviewed literature. The currently available tools for wind simulation in urban environments are too complex for routine use by urban planning practitioners. Thus, the user-friendliness of such tools for microclimate assessment should be improved (as noted by the interviewees), and ideally they should offer combined assessments of all the pertinent parameters.

The large snow falls in the subarctic region draw attention to both the potentials and challenges associated with snow in urban planning. Development of knowledge about relationships between urban forms, snow removal and snowdrifts would be helpful for planning practitioners. Urban morphological dimensions such as street profiles, plot occupancy ratios and block typologies affect both quantities of snow that need to be removed and the quality of snow removal activities, which can consequently affect the quality of urban life.

**Paper 2: Addressing comfort considerations in urban design practice**

Paper 2 explores how urban design practitioners address microclimate through studying submitted proposals for a large urban design project. The significance of urban microclimates for the quality of urban spaces has increased research on urban microclimates. One of the domains within this research field that has been considered in many publications is pedestrian comfort. However, the

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growth in research on urban microclimate and pedestrian comfort has not been accompanied by growth in practical application of the findings. Research on this relationship has provided insights onto the dimensions of urban climatology and urban planning that influence the application of climate knowledge in practice (Eliasson 2000, Mills 2006, Ryser, Halseth 2008). In extending these investigations, paper 2 focuses on another important issue, that is, the influence of urban design practice on addressing outdoor comfort. In following this objective, the study focuses on the role of comfort concerns in development of a large urban design project in a very cold climate.

The architecture urban design competition in for Kiruna urban transformation was held to obtain a strategy and vision for moving the city eastward as well as designing the structure of a new city centre. For this case study a mixed method was employed to gather data. The data encompassed verbal data (responses in semi-structured interviews), textual and visual data (reports and posters submitted to the competition).

The review of the proposals showed that contextual factors e.g. the arctic landscape, mine and existing city centre, were given key roles in the design narratives. In terms of outdoor microclimate, ensuring adequate solar access, managing snow in the urban environments and, (most importantly) provision of shelter from winds were prominent concerns in most entries. These objectives were chiefly justified through reference to simple climate design principles and visualized by schematic diagrams. Further, most of the proposals chiefly focused on microclimate conditions at the medium scale for buildings groups.

The interviewees’ responses highlighted the key issues related to the position of microclimate in urban design. These included the designers’ perceptions, means of justification, key knowledge sources and the importance of microclimate in relation to other design objectives. The participants referred to microclimate as an integral part of all design acts, self-evident and a quality that should not be neglected. It was also argued that microclimate aspects give design clues. The justification of design with regard to microclimate was based on previous work experience, simulation, climate design principles and personal life experience. Previous design experience and simple design principles appeared to be more influential than detailed computer modelling. Some argued that simulation tools are complicated and mostly applied simpler principles. The influential knowledge sources for urban designers were built projects and works by well-known architects, particularly Ralph Erskine.
participants had not found that responding to microclimate concerns conflicted with other design criteria. The responses implied that the designers considered microclimate concerns part of the challenges that arise in all design projects.

The paper concludes by discussing the role of urban designers’ confidence, design process and lack of conceptual knowledge in the (low) application of urban climatology.

**Paper 3: Microclimate assessment method for urban design – a case study in a subarctic climate**

The aim of this paper was to meet the need identified in paper 1 for a simple microclimate assessment tool that could be used in early stages of urban design projects. Thus, the presented approach focuses on the performance of urban forms in terms of providing outdoor environments with comfortable climatic conditions (within inevitable constraints). The introductory parts of the paper present a brief account of comfort assessment for outdoor environments, and introduces thermal comfort indexes such as the Physiological Equivalent Temperature (PET) and Standard Effective Temperature for outdoor (OUT_SET*). In addition, wind comfort analysis criteria are introduced.

Drawing on a method proposed by Brown and DeKay (2001), the presented approach encompasses wind comfort analysis and microclimate assessment based on solar access and wind velocity measurements. Solar access was analysed on three specific dates: 21 December, 21 March and 21 June (the winter solstice, spring equinox and summer solstice, respectively). For assessing wind comfort criteria in the NEN 8100 code proposed by the Netherlands Normalisation Institute are applied (Willemsen, Wisse 2007) (See chapter 2, wind comfort).

The method was applied to analyse one of the urban design proposal for Kiruna’s new city centre. Wind speed and solar access were simulated using a CFD program (Autodesk® Simulation® CFD 2015) and Autodesk® Ecotect®. The results from the simulations were then overlaid to produce combined microclimate maps for three specific dates. The maps illustrate

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4 Ebrahimabadi S, Johansson C, Rizzo A, and Nilsson K L (2015) “Microclimate assessment method for urban design- a case study in subarctic climate”. (Received with comments from Urban Design International. A revised version has been submitted)
relative microclimate differences between areas in the proposed project based on combinations of wind/lee and sun/shadow conditions.

The outcomes showed that microclimate conditions would be favourable in only a small proportion of the studied area at the winter solstice and spring equinox, but in nearly 50% of the area at the summer solstice. Substantial correlation was found between spatial distributions of calculated OUT_SET* values in the study area at the summer solstice and the microclimate assessment map.

The analysis of the design proposal for the new town centre in Kiruna suggested that ensuring solar access in east–west orientated streets is challenging in subarctic cities. Solar access is particularly challenging in city centres, the usual locations of the main public spaces such as city squares and the main commercial streets, where planning for comfort is a high priority. However, location potentials and higher land prices in central areas often give rise to design schemes that include taller buildings and higher plot occupation ratios in centres than in other areas of cities.

