A Classification of Wide Seasonal Range (WiSR) Cities for Early-Stage Decision Making in Public Space Design

by

Simon Leroux

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

In cold climates, prolonged winter weather and poor planning limit the use of public spaces for a major part of the year. While effective strategies exist to extend outdoor activity, their scope of application remains unknown and designers continue to rely on approaches that are incompatible with the local context. As a result, public spaces bear a high cost with low return, and city dwellers and businesses lose out on the important social and economic benefits of attractive public spaces.

In cold- and winter-related planning literature, few studies exist, and several issues persist. Despite the metrics, definitions, and approaches developed to assist design professionals, there are few examples of successful public spaces. Prominent Winter City studies present a narrow perspective on all-year planning needs, as they focus too heavily on the winter season and do not account for human behaviour over time. In turn, public space designers continue to rely on metrics developed solely for one time of year. There is also no distinction between (a) high-latitude cities that have moderate winters and cool summers, and (b) mid- to high-latitude cities that experience severe cold winters and hot summers. This leaves a significant design challenge unattended for (b), as planning solely for one season often conflicts with all-year objectives.

This thesis investigates the key elements for successful public spaces in cold climate cities and proposes a metric that leads to a classification system that will assist in the early-stage identification of global cities that share similar climate challenges.

A review of literature on urban bioclimatology reveals that an understanding of macro scale processes is key to design at the microclimate level. Urban design studies show that public space design principles exist for ideal weather, but there is poor guidance for cities with wide climate variability. A review of human responses to thermal environments shows that heat budget models are effective for addressing physiological needs, but spatial and activity distribution show greater effectiveness for factoring behavioural adaptation—a key component for use and enjoyment of public spaces in cold climate.

An analysis of public spaces in Canada, Northern Italy, Russia, and Japan reveals five principal approaches categorized by permanent, convertible, and ephemeral interventions. Convertible and ephemeral interventions can provide a wider range of activities, and this is shown to be most effective for all-year use and enjoyment when properly implemented. It is concluded that a classification of local climate needs for mid- to high-latitude cities could assist designers in relating microclimate design strategies to local scale planning needs.

An analysis of average monthly climate data for 13 mid- to high-latitude cities reveals important differences in local winter challenges. Comparison of the data to current metrics shows that common terms, classifications, and indices are misleading and offer limited information for planning purposes.

Since no term exists for environments exposed to wide seasonal variation between winter and summer, the term Wide Seasonal Range (WiSR) is proposed. WiSR cities include, e.g., Edmonton, Minneapolis, Ottawa, Kazan, Ulaanbaatar, or Shenyang, and these are mostly in continental and steppe climates. A classification system is proposed for WiSR cities based on 30-year average monthly temperature data for 128 cities meeting a specified criterion. Since winter climate severity depends primarily on temperature or seasonal variation, six classes of Seasonal Range (SR) are proposed for defined thresholds of average temperature of the coldest month (T_{min}) and annual temperature range (T_{range}), i.e., the difference between average temperature of coldest month (T_{min}) and hottest month (T_{max}).

The classification is then used to analyze the relationship between T_{min}, T_{max}, T_{range}, snow cover, and latitude. Results show a strong relationship between T_{range} and T_{min}. On the other hand, latitude weakly correlates with T_{min}, T_{range}, and snow cover, proving that latitude is not a suitable basis for classifying winter climate severity.

The WiSR classification system provides measurable local climate data on winter, summer, and seasonal range that can be viewed from a global perspective. It is proposed as a simple metric that can serve as a starting point for identifying, comparing, and analyzing all-year local climate needs of mid- to high-latitude cities. In turn, planners and designers may better interpret the relevance of public space design strategies for specific local challenges.

Key words: climate metrics; pre-design; public space design; continental climate; steppe climate; cold climate; winter city.

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This thesis would not be possible without the excellent service provided by the university's personnel at the Writing and Communication Center (WCC), librarians, and GIS experts. I am also greatly indebted to the online research community and knowledge sharing platforms.

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List of Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
COST Action 730	COoperation in Science and Technology Action 730
CSI	Climate Severity Index
DWD	Deutscher Wetterdienst
ET	Effective Temperature
ET	Equivalent Temperature
EU RTD	European Union's Research and Technology Development
GHCN	Global Historical Climate Network
GHCN-M	Global Historical Climate Network – Monthly
H/W ratio	Height to Width ratio
HVAC	Heating, Ventilation, and Air Conditioning
ISB	International Society of Biometeorology
IUPS	International Union of Physiological Sciences
KMM	Klima-Michel-Modell
LPDAAC	Land Processes Distributed Active Archive Center
MEMI	Munich Energy-Balance Model for Individuals
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NEO	NASA Earth Observations
NOAA	National Oceanic and Atmospheric Administration
OUT_SET*	Outdoor Standard Effective Temperature
P4SR	Predicted Four-Hour Sweat Rate
PET	Physiological Equivalent Temperature
PHS	Public Health System
PMV	Predicted Mean Vote
PPS	Project for Public Spaces
PWS	Public Weather Service

SET	Standard Effective Temperature
TNZ	Thermal Neutral Zone
UHI	Urban Heat Island
UN	United Nations
UTCI	Universal Thermal Climate Index
WCF	Wind Chill Factor
WCSI	Winter Climate Severity Index

Proposed Abbreviations

SR	Seasonal Range
WiSR	Wide Seasonal Range
ESR	Extreme Seasonal Range
SSR	Severe Seasonal Range
HSR	High Seasonal Range
MSR	Moderate Seasonal Range
LSR	Low Seasonal Range
NSR	Narrow Seasonal Range

List of Symbols

Human heat balance

C	convective heat flow
c_b	specific heat capacity (WsK^{-1} kg^{-1})
clo	standard unit for thermal resistance of clothing (1.0 clo = clothing required for heat balance of a male adult at rest in a steady state environment, where ambient temperature = 21 °C, relative humidity = 50 %, and air velocity = 0.05 m·s^{-1})
E_D	latent heat flow by diffusion of water vapour through the skin
E_{Re}	latent heat flow by respiration
E_{Sw}	latent heat flow by sweat evaporation
F_{CS}	heat flow from the core to the skin
F_{SC}	heat flow from the outer surface of the skin to the outer clothing surface
I_{cl}	thermal resistance of clothing ensemble (measured in K m^2 W^{-1})
M	metabolic rate
MET	standard unit for metabolic rate (1.0 MET = 58.15 W·m^{-2})
P_a	vapour pressure
ρ_b	blood density (Kg/l)
R	the body's net radiation
R.H.	relative humidity
S	the body mass storage of heat flow from cooling or heating
T_a	air temperature
T_{c}	core temperature
T_{cl}	clothing mean surface temperature
T_{mrt}	mean radiant temperature
T_{sk}	mean skin temperature
V_a	air velocity
v_b	blood flow from body core to skin (ls^{-1}m^{-2})
W	physical work output

Meteorology

P_{ann}	accumulated annual precipitation
P_{min}	precipitation of the driest month
P_{th}	precipitation distribution, see Table 4-5 of Chapter 4
P_{smin}	lowest monthly precipitation for summer half-years on the hemisphere considered
P_{smax}	highest monthly precipitation for summer half-years on the hemisphere considered
P_{wmin}	lowest monthly precipitation for winter half-years on the hemisphere considered
P_{wmax}	highest monthly precipitation for winter half-years on the hemisphere considered
T_{ann}	annual mean near-surface (2 m) temperature
T_{max}	average temperature of the hottest month
T_{min}	average temperature of the coldest month
T_{range}	average temperature range between coldest and hottest months

1. Introduction

1.1 Problem Statement

For thousands of years, humans generally lived within the most habitable climates of the world, i.e. temperate and tropical climates. However, for social, political, and economic reasons, many began to occupy less habitable regions. These include climates that experience severe cold winters, many of which also experience hot summer conditions. In these parts of the world, cultural influences from Europe and technological influences from the industrial revolution generally led to public spaces that do not reflect local climate needs. As a result, many public spaces in Wide Seasonal Range (WiSR) cities (developed and defined later in the thesis) can only be used comfortably during summer, leaving them unused for a major part of the year. This has many important social, physiological, and economic ramifications for the public realm, e.g., reduced return on investment of public space construction, maintenance, and operating costs; promotion of sedentary behaviour; decreased local commercial activity; and a weakened sense of collective identity and social cohesion. These effects have a greater impact in dense urban centres, where a major portion of city dwellers depend on suitable public services and spaces to accomplish their everyday activities, including commuting, running errands, and social gathering. To a great extent, a city's vitality depends on the quality of its public realm, which largely concerns the human experience at street level.