The method is intended to offer simple and representative microclimate evaluations. Urban design practitioners are more familiar with wind and solar analyses than thermal comfort indices. The aim of the presented method was not to include thermal comfort measurement directly in the design. However, as thermal comfort is strongly influenced by solar radiation and air flow, it can identify different thermal zones in outdoor environments.
7. Synthesis and conclusions

Incorporation of microclimate factors into urban design is influenced by various factors, both internal and external to urban design practice. The literature on the use of urban climate knowledge in urban design has given high importance to the problems with knowledge transfer between urban climatology and urban design (Mills, Cleugh et al. 2010, Eliasson 2000, Erell, Pearlmutter et al. 2011). Without ignoring the importance of these problems, the research underlying this thesis focused on current incorporation and understanding of urban climatology by urban design practitioners, to investigate possible barriers embedded in the practice. Since the research focused on cases with subarctic climates, the answers to the research questions are most specifically related to processes in cold climates with regard to:

- Local planners’ perspectives: distinctive aspects of subarctic climates to consider when incorporating microclimate factors into urban design with regard to the experience of local planners;
- Designers’ attitudes: urban designers’ views of outdoor microclimates and means of addressing them in the design process;
- Integrating comfort assessment: means to assess comfort of planned outdoor spaces in urban design projects based on wind conditions and solar access.

These studies are presented in detail in the appended papers. Answers to the research questions, synthesized from findings presented in the appended papers, are provided in the following sections.

7.1. Question 1: What are the barriers to integrating climate factors into urban design in a subarctic climate?

The studies reported in papers 1–3 revealed, to various degrees, several challenges associated with addressing microclimate factors in urban design. Some of these challenges are context-related and some have general characteristics. The findings showed that both designers (paper 2) and the local
planning practitioners (paper 1) regard subarctic climates as having distinctive implications for urban planning and design. Two particular features of these climates, the extreme cold and prolonged snow cover, have heightened local planners’ awareness of the impact of climate on urban life. Nevertheless, as outlined below, several barriers hinder incorporation of urban climatology into their practice, including: design-based, attitudinal and organizational, conceptual and technical issues.

**Design-based issues**

High latitude cities with subarctic climates pose several challenges for urban designers. Local planners and urban design practitioners highlighted the significant aspects of this climate for design. Because of the extraordinary climate, failure to consider microclimates during planning will have starker consequences than usual for public spaces (paper 2). Controlling wind, using snow in the urban environment, applying design to improve snow removal, controlling snowdrifts, the generally low sun elevation and risks of overshadowing were among the significant design challenges highlighted. In terms of outdoor comfort, controlling wind was shown to be a critical concern for practitioners (papers 1 and 2). However, attempts to do so mainly involve use of simple climate design principles and work experience, and are rarely based on detailed wind analysis (Paper 2). In Kiruna’s urban design competition, participants consisted of international firms of various scales and the competition’s subject and scale offered opportunities to address microclimate-related issues from an early design stage. Nevertheless, the teams mainly addressed microclimate factors, (particularly wind) by climate design concepts that are commonly used in practice.

The importance of facilitating snow removal through design was raised in the interviews (papers 1 and 2), and addressed in some of the design schemes submitted to the competition. However, there is a lack of suitable knowledge sources about the relation between urban form and snow removal (Paper 1), so related design efforts emerge primarily from creativity, intuition and personal experience.

The findings also show that large seasonal variations in the high-latitude subarctic climate offer design opportunities, which are not always sufficiently recognized. These include the abundant snow and ice in the winter, and the long summer days. Snow and ice provide numerous opportunities for recreational activities and the creation of attractive public spaces in cold climates. Other attractive features of high latitude cities are the long days and
the possibility to exploit direct daylight from the north (if obstacles imposed by the low sun elevation in high latitudes, particularly in late afternoon hours, can be overcome)

The low sun elevation at high latitudes is a major concern in the design of outdoor spaces, which (together with wind) complicates provision of outdoor comfort. The problem is particularly relevant for east-west oriented streets during the late winter months (March and April) in these environments (Paper 3). However, analysis of solar access during these critical months in early design stages can help designers to modify street geometry and building volumes to improve solar access and outdoor microclimates.

Attitudinal and organizational barriers
The importance of attitudinal factors in the incorporation of urban climatology into urban design was emphasised by the local planners when they discussed the lack of support from the local politicians for a climate-oriented approach in planning. Although the local politicians are aware of some climate-related dimensions of urban planning and design, they rarely prioritise associated issues (paper 1). Hence, planners feel powerless to pursue climate-related objectives in planning. The attitudes prevailing among the local politicians about the subarctic climate tends to focus on difficulties posed by the subarctic climate for planning, for example the need for extra parking in the city centre or the high costs of snow removal operations, whereas little attention is paid to the opportunities it provides for social life and the local economy. The local planners also have a significant role to play in providing support for pursuing climate objectives in their planning activities, particularly when developing new projects. On the other hand, the municipal planners can play a significant role in building local politicians’ awareness and understanding of climate-related opportunities and challenges, particularly when new politicians are elected. The attitudinal barriers are also related to collaboration between planners in municipal planning. Some of the participants in the stage 1 expressed that they had felt alone in pursuing climate aspects in planning, and had experienced very little engagement from other colleagues (paper 1).

Conceptual and technical shortcomings
The interviews with local planners (paper 1) and urban designers (paper 2) revealed a broad range of understandings about planning-related aspects of climate amongst the practitioners. They were aware of various aspects of microclimate that are relevant in urban planning, but lacked a conceptual basis
connecting climate objectives at different scales. The perception of climate in urban planning among the local planners related mainly to seasonal aspects of climate, e.g. handling snow and ice, and to a lesser degree, outdoor comfort.

Urban designers manifested confidence in their knowledge for dealing with microclimate-related aspects of urban design (paper 2). Their responses in interviews suggest that they see the extraordinary climate of the subarctic region as a design clue, which can be addressed by applying creativity and intuition in design, and generally rely on descriptive design principles to design for outdoor comfort. Thus, designers’ knowledge about urban microclimates is largely based on a set of experimental and descriptive rules that can be quickly used in design rather than having scientific or analytical foundations.

Conceptual shortcomings are concerned with the lack of basic knowledge which can guide planners and designers in understanding the relations between different aspects of urban microclimate and urban form. Such knowledge enables planner and designers to recognise the implications of planning and design decisions on urban microclimate. It is particularly important when deciding on the use of climate design principles, analytical tools or the need for consultation with urban climate experts.

The need to develop suitable tools and methods for integrating consideration of urban climate in urban design has been addressed in the literature (Mills, Cleugh et al. 2010), but little published information pertaining to planning and design in cold climates is available. The interviews with the local planners (paper 1) illuminated several particular aspects of subarctic climates that require knowledge development. One is the relationship between urban form and snow, which is a crucial concern for design in cold climate, but more research is needed on effects of urban morphological parameters such as density, occupation ratios and street geometry on snow drifts and removal.

### 7.2. Questions 2: How do urban design practitioners address outdoor comfort in design processes?

The nature of urban design affects incorporation of climate knowledge into practices of urban designers. From a technical-rationalist view, urban design is a linear process in which design results from analysis of facts to find an optional solution (section 5.2). In this respect, urban microclimate analysis should be a fundamental element of the design process and basis for the final product of the design process. However, the interviews with the urban designers (paper 2) presented a different picture. Their responses suggest that most of them
consider microclimate to be an important part of the design context, especially in subarctic climates, as there will be severe consequences if designers fail to consider it appropriately. Nevertheless, they tend to see the microclimate as a design clue, which may influence designs, or an opportunity from which a design concept can emerge, rather than as an essential foundation of design. Whilst the practitioners emphasised the importance of microclimate in urban design, interviews and the review of proposals did not suggest the existence of a systematic approach to microclimate factors within design processes. The review of proposals (paper 2) revealed that some (but not all) of the proposals took microclimate into consideration, and both the scope and scale of microclimate analyses varied widely among them.

The literature on use of urban climate knowledge in urban design suggests that urban climate knowledge has a low impact in urban planning and design. Urban designers, on the other hand, are confident about their professional capability to address climate issues in design (paper 2). They consider climate aspects as natural and inevitable aspects of planning and design. While this signifies a positive attitude towards considering climate in urban planning and design, characteristics of urban design affect how climate issues are addressed in urban design. These include: the justifying mechanisms, knowledge sources, nature of the design process, designers’ confidence about their knowledge (paper 2).

Urban design practitioners mainly address comfort in design by applying simple climate principle and/or through employing design concepts which include microclimate solutions. They rarely use quantitative analytical methods during the design process, relying instead on simpler design principles and guidelines. This approach accelerates and reduces the complexity of the design process, and avoids the possibility that different kinds of more sophisticated analyses might provide conflicting results that are difficult to reconcile. For example, a certain building height and built ratio might be desirable for a design because it ensures a higher density preferred of other reasons in a given area, but adversely affect both wind and solar radiation in neighbouring outdoor spaces. One example from the competition outlined a cluster of buildings placed around a central open space, with the height of buildings increasing from the centre to periphery of the cluster (paper 2). This concept aimed to answer several design objectives including creating a meeting place with sense of enclosure, sheltered from winds and with a good degree of direct sun access due to gradual building height changes. In this respect, a design
concept that is associated with several design goals is desirable. Such design concepts are present in some of the entries to the Kiruna urban design competition. With respect to outdoor microclimate, reliance on simple climate principles entails uncertain outcomes that can have severe consequences in extreme climates.

The incorporation of microclimatic considerations in urban design is also influenced by the knowledge sources used by urban designers. According to the interviewees, the main sources of learning and inspiration for architects and urban designers are built projects and works by other architects. Ralph Erskine is a particularly influential architect due to his interest in designing with sensitivity to the local climate. The design language is predominantly visual and designers are most accustomed to learning and communicating their ideas through drawings and illustrations (Lawson 1997) or by visiting and experiencing an existing building or urban space (paper 2). Thus, publications on urban microclimates by urban climatologists receive little attention by the designers for several reasons. Scientific publications are mainly circulated in academia and rarely accessed by design practitioners. Furthermore, few of these publications are oriented towards practical utility. Thus, it is necessary to translate urban climate knowledge into design guidelines and tools that facilitate transfer of climate knowledge to urban design practice.