It is necessary for public space designers to have thorough knowledge of local climate and strategies for modifying microclimates. However, it is insufficient to plan solely for summer or winter in many cities with cold winter weather (WiSR cities), as season-specific needs must be considered in relation to all-year planning objectives. But while an all-year perspective is key to public space design in WiSR cities, most studies on climate-sensitive planning and design treat summer and winter needs separately. Global climate change is also likely to add to the challenge: more extreme weather events are expected, and many mid- to high-latitude regions are expected to have greater spatial variability and more freeze/thaw events (Shabbar and Bonsal 2003).

1.2 Research Needs

Over the last 60 years, various theorists and practitioners in urban design have studied important social, psychophysiological, and behavioural aspects of well-being within the spatial design of the city (J. Jacobs 1961; Gehl [1971] 2011; A. B. Jacobs 1993; Lynch 1960; 1981; Moles and Rohmer 1982; Rossi 1982; Whyte 1980; 1988). However, there are very few studies on urban design in cold climates. Moreover, there are even fewer studies investigating public space design for cities with severe cold winters, which also generally experience hot summers within the same year. The variation between winter and summer weather is key because public spaces in cities with wide seasonal variation require different design strategies than cities with little variation across the seasons. For cities that experience wide seasonal range, spaces designed entirely in response to the cold season are often problematic during warmer seasons, while spaces designed explicitly for the hot season are only usable for a limited part of the year.

While some successful cold- and winter-exposed public spaces exist in practice, these are rarely documented. Within the literature on cold- and winter-related urban design, few studies manage to situate findings within a standard temporal and geographic context that is relevant for design purposes. Widely accepted definitions such as “Winter City”, “cold climate”, “snow climate”, or “northern settlement” place too much emphasis on single aspects of winter climate, and hence do not capture the essential challenge of seasonal variation.

Most importantly, there are no simple and measurable metrics to clearly identify specific climate challenges for urban planning and design in cities that experience severe winter climate. If a design professional wishes to locate relevant design precedents from other parts of the world, they must browse at length through various weather data to determine whether such precedents experience comparable climate to that of the project at hand. There are many issues with this. On one hand, the design professional must already possess a broad awareness of climates around the world and know their key challenges for design. On the other hand, they must also rely on their interpretation of those climates in different seasons. Further, this step in the pre-design stage is often treated with low importance, despite the fact that early decisions have the strongest impact on project outcomes and demand little cost (Kohler and Moffatt 2003).

1.3 Objective

This thesis investigates key elements of successful public spaces in WiSR cities and proposes a metric that leads to a classification system that will assist in the early-stage identification of global cities that share similar climate challenges. The method used to develop the WiSR climate classification in Chapter 5 may also inform experts in climatology, outdoor thermal comfort, and urban planning and design on developing climate metrics for cities challenged by wide climate variability. Figure 1.1 illustrates the role of metrics in the cyclical transfer of information between actual experiences in the built world and planned experiences, i.e., projects for the built world. In essence, metrics analyse and synthesize data from the built world to highlight key information for design.

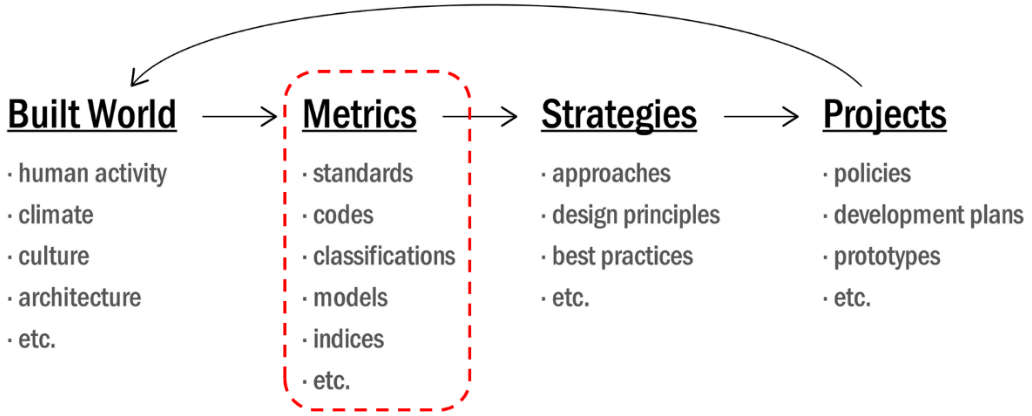


Figure 1.1 Cyclical flow of information between the built world, metric, strategies, and projects for the built world.

1.4 Scope

This thesis uses a "research for design" approach, as distinct from "research in design" and "research through design" (Frayling 1993; Frankel and Racine 2010). The research focuses on the analysis and development of climate metrics, i.e., terminology, indices, models, and classifications that inform design strategies. The objective is not to provide planners and designers with an explicit set of public space design strategies or best practices. Instead, strategies and approaches are analysed to understand the basic factors to be integrated into the development of climate metrics for early-stage design.

The data analysed in this thesis is collected from previously published literature on urban bioclimatology, urban planning, public space design, human thermal ergonomics, and human spatial behaviour. Moreover, evidence is presented by using published photographs of built precedents in use (used and not used), climate data for the most recent available 30-year period (1981-2010 or 1961-1990) from datasets such as the Global Historical Climate Network (GHCN) and others by the National Climatic Data Center (NCDC), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and Deutscher Wetterdienst (DWD). Population data for the latest available census (1999-2015) by the United Nations (UN) is used for the purpose of identifying global metropolitan cities in Chapter 5.

This thesis argues that a thorough understanding of macro, meso, and local climate processes is needed to properly address needs at the micro scale. While microclimates are important to this thesis, they are not examined in detail, since it will be shown that the major issue of microclimate design are more related to a poor understanding of climate needs for planning and design at larger scales. Once the relation between macro and microclimate processes is thoroughly understood, then public spaces can begin to address all-year planning and design needs. As such, there is a greater focus on advective components of weather and climate, e.g., atmospheric exchanges of heat and moisture, as opposed to solid components of climate, e.g., surface geometry and material properties.

The literature review concludes that existing concepts, classifications, and prediction tools are not suitable to address the specific challenge of wide seasonal range climates. Thus, this thesis proposes the term Wide Seasonal Range (WiSR) to denote environments characterized by a significant thermal range between the coldest and hottest months of the year. These are typically located in continental and cold steppe climate zones of the Köppen-Geiger Classification. But as Chapter 4 will show, this categorization is too broad for early-stage decision making in urban planning and design, so it becomes necessary to define a more detailed classification system. Today it is possible to conduct Computational Fluid Dynamics (CFD) at a fine scale. However, this is generally a demanding process that is usually a research activity and rarely able to be incorporated into public space design. Hence, a classification system that allows comparable cities with similar climate to be identified would guide a designer with relevant precedents. Thus armed, a designer could choose to conduct a more detailed analysis of the comparable cities. For large projects, one could conduct computational analysis of microclimate modifiers. Hence, the goal of this thesis is to propose a classification system that will serve as a useful pre-design tool to inform schematic design or design development.

This thesis defines public spaces as urban outdoor spaces that, during acceptable microclimate conditions, support collective social activities (see Gehl's principle of Necessary, Optional, and Social Activities in Section 2.2). As scholars on public space assert, public space is "[…] a physical manifestation of the public realm." (Mehta 2014, 53 citing Thomas 1991) Specifically, focus is kept on outdoor and semi-outdoor pedestrian spaces at grade exposed to a wide range of microclimate conditions throughout the year. This includes squares, covered arcades, pedestrian streets, enlarged sidewalks, partially enclosed transit hubs, harbourfronts, forums, bazaars, and all other publicly accessible outdoor spaces which cater to collective social and economic activities. This thesis does not concern spaces not open to the general public, spaces for traffic, or any other spaces that do not serve purposes of human interaction. It also does not address virtual public environments.

Since public space design is largely concerned with human spatial behaviour, particular attention is given to human activities for relevant scales of time and space. Further, the thesis investigates the influence of cold- and winter-related effects on the all-year use and enjoyment of public spaces. There is particular emphasis on the cold season, since winter remains the more challenging time of year in WiSR cities. However, an all-year perspective is maintained as the main challenge of seasonal variability lies in addressing the problem of opposing winter and summer needs.

Some semi-public spaces are examined to understand their influence on the all-year use and enjoyment of public spaces. However, private and semi-private spaces are not addressed. Sociopolitical, cultural, economic, energy, or ecological aspects of public spaces are not in scope. While Chapter 5 focuses on metropolitan cities with populations equal to or greater than 1 million, the findings of this thesis and its proposed classification can also be useful for smaller cities and towns with densely populated urban cores that experience wide seasonal variability.

1.5 Approach

The thesis begins by reviewing literature from a macro to micro perspective, describing elements of weather and climate; key factors of successful public spaces; and human thermal ergonomics. This ultimately highlights the factors that most directly influence human activity within public spaces for different thermal conditions.

To assess the current state of public space design in WiSR cities, the development of the Winter City movement is described, and its major findings are highlighted. Then, to understand the advantages and disadvantages of different design approaches, built precedents are compared and contrasted to show their effectiveness toward the all-year use and enjoyment of public spaces.

From the literature review and precedent study, it is determined that a greater understanding of the local climate within which these public spaces are set is needed to properly assess microclimate design needs. As such, a preliminary analysis is conducted on local historical climate data for 13 cities in different climates across the Northern Hemisphere. In this analysis, data calculated from averaged 30-year weather measurements on average monthly temperature, total monthly precipitation, total monthly sunshine hours, and average wind speed for winter (December, January, and February) are compared for each city to demonstrate the wide range of possible winter climate conditions.

Following this, the thesis reviews the key terminology, concepts, and climate metrics that currently inform planning policies, strategies, and guidelines regarding cold- and winter-related issues. These are analyzed to understand their limitations in addressing all-year public space design challenges from macro and local perspectives.

Informed by these findings, it is then determined that further evidence is needed to support the argument that existing concepts and metrics are not well suited for addressing cold- and winter-related issues in WiSR cities. Hence, the Wide Seasonal Range (WiSR) Climate Classification System is proposed as a design tool for identifying cities with comparable climate. Using the classification, an analysis is undertaken to assess 30-year (1981-2010) monthly temperature normals by the Global Historical Climate Network (GHCN) for all metropolitan cities of the world that satisfy a minimum criterion defined for winter climate. This is followed by a comparison of WiSR and Köppen-Geiger classifications, which highlights differences and similarities among the cities and the specific metrics that can be used to identify local climate severity for the coldest and hottest times of year. Finally, the uses of the classification are discussed in relation to the all-year performance of public spaces in WiSR cities.

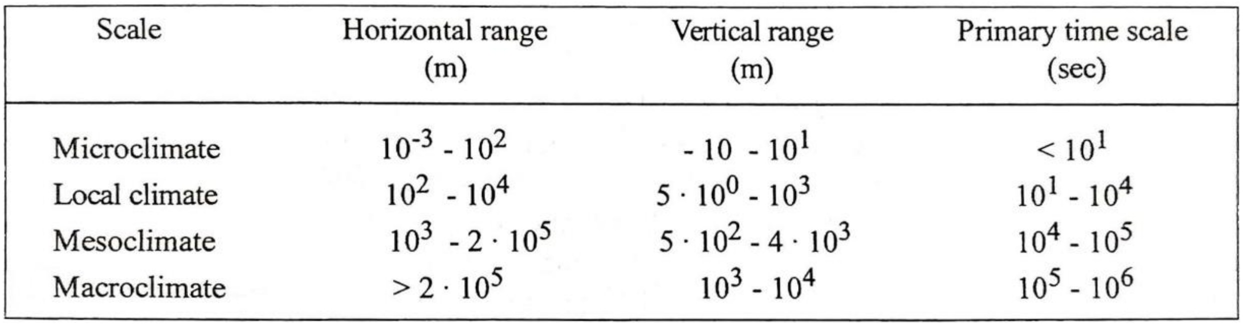
2. Background

This chapter overviews the key elements of weather and climate, public space design, and human responses to thermal environments. It also highlights the connection between these elements regarding the use and enjoyment of public spaces in WiSR cities.

2.1 Weather and Climate Elements

To discuss the various processes and issues related to weather and climate, research in meteorology and climatology has led to the establishment of key principles, scales, terms, and classification maps, among other analysis and communication tools. One principle that underpins any discussion of climate phenomena is that local weather results from the interplay between the earth's atmosphere and its surface. Components of the atmosphere are qualified as *advective*, while components of the earth's surface are qualified as *physical* (Hare 1997).

The term *climate* refers to repeated patterns of weather at certain scales of time and space. Most climate processes fit within specific classes of size, duration, and location. However, since weather is an open system, processes at one scale influence those of adjacent scales. Climate processes are classed according to four distinct scales of space and time: macro, meso, local, and micro (see Table 2-1). Climate processes for each scale can be viewed in plan (see Figure 2.1) and a cross-section view shows the respective height of boundary layers (see Figure 2.2). Existing classification maps provide a macroscale representation of climate zones according to vegetation types (see Figure 2.3). However, as Chapters 4 and 5 will show, the purposes of urban planning and design call for classification systems that account for human activity at meso, local, and micro scales.



Scale	Horizontal range (m)	Vertical range (m)	Primary time scale (sec)
Microclimate	10^{-3} - 10^{2}	- 10 - 10^{1}	$< 10^{1}$
Local climate	10^{2} - 10^{4}	$5 \cdot 10^{0}$ - 10^{3}	10^{1} - 10^{4}
Mesoclimate	10^{3} - $2 \cdot 10^{5}$	$5 \cdot 10^{2}$ - $4 \cdot 10^{3}$	10^{4} - 10^{5}
Macroclimate	$> 2 \cdot 10^{5}$	10^{3} - 10^{4}	10^{5} - 10^{6}

Table 2-1 Spatial and temporal scales of climate. (Yoshino [1975] 2005)

Figure 2.1 Plan views of different possible micro-, local, and mesoclimates (top to bottom, respectively) in Montréal. (Imagery provided by Google Earth using 2020 data courtesy of NOAA; Landsat/Copernicus)

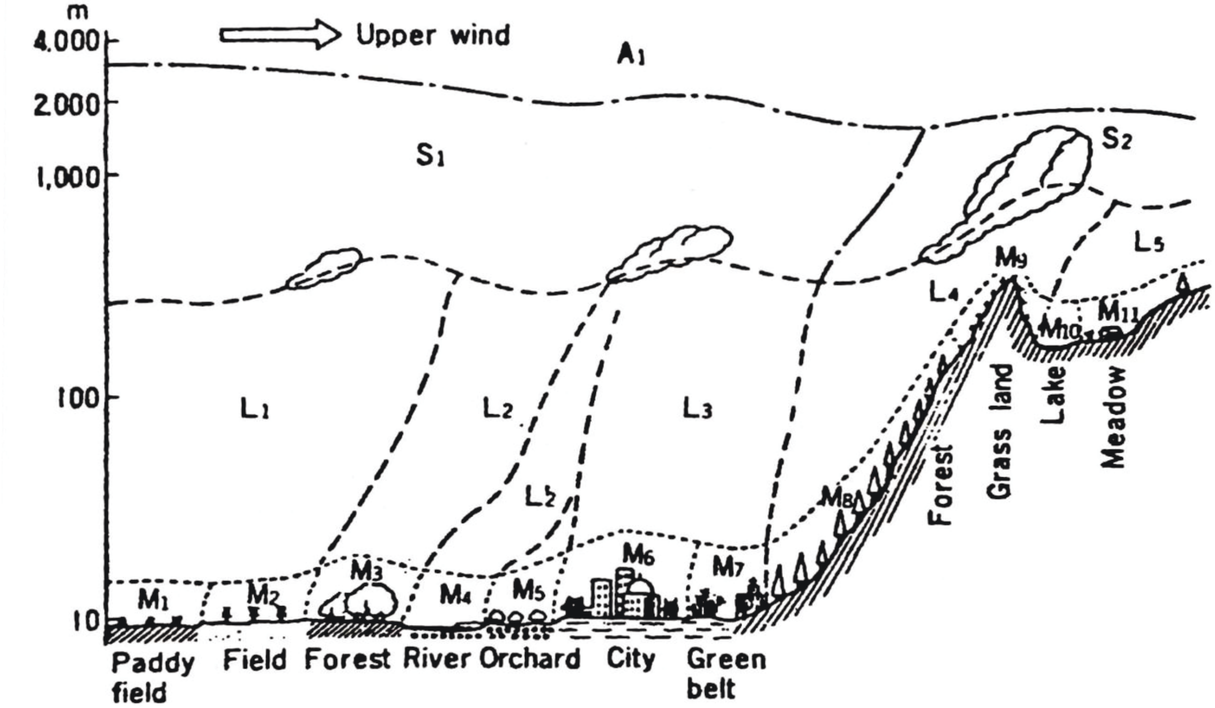


Figure 2.2 Schematic cross-section highlighting typical vertical boundaries for micro- (M1–M11), local (L1–L5), meso (S1–S2) and macro (A1) climatic phenomena. Horizontal boundaries are not to scale. (Yoshino [1975] 2005)