Urban climatologists see a considerable need to improve the application of urban climate knowledge in urban planning (section 5.1). The interviews with local planners (paper 1) and urban designers (paper 2) suggest that practitioners have a different perception about whether microclimate has been adequately addressed in planning. Thus, two explanations for this discrepancy can be extracted from the interviews. Firstly, planning practitioners consider that urban projects involve complex processes, and the way urban microclimate is currently incorporated into planning and design (via practitioners’ experimental knowledge) is adequate because it does not add to the complexity of planning or increase expenses. In this regard, attempts to address climate-related issues more deeply might lead to imbalances between various matters that should be considered in a planning project (paper 1). Another explanation relates to the practitioners’ confidence in their professional capabilities in addressing microclimate aspects, which makes them reluctant to collaborate with experts from other disciplines. More specifically, design practitioners (architects and urban designers) consider climate knowledge to be part of the core expertise that they apply in all projects. A main pillar in architects’ identity is holistic expertise in both aesthetic and technical aspects.
(Cohen, Wilkinson et al. 2005, Tøsse 2014), and the architects’ belief that they have holistic expertise was clearly reflected in some of the interviews. This in turn affects urban design practitioners’ responses to microclimate concerns, (regarding them as within the scope of their professional expertise, rather than aspects that may require help from experts from other disciplines to tackle).

7.3. Question 3: How can wind and solar considerations be integrated into the design of urban spaces?

Developing tools and methods that assist practitioners to analyse and predict microclimates is crucial for improving the application of climate knowledge in urban planning. Such tools and methods are particularly important for designing in extreme climates, where failure to consider environmental comfort may have severe consequences for life in outdoor environments. The interviewed planners (paper 1) expressed concerns regarding urban designers and architects deploying urban design concepts, e.g. dense small-scale urban schemes, without considering the local climate of subarctic cities. The examples of climatically unsuccessful designs provided by the local planners were mainly related to unsatisfactory consideration of wind and snow in urban environments. Urban design practitioners primarily rely on simple climate design principles to address comfort in design proposals. Such principles are helpful for simplifying design processes, but not for ensuring that a proposed design will have a favourable microclimate impact.

With the aim to improve use of tools for analysing microclimate in design processes, a method intended to help designers incorporate consideration of outdoor comfort in design was outlined and applied in a case study from Kiruna. Such a method should help designers to assess effects of design features such as building placement and volume, outdoor landscaping and dimensions, and orientations of streets on outdoor microclimate. As outdoor comfort is the focal concern of this method, understanding the nature of physiological thermal comfort is a crucial foundation. Most thermal comfort indices were initially developed to assess indoor climates, although some are also applicable for assessing outdoor comfort, such as PET and OUT_SET* (Erell, Pearlmuter et al. 2011, p.128). Estimation of PET and OUT_SET* that are based on the energy balance equation of the human body, requires data on air temperature, relative humidity, radiation, air velocity and human-related parameters of metabolic rate and clothing insulation level. These data are usually obtained from meteorological stations and field measurements for
existing urban areas. For design proposals, computer simulations and meteorological data may be used to gather the required information. Assessing outdoor comfort is a complicated task for urban design practitioners with regard to the required data and computer tools needed for data simulation and calculation of comfort indices. Beside these difficulties, aiming to create optimal thermal comfort conditions has limited practical values when considering constantly fluctuating outdoor microclimates and the multiple objectives of urban design projects. In subarctic climate settings, the extremely low temperatures and solar radiation during large parts of the year are far from physiologically comfortable conditions. Hence, estimating thermal comfort in an exact quantitative sense by using thermal comfort indices has limited practical value for most urban design projects, especially in subarctic climates. Instead a method is proposed for addressing this issue that is based on few climate parameters that significantly influence thermal comfort and can be modified effectively by design.

In the proposed method, comfort is addressed in two ways, one relating to wind comfort and one to thermal sensation by combined consideration of wind conditions and solar access, which can be respectively simulated by readily available CAD and CFD computer programs. With regard to thermal sensation, the method estimates relative microclimate differences within a given urban space based on combined analyses of solar access and wind speed. This is done by overlying images obtained from solar access and wind speed analyses (Figure 16). Wind and solar assessments are conducted for three key dates: the winter solstice, spring equinox and summer equinox. By overlaying the results from the two analyses, a map is produced that shows variations in wind/lee and sun/shadow patterns in the studied urban space.
The method produces two types of results: quantitative and visual. The quantitative results include areal ratios of different combinations of wind and solar conditions. These results can be used to compare design alternatives in terms of ratios of desirable microclimate conditions. They can also be used to compare microclimate variations in a given proposal. The visual results are maps showing the spatial distributions of different microclimate combinations in a studied urban space, either proposed or existing (Figure 17).

Figure 16. Workflow of the proposed method.
Comparisons of results from microclimate assessments with OUT_SET* thermal index calculated (for summer solstice) using simulated data (Paper 3) showed a high degree of correlation between spatial distributions of desirable microclimate combinations (sun and lee areas) and areas with relatively high OUT_SET* values. The correlation provides support for use of the microclimate assessment method as a means to identify thermal comfort variations in urban spaces. This method have proved useful for assessing relative differences in thermal comfort and hence addressing two key issues: the difficulty of calculating thermal comfort values for urban design practitioners and the limited value of aiming for ideal thermal comfort conditions.

7.4. Conclusions

The aim of the research, to investigate difficulties of addressing outdoor, climate comfort in urban design, was pursued in three stages, with different main foci. The first stage consisted of interviews with local planners, aimed at elucidating key barriers hindering the incorporation of climatic factors in urban planning in subarctic regions. Key findings include the identification of barriers related to design-based, attitudinal, organizational, conceptual and technical issues. The design-based issues relate to context-related difficulties for comfort design in cold climates, namely low sun elevation and snow. Attitudinal and organizational barriers include the neglect of opportunities and challenges associated with urban liveability in cold climates, failure to exploit local knowledge and a lack of engagement among planners and local politicians.
Conceptual and technical barriers are related to a lack of climate knowledge among practitioners and the aspects pertain to methodology and principles to be used in design, particularly about wind, comfort and snow in urban environments.

Research in the second stage centred on urban design practice. The findings show that urban design practitioners predominantly rely on basic climate design principles and rarely use analytical tools in design. In terms of knowledge sources for urban designers, existing urban environments, works by other architects, architects’ own work experiment and everyday life experiences are influential sources of learning and inspiration. The third stage was concerned with methods to integrate outdoor comfort assessment into design. As precise measurement of thermal comfort has little practical value in the focal settings, a method was developed based on wind comfort and combined wind and solar conditions analyses. The method can be used for evaluating design alternatives and in detailed design phases to facilitate decisions regarding elements such as vegetation and urban furniture.

The reported studies in chapter ‘theoretical perspective’ correspond to problems related to diverse applications of urban climate knowledge in urban planning and design, of which, pedestrian comfort is the focus of this thesis. The findings of this study, particularly paper 1, extends the research reported in section 5.1, but more specifically to the subject of study i.e. environmental comfort in cold climates. For instance, knowledge based issues (the need for knowledge development about snow), attitudinal (neglecting the potential of subarctic climates for liveability) and organisational (lack of engagements with other planners) are in line with the reported studies but more specific to climate-sensitive design in subarctic climates. Besides, relations between the two fields (urban climatology and urban planning), theories on design and design methods (section 5.2.) offer insights into the role of design process on the integration of other knowledge sources (e.g. urban climate into urban design). The process of urban design is complex and often involves multiple actors and is confined by temporal, fiscal and regulatory constraints. In the core of this process, designing the physical environment is conducted by a single designer or team who provide solutions for the design. The design process in this context refers to conceptual design, i.e. the activity of designing the physical form conducted by individuals or teams of designers in the course of developing an urban design project.
The remainder of the section presents the conclusions based on three stages noted above, regarding needs to develop more knowledge of key aspects of subarctic climates to support urban design in cold climates and to improve use of instrumental knowledge on environmental comfort (climate design concept and analytical tools) in urban design.

**Urban design for environmental comfort in cold climates**

The appended papers highlight three issues that are crucial for improving environmental comfort in cold climates and can be influenced by urban design:

- provision of sheltering from wind,
- maximising solar access and,
- managing snow in outdoor environments.

With regard to wind, due to the prolonged periods of cold temperature in subarctic climates, the convective heat loss caused by wind is a major source of discomfort in all seasons and therefore wind-sheltering must be prioritized, and solar access has significant impact on the use of public spaces due to its contribution to thermal comfort as well as its cultural significance in the Nordic context (Thorsson, Honjo et al. 2007). Ensuring direct solar radiation for outdoor environments is challenging due to the low sun angles in high latitude cities. Thus, if ensuring solar access is a major design objective large unobstructed spaces between buildings will be needed, but this will probably be impracticable in central areas of cities (paper 3).

Design to enhance snow conditions in urban environments involves tackling aspects of physical discomfort related to snow and exploiting snow-related possibilities for outdoor activities. Discomfort dimensions of snow, such as snowdrifts and excessive needs for snow removal activities are relatively well known. Compared to wind and sun, little research has been conducted about snow in urban environment. There are some design guidelines available for snowdrift for simple urban settings (e.g. in Swedish: Glaumann, Westerberg 1988). In addition a few publications (cited in Paper 1) have evaluated the utility of CFD models for predicting snowdrifts. Use of CFD for prediction of snowdrift in complex urban environments can provide accurate results (Tominaga, Okaze et al. 2011). However, in contrast to use of CFD for wind simulation, technical details of CFD modelling for snowdrift are less researched and documented. As such, the use of CFD for predicting snowdrift in urban
environment is yet difficult for practitioners, even for those familiar with CFD modelling.

Besides discomfort aspects of snow, its aesthetic values and potentials for environmental stimuli and recreation also require more research. In this respect, experimental design-based research has potential for creating and testing new concepts. An example is given in (Figure 18) that depicts a preliminary sketch of a street profile highlighting the potentials for transport and recreation provided by the seasonal variations in subarctic climates. The proposal is concerned with using the large amounts of snow available in subarctic cities during much of the year to provide cross country ski and snow mobile tracks (bottom drawing). The figure also illustrates the utility of sketching to define problems and find alternative solutions.

Figure 18. Design as a means to investigate creative ways of using snow in urban environments. The figure shows schematic road sections in summer (top) and winter (bottom). The lower section shows a concept for accommodating cross-country ski and snow mobile tracks parallel to car areas in the street (adapted with permission from SWECO Architects).

Cross (2007a, p. 37) describes the role of design sketches as assisting ‘problem structuring through solution attempts’. The use of design in research, or research-by-design has been a contested idea which is gaining growing
acceptance as a valid research method for disciplinary and trans-disciplinary research (Lenzholzer, Duchhart et al. 2013, Doucet, Janssens 2011, Forsyth, Crewe 2006).