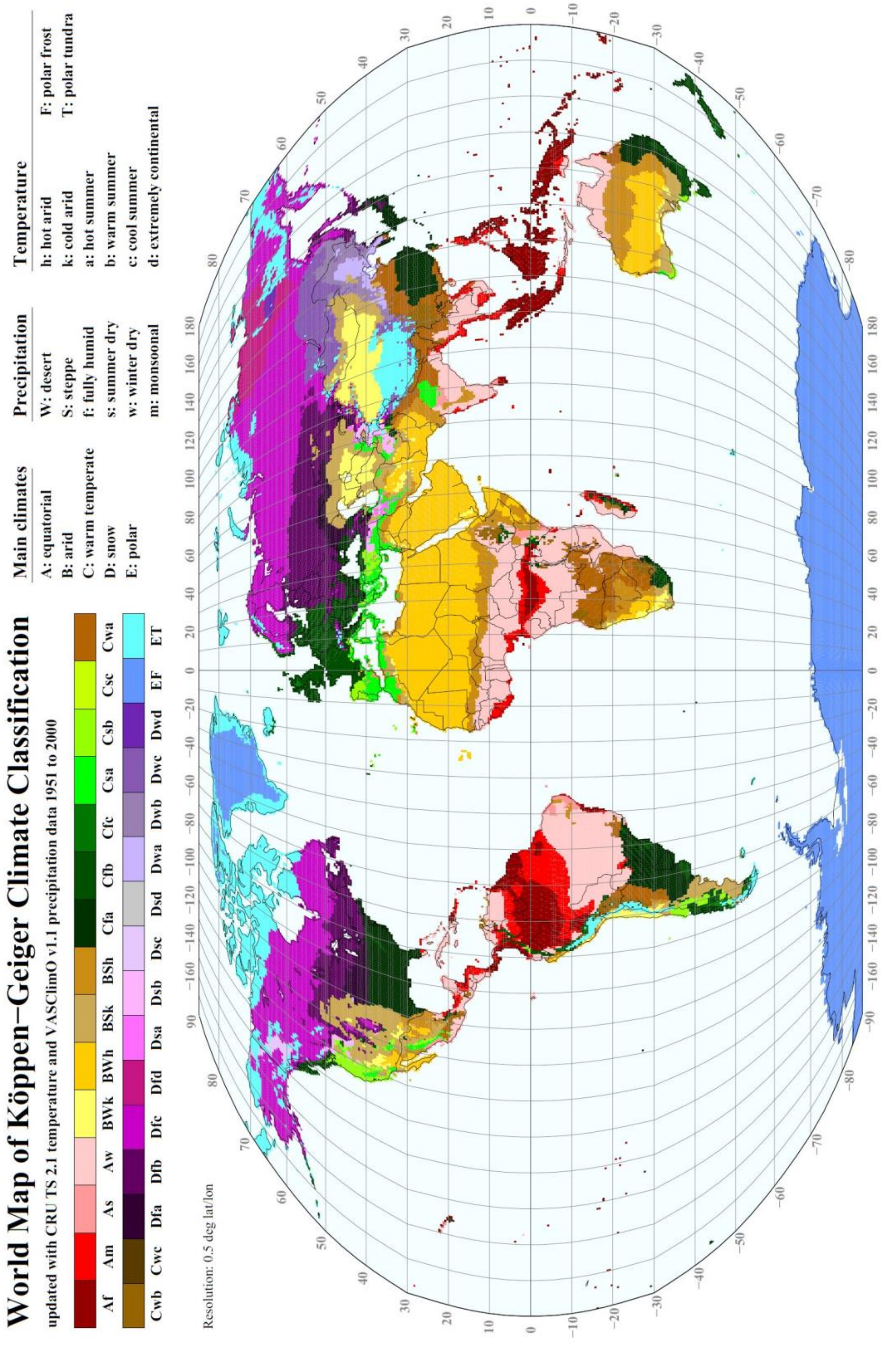


Figure 2.3 The Köppen-Geiger Climate Classification system. (Kottek et al. 2006)

Macroclimate

When discussing key determinants of macroclimate, Hare (1997) states that the variability of climate essentially results from the interplay of advective and physical components. Advective components refer to macroscale airstreams in the atmosphere, which follow two distinct and permanent patterns. Between the earth's poles and the equator, the westerlies—referring to strong air currents coming from the west—meander toward and away from the equator, forming ridges and troughs (see Figure 2.4). In the tropics, the easterlies—referring to strong air currents coming from the east—have a relatively stable pattern moving westward along the equator.

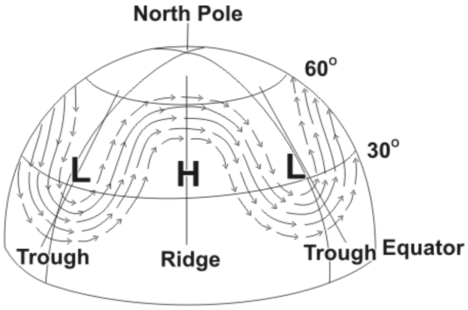


Figure 2.4 Schematic depiction of westerly ridges and troughs. (Canadian Meteorological and Oceanographic Society, n.d.)

These currents result from the advection caused by physical components, which include the earth's tilt and rotation, the uneven distribution of solar radiation beaming on the earth's spherical shape, and surface properties, e.g., topography and material properties of mountains, valleys, and water bodies. Figures 2.5 and 2.6 show views of the westerly jet streams in the northern hemisphere for different times of year.

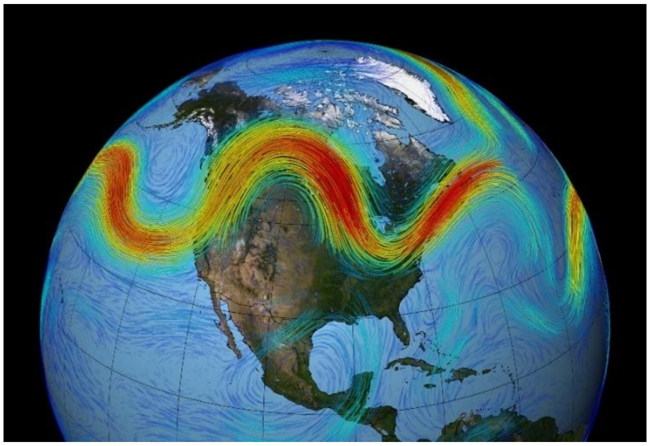


Figure 2.5 Data visualization of the polar jet stream from June 10 to July 8 1988. Measured by NASA's MERRA dataset (NASA/Goddard Space Flight Center Scientific Visualization Studio)

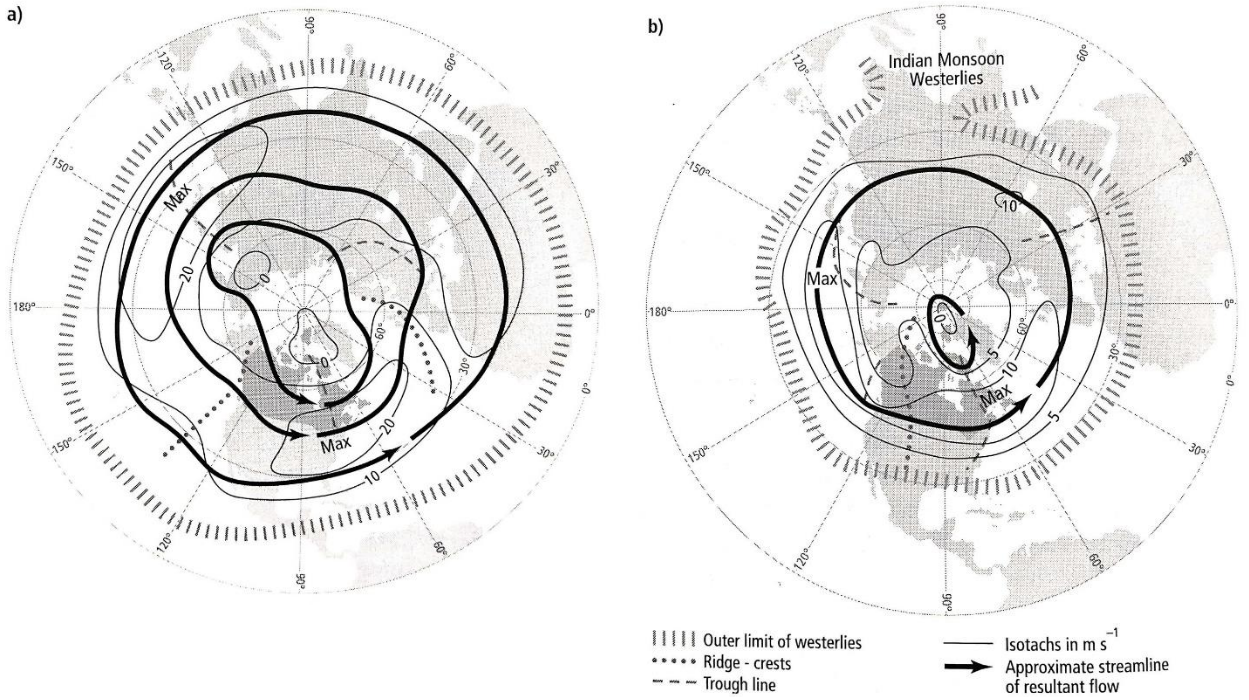


Figure 2.6 Northern Hemisphere maps depicting the flow of the westerlies for a) July and b) January. (Hare 1960 in Bailey et al. 1997)

Since airstreams carry heat and moisture over specific regions, certain regions experience a wide range of weather intensity while others—despite being at a similar latitude—experience only moderate conditions. For instance, in maritime climates, the westerlies moderate local temperature extremes by bringing oceanic air currents, hence keeping air temperatures above freezing level. In continental climates—referring to inland regions of North America and Eurasia—airstreams can carry frigid cold air from the arctic and converge with other warm or temperate airstreams. Without the moderating effect of ocean air currents, this frequently results in greater local temperature extremes at daily, seasonal, and annual time scales. Figure 2.7 shows the global distribution of average monthly surface temperatures for January and July 2019, respectively.