**Reliance on simple climate design principles**

It has been shown that when addressing outdoor comfort in urban design, practitioners tend to rely on climatic design principles and seldom employ analytical tools. Several instances of design concepts based on simple climate design principles were found in the entries submitted to the Kiruna urban design competition. These principles are simple design concepts for estimating the microclimate performance of built environments at various scales. Analytical tools in this context are methods for simulating microclimatic variables in a proposed or existing environment, such as wind speed or thermal sensation in an outdoor urban environment.

Provision of sheltering from wind has been an important aim in the proposals submitted to the Kiruna competition. Most of the participating teams used design rules of thumbs such as avoiding tall buildings or clustering buildings to form sheltered inner spaces (paper 2). Despite the growing availability of computer tools that allow detailed analysis with acceptable accuracy, urban design practitioners rely mainly on climate design concepts when addressing wind comfort. An example given by the interviewees in stage 2 was that a street network built on a 90-degree grid and/or long straight streets would increase wind speeds and cause discomfort, whereas a grid network with irregular geometry would create a calmer wind environment. However, such a principle is ambivalent, and does not clarify the relationship between physical dimensions of streets and wind strengths. Similar instances of reliance on crude design concepts can be found in relation to other urban design issues. For instance, the ‘compact city’ concept has gained much ground in urban design as an urban form concept with high potential for urban sustainability, particularly as a means of reducing car travel in urban areas. However, scepticism has been expressed regarding both the real effect of this concept on urban travel (Mindali, Raveh et al. 2004) and the means to implement it (Williams 2005). Such questions and scepticism also apply to the use of crude design concepts in relation to wind comfort. Hence using such concepts can be misleading and is likely to have uncertain outcomes.

**Partial adoption of climate design principles**

Due to the strong influence of urban form on wind and solar conditions, several design guidelines have been developed to provide practitioners with
simple design principles (e.g. see Glaumann, Westerberg 1988, DeKay, Brown 2013, Lenzholzer 2015). A problem with using climate design principles for incorporating microclimate factors in urban design is that they might be applied separately or partially without considering their interactions. For instance, in cities located at high latitudes ensuring solar access in east–west oriented streets requires a large width to height ratio. At latitude 64 °N, a street width to height ratio (H/W) of nearly 0.45 is required to ensure solar access in March in an east–west oriented street (paper 3). However, for a symmetric street canyon, such H/W is likely to generate an ‘isolated roughness flow’ (Oke 1978, p. 267) when winds blow normal to the street direction, and thus very little wind shelter will be provided by the built environment. Therefore, relying on separate design principles without considering their interactions can result in conflicting outcomes. Another problem is that climate design principles are partially employed in design. As such, it is essential for designers to have a basic understanding of the urban microclimate that can prevent the adoption of conflicting or incomplete approaches in design for outdoor comfort. This emphasises the need for clear goal-setting and taking a ‘comprehensive approach to problem solving’ (Erell, Pearlmutter et al. 2011, p. 144).

Balanced application of climate design principles and analytical tools

Theories on design and design method, which are briefly presented in the Chapter 5, provide insight into practitioners’ reliance on climatic design principles. To summarize, these theories characterize design as a solution-led (rather than analysis-led) process, derived from organizing principles or ‘primary generators’, which relies on abductive reasoning and progresses through self-reflection loops (Darke 1979, Schön 1983, Lawson 2005, Cross 2007b). Primary design concepts provide the starting points of design, which are elaborated by the designer(s) through iterative testing and modifying activities until the design goals defined in the beginning of the design process are met.

Based on this understanding of design processes, both types of reasoning about the microclimate performance of urban form (climate design principles and analytical methods) are useful, but for different design phases. The design principles and simple rules of thumb are more effective when design initiators are about to emerge. During this phase, simple how-to rules can be quickly integrated in the generation of initial design concepts. In contrast, the tools for analysing microclimates have little applicability when initial concepts are
emerging. When primary design concepts are taking shape in the initial stages of urban design projects, many of the issues affecting outdoor comfort (e.g. buildings orientation and heights and street profile geometry) cannot be precisely determined. It is not uncommon in the beginning phases of the design that some aspects of design are left undetermined in order to maintain flexibility for later phases when there will be enough information to decide. Therefore, analytical methods cannot be used effectively due the lack of details required for analysing microclimate factors. However, such tools can be highly valuable when the concepts are more developed and should be tested and modified.

A major identified problem is that practitioners currently rely heavily on simple climate design principles, as accurate predictive design tools. This suggests that improvements in addressing outdoor comfort in urban design requires a more balanced application of climate design principles and analytical methods for addressing microclimate issues. This does not imply that use of climatic design principles should be rejected, but that climate design principles and analytical tools should be judiciously applied in appropriate design phases and at appropriate scales. This would help designers and stakeholders to be better informed about the microclimate performance of design projects.

7.5. Suggestions and final considerations

In order to create such a shift in practice as outlined above, the following suggestions are proposed:

- **Clear goal definitions**: in order to achieve microclimate goals, clients must clearly defined microclimate goals in design projects through measurable objectives. This issue was illustrated in the Kiruna design competition as the brief emphasized the climate’s importance, but without further clarification. Clarity is especially important in the design of outdoor environments, due to the lack of standards and legal instruments regarding the quality of outdoor microclimates in comparison to building design.