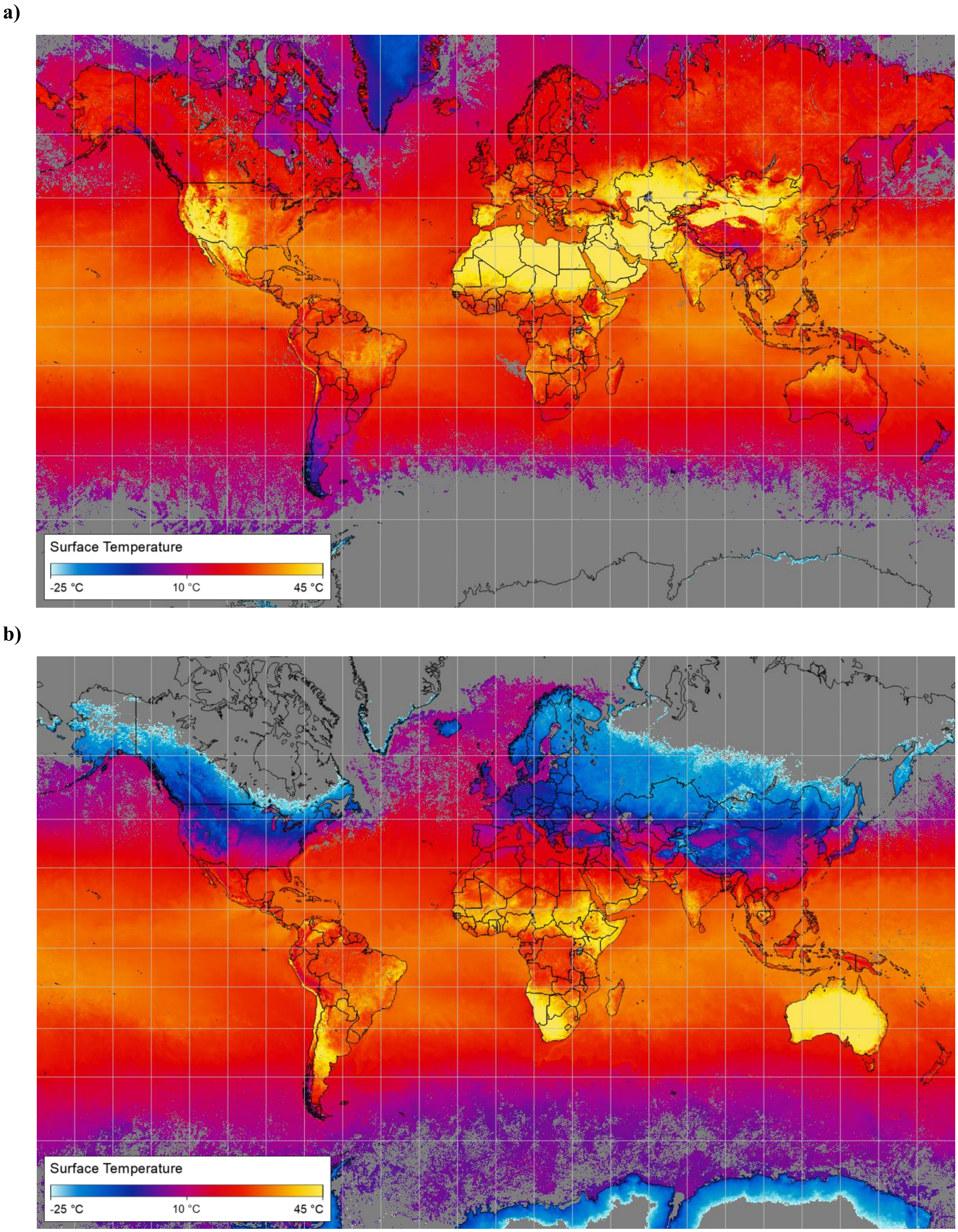


Figure 2.7 Global map of monthly land and sea surface temperature for a) July 2019 and b) January 2019. (Land: NASA Earth Observations team using data courtesy of the Land Processes Distributed Active Archive Center (LPDAAC) and the MODIS Land Science Team 2020)

Mesoclimate

At the meso scale, human activities can significantly alter climate processes. Oke et al. (2017) note that mesoscale effects of urban development generally result from the added roughness created by the aggregation of varying building geometry, increased air pollution, output heat generated by human activities (also known as anthropogenic heat), redistribution of water and moisture, modified vegetation cover, and modified land surface properties. The transformations may occur at micro or local scales, but their combination results in larger mesoscale effects. For instance, calm winds, excess anthropogenic heat, and an abundance of highly emissive materials can give rise to the Urban Heat Island (UHI) effect (see Figure 2.8).

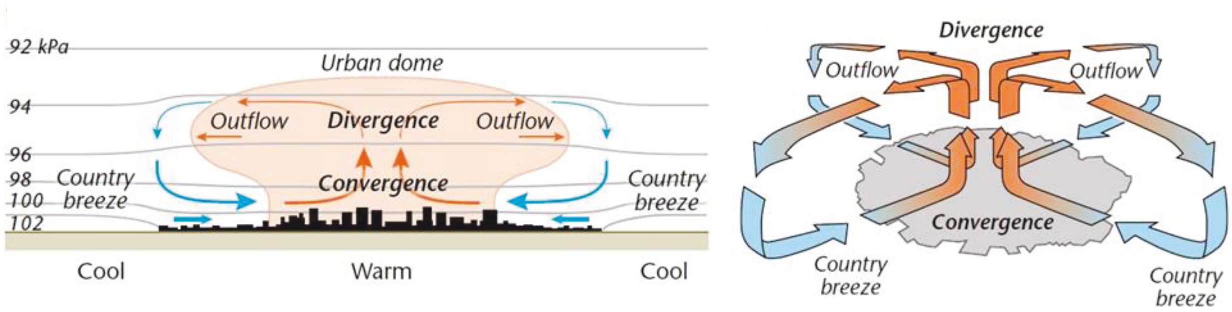


Figure 2.8 Mesoscale schematic showing typical air flow dynamics traversing Urban Heat Islands (UHI). (Adapted from Oke et al. 2017)

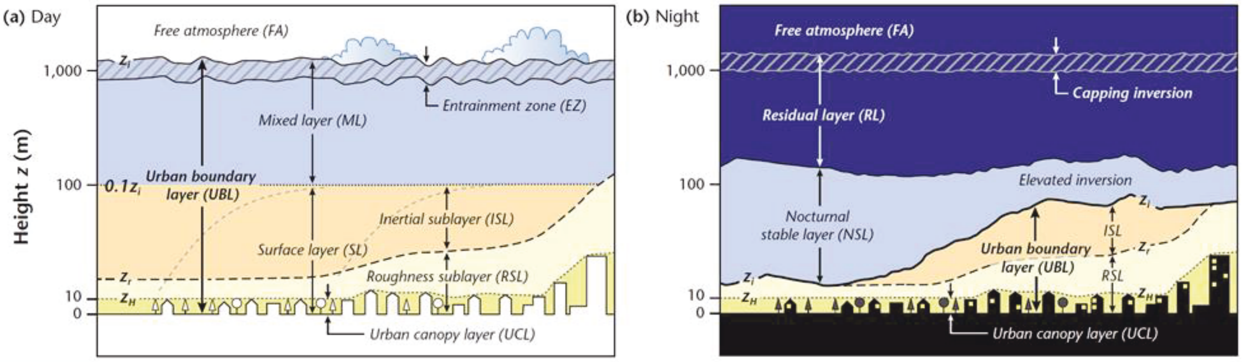


Figure 2.9 Cross-section view of the atmosphere's boundary layers for day (a) and night (b). Boundary layers fluctuate depending on time of day, seasons, and physical changes in land and water surfaces. (Oke et al. 2017)

Local Climate

At the local scale in mid to high latitudes, the features of urban districts and neighbourhoods can alter the intensity of wind flow and solar radiation. Key features include building density, spacing, orientation, and geometry, in addition to biophysical and geophysical characteristics such as vegetation type, density, diversity; location; presence of water basins; and soil permeability (Ibid.; Dursun and Yavaş 2016). Figure 2.10 demonstrates the local climate effect of wind flow according to the urban layout. In general, when urban geometry is oriented toward the dominant wind direction, a staggered distribution buffers air flow, while a grided distribution channels air flow through its principal axes.

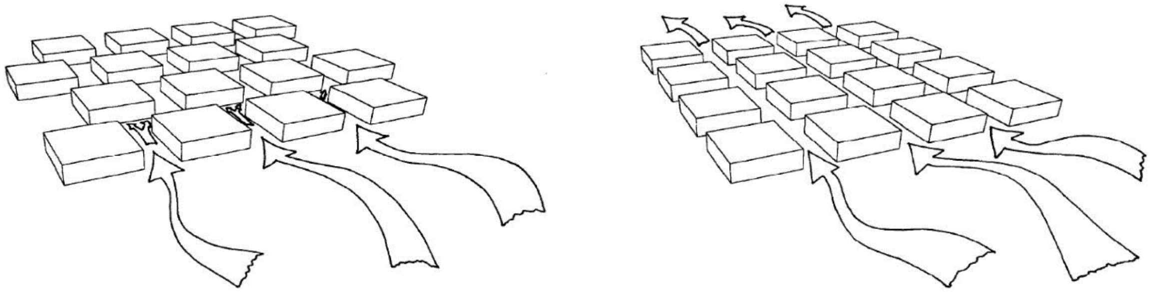


Figure 2.10 Diagrammatic representation of wind flow through staggered and gridded building distributions. (unknown source cited in Shishegar 2013)

Microclimate

The micro scale is most relevant to public space design as it contains all the climate processes found within plazas, street canyons (i.e. streets with buildings on both sides), squares, parks, and other common pedestrian environments. At this scale, factors of human thermal sensation and comfort are of particular importance. The microclimate parameters affecting thermal sensation and comfort are air temperature, mean radiant temperature, relative humidity, and air velocity (see human heat balance in Section 2.3). As with the local scale, urban microclimates in mid to high latitudes are particularly influenced by wind flow and solar radiation. These variables relate to the microclimate parameters of mean radiant temperature and air velocity, respectively.

Exposure to solar radiation is mostly influenced by the height of surrounding urban geometry, the solar angle (based on latitude, time of day, and season), and street canyon width. Concurrently, lower buildings and wider streets increase access to solar radiation at grade. Nevertheless, urban geometry also impacts wind flow. Three types of phenomena can illustrate the influence of urban geometry on air velocity at grade. Downwashing occurs when a large volume, e.g., a slab-shaped tower, obstructs air flow and redirects air flow downward, thereby creating turbulence at its base. Various types of vortices—e.g., corner, helical, or horseshoe vortices—occur when a similar volume contains sharp edges, as it increases the roughness between the overall wind flow and planar surfaces. Channelling occurs when geometry funnels air flow coming from two or more directions, resulting in a constriction jet (Cochran 2004; Elshaer et al. 2016).

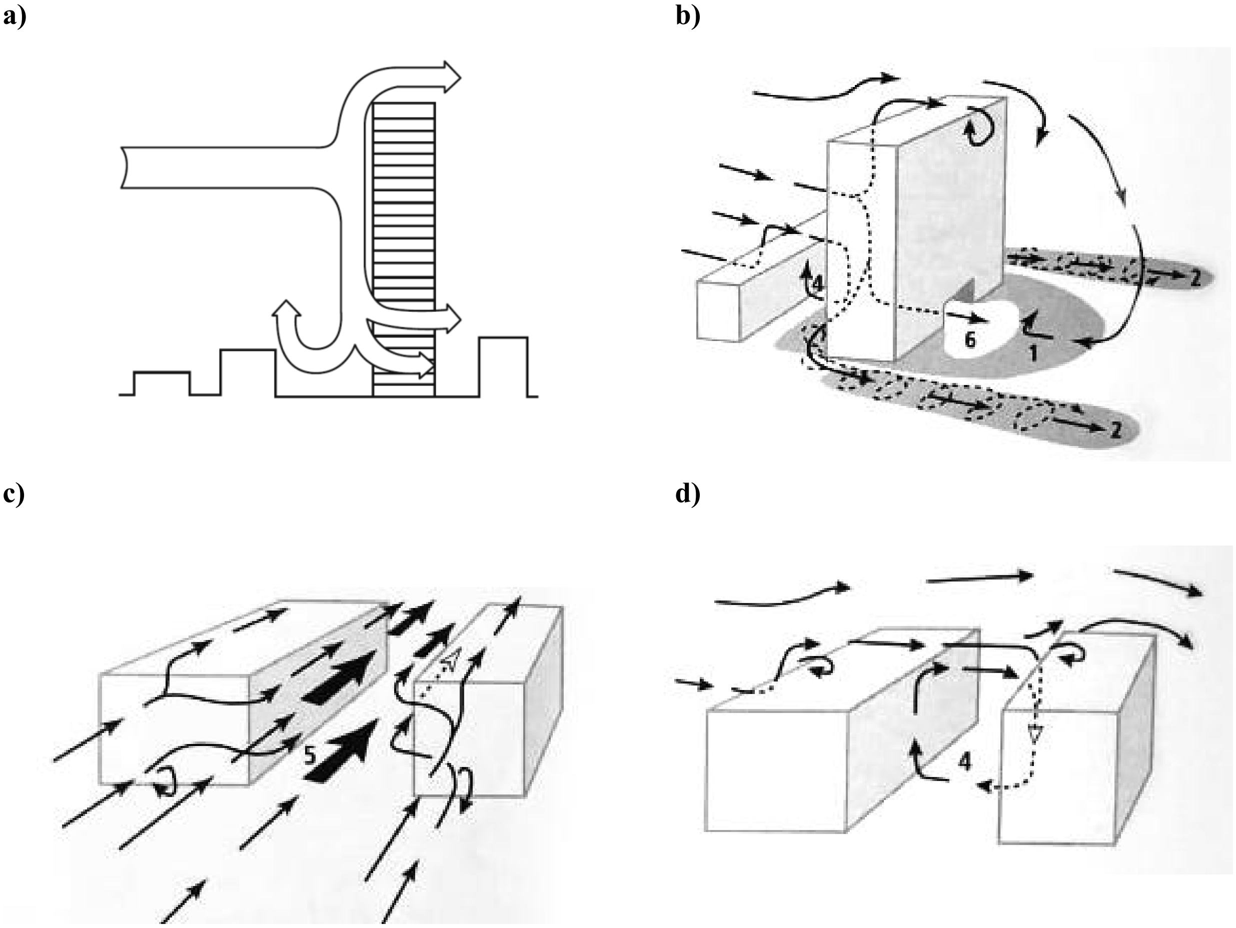


Figure 2.11 Schematic of microscale air flow in built-up areas, such as **a)** and **b)** wind hitting a tall, flat building much taller than surrounding geometry, **c)** wind flow parallel to a street's long axis, and **d)** perpendicular to a street's long axis. Number reference: 1. lee cavity, 2. 'horseshoe' vortex system, 3. elevated corner vortices (cropped from view), 4. canyon vortex circulation, 5. constriction jet, 6. through-flow jet. (Cochran 2004; Oke 1997)

While the calculation of the solar angle is common knowledge among design professionals, there are tools which can assist design by analyzing the spatial consequences of various factors. For instance, the parameters listed above for solar exposure and wind flow can be analyzed simultaneously using the height to width (H/W) ratio (Oke 1988). The height to width (H/W) ratio provides a simple method for calibrating spatial relationships for purposes of shelter (i.e., wind deflection), pollution dispersion, urban warmth, and solar radiation. According to Oke, when considering only urban geometry and local data for solar radiation and wind flow, a lower limit of 0.4 H/W is suggested for shelter from wind. An upper limit of 0.6 – 0.65 H/W is suggested to allow access to solar radiation and dispersion of pollutants. Consequently, the recommended range that meets all four purposes is between 0.4 and 0.6 H/W.