- **Knowledge improvements**: this objective has been stated in the relevant literature, with regard to better communication of climate knowledge. The issue can be addressed in university curricula for urban design (i.e. via design courses with a particular climate focus) as well as courses for professionals. It is important for practitioners to develop overall understanding of relations between urban forms and
microclimates at different scales, as well as design tools, i.e. scientifically robust climate concepts and analytical tools. There is also a need for more profound interdisciplinary approaches in urban design education (paper 2) and practice that encourage collaboration with experts in other disciplines, and exploitation of technical and conceptual advances in other disciplines for design of cities.

- **Theory building based on microclimate research:** normative theories on urban form often emphasize the significance of comfort in outdoor environments. However, these theories often remain discursive, with no rooting bases in evaluative measures for comfort. Incorporating objective, scientifically robust microclimate measures in theories on urban form would help to make environmental comfort an indigenous value within the discipline, rather than an annex borrowed from urban climatology. This requires a clear understanding of the variables being measured, and how they influence the functions of spaces.

- **Improving communications between research and practice:** the interviews with design practitioners (Paper 2) showed that built projects, existing environments and works by known architects are the influential sources of information for designer practitioners, whereas research publications have little influence in practice. The outcomes of scientific research, even those intended to be used in practice, are mainly communicated among researchers through academic journals and conference proceedings. These are very seldom read by professionals. Thus, it is not always clear how to find practically oriented knowledge about outdoor comfort. So it is not only essential to prepare research results in formats that can be easily comprehended and applied in practice, but also to distribute them through conferences and media that are accessible for practitioners. Books, open access journals and on-line guidelines have the potential to reduce the communication gap.

### 7.6. Future studies

The study presented in this thesis is primarily an explorative investigation of microclimate considerations in urban design, with a focus on cold climates. The first stage of the study identified areas for knowledge development in relation to planning and design in subarctic climates. Stage 3 of the study showed the difficulty of ensuring solar access for public spaces in high latitudes.
Some aspects of the subarctic climates, such as low sun elevation and excessive snow are unusual to many urban design practitioners. Thus, research into creating design guidelines for such areas will have great practical value.

Studies of street canyon geometry usually focus on the height to width ratio (H/W) of streets in relation to pedestrian thermal comfort. In subarctic climates, the large amount of snow adds another dimension to the design of the street. It would be beneficial to research street geometry in high latitude cities by considering requirements for snow removal, wind sheltering and solar radiation.

Experimental design based research together with simulation methods for wind and thermal comfort could be undertaken to investigate how snow can be used to improve outdoor comfort during winter in subarctic climates.

It is not uncommon to focus on winter when considering the outdoor environment in subarctic climates. Further research could explore urban design possibilities for improved outdoor comfort during the snow free periods.
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Appendices

Appendix 1- questions of interview with urban planners (paper 1)
Appendix 2- questions of the interview with urban designers (paper 2)
Appendix 1- questions of interview with urban planners (paper 1)

Samhällsplanering i krävande klimat [Urban Planning for cold climate]

Inledning [Introduction]
Vilka är dina arbetsuppgifter och ansvarsområden? [What are your duties and responsibilities?]
Vilken är din bakgrund? (utbildning) [What is your background? (Education)]
Hur länge har du jobbat? [How long have you worked?]
Hur arbetar du med planering i kallt klimat? [How do you work with planning for cold climates?]
Vilka övriga inom kommunen arbetar med planering i krävande klimat? [Who else within the municipality works with planning for cold climate?]

Synen på planering i kallt klimat [Views on planning in a cold climate]
Behöver kallt klimat behandlas särskilt i planering (trafikplanering, bebyggelseplanering)? Hur? [Does cold climate need to be specifically addressed during the planning process (traffic planning, physical planning)? How?]
Anser ni att krävande klimat har en särskild effekt på resvanor och val av transportslag? Berätta [Do you consider that cold climate has a particular impact on the travel behavior and choice of transport? Explain]
Anser du att din organisation bedriver ett kontinuerligt och systematisktarbete när det gäller planering i krävande klimat? [Do you think that your organization conducts continuous and systematic work in the planning for cold climate?]
Om du jämför klimatfrågan inom planering av krävande klimat med en annan planeringsfråga, vilken roll (hur stor roll) har klimatet i jämförelse? [If you compare the climate issue in the planning of harsh climates with another planning matter, what role (how big of a role), does the climate have in comparison?]

Planer och program för planering i krävande klimat [Plans and programs for planning in cold climate]
Har du i ditt yrkesutövande arbetat med särskilda program för planering i krävande klimat? [Have you in your profession worked with special programs for planning for cold climate?]

Har ni särskilda säkerhetsprogram för planering i krävande klimat? Vilka? [Do you have special (traffic) safety programs for planning in harsh climate? What kind?]

Har ni särskilda vinterväghållningsprogram? Vilka? [Do you have special winter road maintenance programs? What kind?]

Har ni särskilda belysningsprogram för planering i krävande klimat? Vilka/hur? [Do you have special lighting programs for planning in cold climate? What kind/ how?]

Andra program? Vilka? [Other programs? What kind?]

Har ni särskilda program för att jobba med tillgänglighet i krävande klimat? [Do you have specific programs to work with accessibility in cold climates?]

Har ni särskilda program för att jobba med attraktivitet i krävande klimat? [Do you have specific programs to work with attractiveness in cold climate?]

Hur behandlas planering i krävande klimat i översiktsplanen, fördjupningar av översiktsplaner och detaljplaner? När kommer planering i krävande klimat in i planprocessen och i vilka sammanhang? [How is the planning of the cold climate dealt with, in the comprehensive plan, detailed comprehensive plans and detailed plans? When do the climate considerations come into the planning process and in what context?]