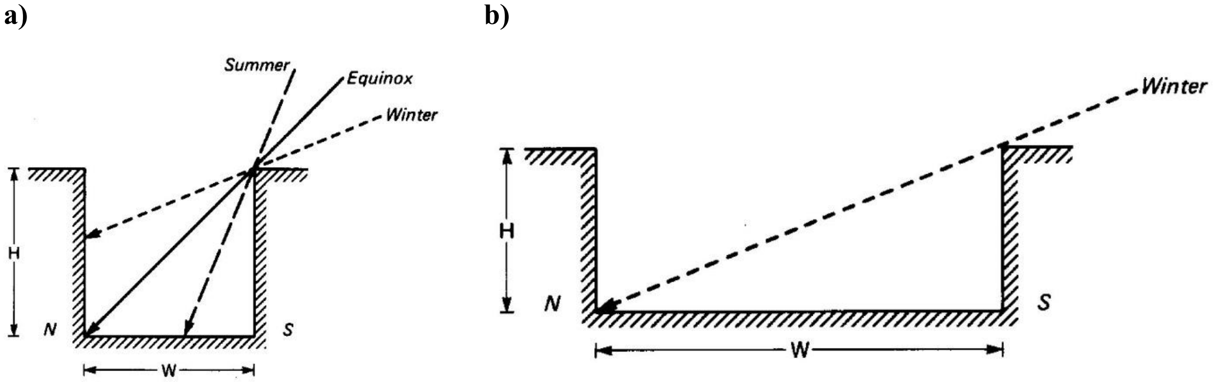


Figure 2.12 Schematic depicting the shading effect of urban geometry for different Height to Width (H/W) ratios. Arrows indicate the sun angle for cities at 45 °N latitudes, where **a)** shows angles at summer and winter solstices and the equinox for a H/W ratio of 1.0, and **b)** shows a typical mid-day winter sun angle for a H/W ratio of 0.4. (Oke 1988)

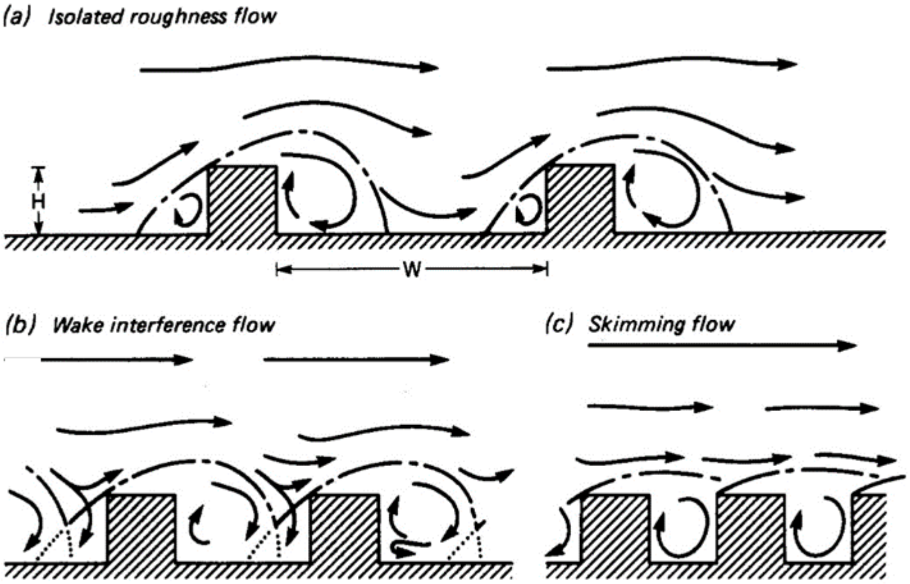


Figure 2.13 Schematic showing the effect of increased surface roughness on air flow according to ranging H/W ratios. (adapted from Oke 1988)

But while climatic factors are essential to public space design, their successful integration within public space design requires that they be considered alongside other fundamental design requirements (Eliasson 2000; Dursun and Yavaş 2016). In light of this need, the following section highlights requirements for the successful use and enjoyment of public spaces.

2.2 Elements for Successful Public Spaces

Urban design experts assert that successful public spaces require the presence of people (Gehl [1971] 2011; Whyte 1980). While comfortable microclimates can attract people for recreation and leisure purposes, people primarily attend public spaces to accomplish compulsory tasks such as going to work, school, or home. Thus, prior to analysing the factors that contribute to successful public spaces, it is essential to introduce Jan Gehl's principle of Necessary, Optional, and Social Activities. As Gehl (2011) maintains:

> *Necessary activities* include those that are more or less compulsory – going to school or to work, shopping, waiting for a bus or a person, running errands, distributing mail – in other words, all activities in which those involved are to a greater or lesser degree required to participate. […]
>
> *Optional activities* – that is, those pursuits that are participated in if there is a wish to do so and if time and place make it possible – are quite another matter. This category includes such activities as taking a walk to get a breath of fresh air, standing around enjoying life, or sitting and sunbathing. […]
>
> *Social activities* are all activities that depend on the presence of others in public spaces. Social activities include children at play, greetings and conversations, communal activities of various kinds, and finally – as the most widespread social activity – passive contacts, that is, simply seeing and hearing other people. […] These activities could also be termed "resultant" activities, because in nearly all instances they evolve from activities linked to the other two activity categories.
>
> Gehl (2011, 9-12)

This urban design principle serves as the basis for many elements of this thesis, as it effectively synthesizes the design elements of *spatial configuration*, *activity distribution*, and *ambient stimuli* in relation to the goal of increasing the use and enjoyment of public spaces by *people* over *time*.

As stated above, greater emergence of social activities results when necessary and optional activities are adequately distributed. This phenomenon remains consistent for many public spaces around the world. For instance, Piazza del Campo in Sienna and La Rambla in Barcelona represent popular examples of successful activity distribution (see Figure 2.14).

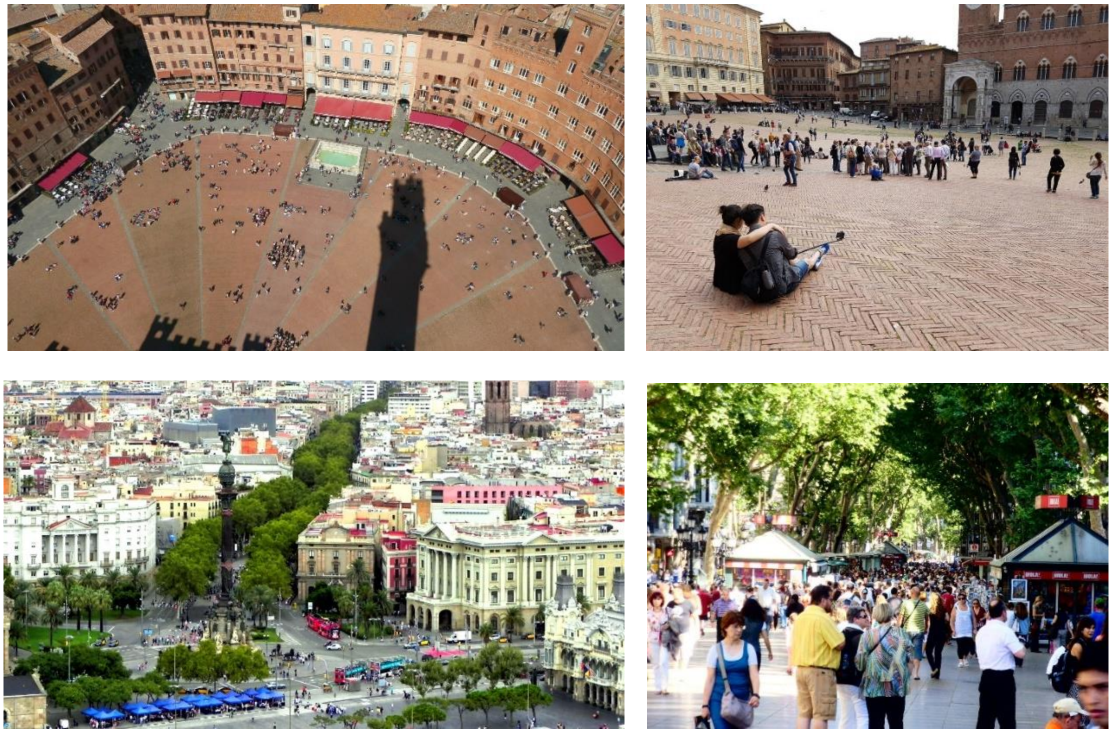


Figure 2.14 Piazza del Campo in Sienna (top left: May 4, 2017; top right: June 2, 2017) and La Rambla in Barcelona. (bottom left: Michel Gauthier, September 1, 2012; bottom right: Chris Bakker June 11, 2009)

Moreover, Gehl notes that necessary activities take place regardless of the outdoor climate, while optional activities typically occur when outdoor conditions suit prolonged activity. Figure 2.15 to Figure 2.18 present a schematic rendition of Gehl's principle. They depict potential scenarios in which the distribution of necessary and optional activities can lead to different patterns of use according to time of year and exposure to ambient stimuli—i.e., human sensation and perception of the surrounding environment.

Legend:

	Activity Examples:			Uses:
People	● *Necessary*	● *Optional*	● *Social*	▨ Private / Semi-Private
🟨 Activity Modifiers	walk, cycle, transit, drive	rest, pause, replenish, read, explore, exercise, shop, browse	meet, talk, trade, share, dance, play	🟨 Semi-Public
				— Public

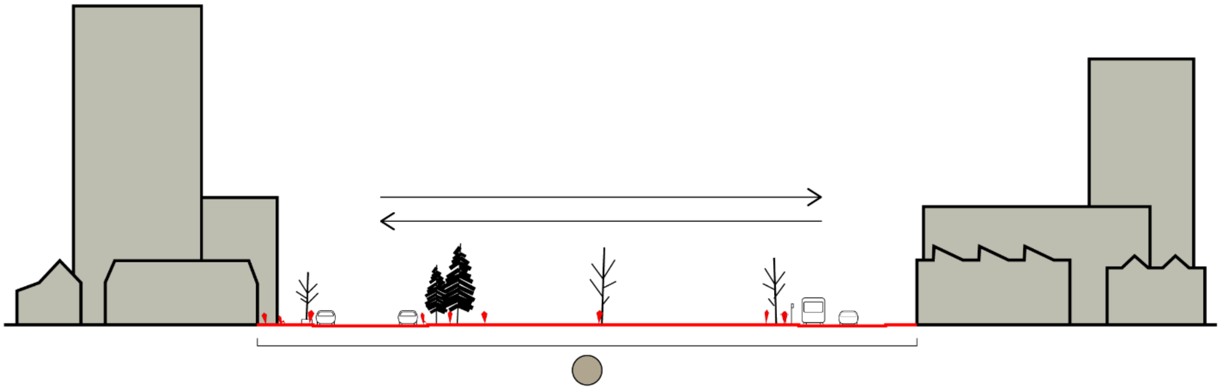


Figure 2.15 Necessary activities are those centred around compulsory tasks, such as moving from A to B. During frigid cold weather, the uses of public spaces is usually limited to necessary activities.

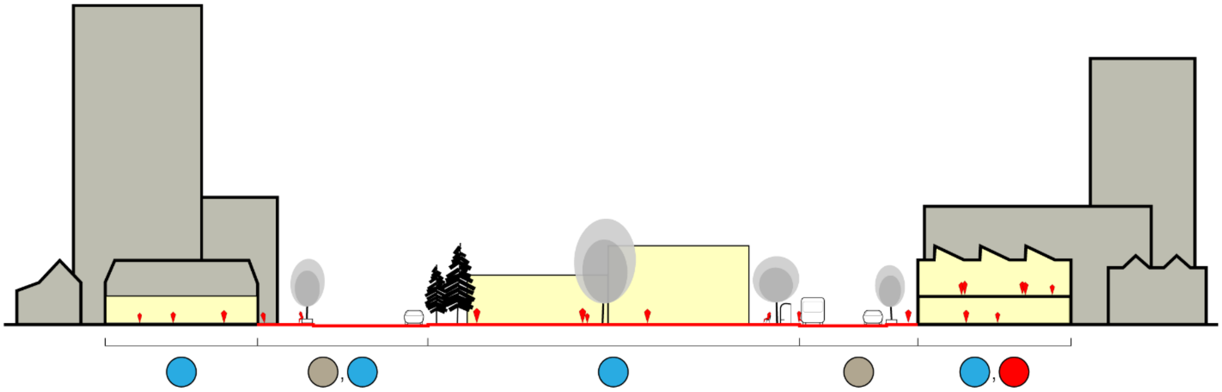


Figure 2.16 Optional activities are voluntary in nature, which typically attracts more leisurely behaviour and longer staying times. These mostly occur during comfortable outdoor conditions.

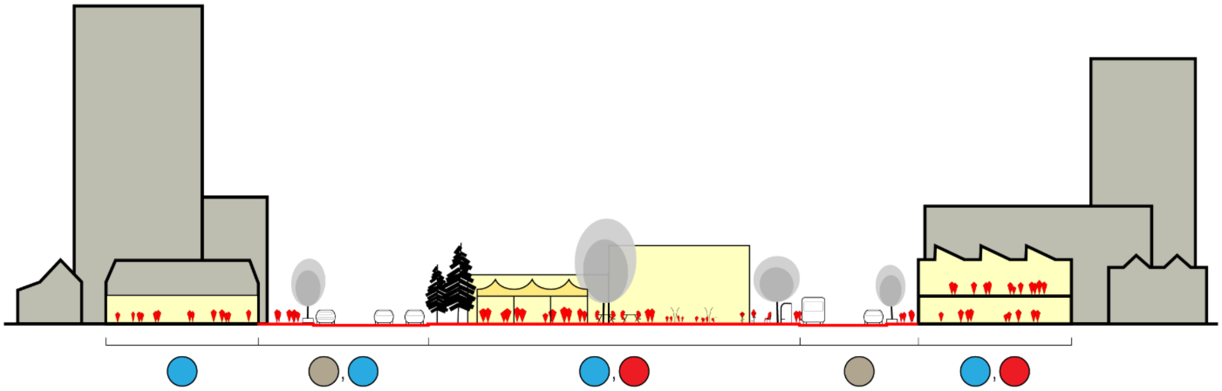


Figure 2.17 During comfortable weather, an adequate distribution of necessary and optional activities can lead to greater emergence of social activities.

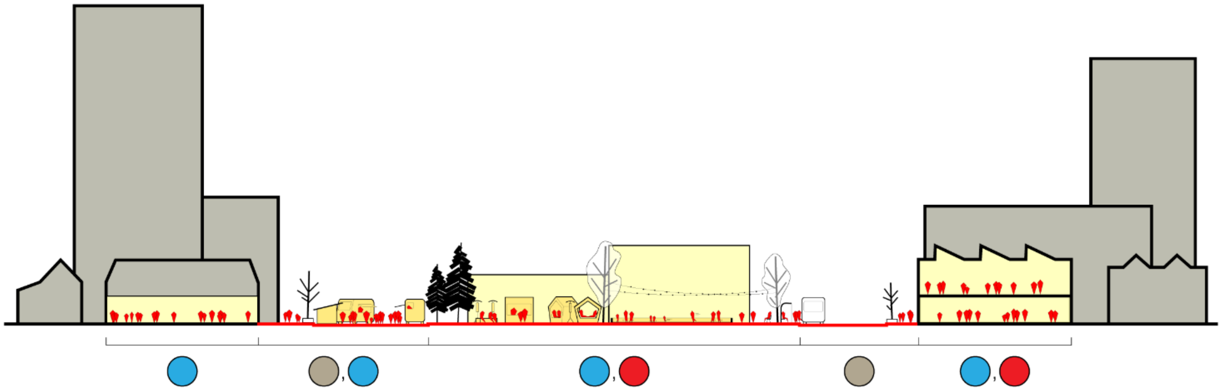


Figure 2.18 On cold winter days, certain design approaches can offer users a greater degree of control over their use of the thermal environment. Examples using these approaches are elaborated in Chapter 3.

Seminal Work on Public Spaces for Use and Enjoyment

Major contributions to the study of human spatial behaviour in outdoor public spaces can be attributed to architect Jan Gehl and urbanist William Whyte. Gehl's work revealed that the major prerequisite for extended human activity in outdoor urban environments is an adequate distribution of necessary activities. Concurrently, he showed that a greater number of city dwellers using the spaces between necessary activities resulted in greater demand for optional activities, and that the increased presence of users following the introduction of optional activities led to more spontaneous social activity. Moreover, he emphasized the need for public spaces to be designed at human scale and suiting human senses. Pointing to the previous lack of attention to critical areas of the public realm, Gehl proposed principles and strategies—e.g. necessary, optional, and social activities—for increasing the use and enjoyment of street-level public spaces (Gehl [1971] 2011; Gehl and Gemzøe 1999; Gehl et al. 2006; Gehl and Gemzøe 2006; Gehl 2010).

Whyte's contributions shed light on the factors extending use and enjoyment, as well as attracting the return of users to public spaces. Most notably, Whyte showed that an increase in the number of seating choices led to an increased attendance of public spaces. Even though certain environmental factors—microclimate, urban geometry, materials—showed importance in the overall perceived quality of public spaces, the possibility of choice was most the consistent factor influencing user satisfaction in public spaces (Whyte 1980). However, choices are not necessarily perceived, and so the presence of people using public spaces can signal potential uses to passersby. In this manner, both Gehl and Whyte arrived at the conclusion that "What attracts people most, it would appear, is other people." (Ibid., 19) Guided by Whyte, Gehl, and other experts on public space design, the Project for Public Spaces (PPS) applied key principles to the design of numerous public spaces around the globe, which laid the ground for what is currently known as the placemaking movement (PPS 2007).

From the literature on the use and enjoyment of public spaces, it is concluded that to achieve successful outcomes, designers must satisfy two essential requirements:

1. Attract users to public spaces.
2. Provide conditions for extending the duration of use and enjoyment within public spaces.

Both requirements are fulfilled when the combined effect of multiple factors results in public spaces that suit user needs and preferences. As such, it is essential that all significant factors be considered in relation to the satisfaction of a diverse set of users. The first requirement mostly concerns the location of public spaces and their ease of access with respect to the distribution of necessary activities. The second requirement concerns the main elements of environmental design which lead to user satisfaction and enjoyment.

Key Factors for Use and Enjoyment

The main elements of environmental design may be categorized as ambient stimuli, spatial configuration, activity distribution, and user control. Figure 2.19 shows Project for Public Spaces' (PPS) diagram of key factors influencing the quality of public places.