Arbetar din organisation med planering för särskilda människor eller grupper i planering i krävande klimat? [Does your organization work with planning for peoples with special needs in planning for cold climate?]

Anser du att befolkningen efterfrågar planering som tillgodoser det särskilda förhållandena i krävande klimat? [Do you think that people are demanding planning that meets the specific conditions for cold climates?]

Anser du att byggföretag, fastighetsägare och exploateror efterfrågar planering som tillgodoser det särskilda förhållandena i krävande klimat? [Do you believe that construction companies, property owners and developers are demanding planning which meets the specific conditions of cold climates?]

Identifierade problem [Identified problems]
Vilka brister och problem för planering i krävande klimat finns i din organisation, enligt din uppfattning? (trafikplanering och bebyggelseplanering)

[What shortcomings and problems of planning in cold climate exist in your organization, in your opinion? (Traffic planning and physical development)]

Kunskapen kring planering i kallt klimat [Knowledge of planning in a cold climate]

Finns frågor som rör planering i krävande klimat i det kontinuerliga arbetet i din organisation? Den politiska agendan? [Are issues related to the planning of cold climate considered in routine work of your organization? In the political agenda?]

Anser du att du och dina kollegor har tillräcklig kunskap om planering i krävande klimat? [Do you feel that you and your colleagues have sufficient knowledge of planning in harsh climate?]

Var hämtar ni kunskapsstöd (vilka dokument el dyl)? [Where do you collect knowledge support (which documents or similar)?]

Har politikerna tillräcklig kunskap när det gäller planering i krävande klimat? Hur yttrar det sig? [Does the politicians have enough knowledge regarding planning in cold climate? How does it manifests itself?]

Vilka kunskapsbrister ser du att det finns när det gäller planering i krävande klimat? [What knowledge shortcomings do you see existing when it comes to planning for cold climates?]

Vad behöver ni i din organisation arbeta vidare med? [What do you need to work further with within your organization (in relation to planning for cold climate)?]

Vad behöver forskningen arbeta vidare med, tycker du? [What does the research need to work further on with?]

Finns det konflikt mellan nuvarande planeringssystem och vad som krävs av krävande klimat? Ange ex? (täthet, bostads efterfrågan) [Is there a conflict between the existing planning system and what is required for cold climate? Give example? (Densification, housing demands)]

Avslutning [Conclusion]

Om vi ska försöka summera, vilka är de absolut viktigaste frågorna när de gäller planering i krävande klimat? [If we will try to summarize, what are the most important issues when it comes to planning for cold climates?]

Något annat att tillägga? [Further comments?]
Appendix 2- questions of the interview with urban designers

The aim of this interview is to explore the position of environmental comfort in urban design practice. The interview is conducted as part of my PhD study that is about climate-sensitive urban design in cities with a cold climate. Climate-sensitive in the context of my PhD is primarily concerned with consideration of microclimate factors in urban design.

The interest in climate-sensitive urban planning and design is growing both in research and practice. Research on this matter has shown that there are problems for incorporating climate knowledge into urban planning. By this interview, I intend to know how you have observed and experienced working with microclimate factors in urban design practice. Although some of the interview questions are case specific, your responses needn’t be limited to a case. You are encouraged to answer the questions in a discursive manner. Your answers will be used in a scientific article in which your identity will be anonymous. With your permission, I will use a voice recorder and take notes during the interview. The recording is to accurately note the information you provide, and will be used for transcription purposes only. If you choose not to be voice-recorded, I will take notes instead.

Your background

Name:

Education/ professional qualifications:

Current position/ responsibilities:

Work experience (years):

1. Experience and knowledge in climate-sensitive urban design

Does environmental comfort have importance for your urban design practice? Why/why not? In what way?

Are climatic issues addressed in urban design schemes that you are currently involved in?

Have you worked with a project(s) in which the integration of microclimate factors was a primary design objective? If so, please explain.

When considering an urban design project:

What are the design principles that you feel are important to improve the comfort of urban spaces in cold climates?
Of these principles, which do you feel are the most important urban design principles for design in cold climates?

Do you feel that a climate-sensitive approach is more difficult when designing for cold (sub-arctic) climates? (in comparison to more temperate or warmer climates)

2. Case study Kiruna/Gällivare

Do you feel that the competition provided adequate information about microclimate conditions/ issues? (Kiruna)

Do you feel the competition programme had clear climate objectives? (Kiruna)

Do you feel that the municipality provided adequate information about microclimate conditions/ issues? (Gällivare)

Did your team receive help from experts in microclimate during the design phase? If yes: what type of information did you receive from the experts? How was such information integrated into the design?

Did your team have design objectives related to environmental comfort? If yes, how did the objectives affect the final design?

Did you experience that comfort related urban design objectives were in conflict with other design objectives? If yes, please explain the conflicts and how they were resolved?

3. Improvements

What changes can be undertaken in the design programme/brief to improve the ability to incorporate microclimate factors consistently in the entire design process (from conceptual design to delivery)?

How do you think architecture and urban design education can be improved to better integrate climate knowledge in practice?

Do you think that urban design professionals need better skills in and understanding of microclimate factors?

In regards to microclimate factors, do you think that there is sufficient best practice guidance/ research available to the urban design industry?

4. Other comments: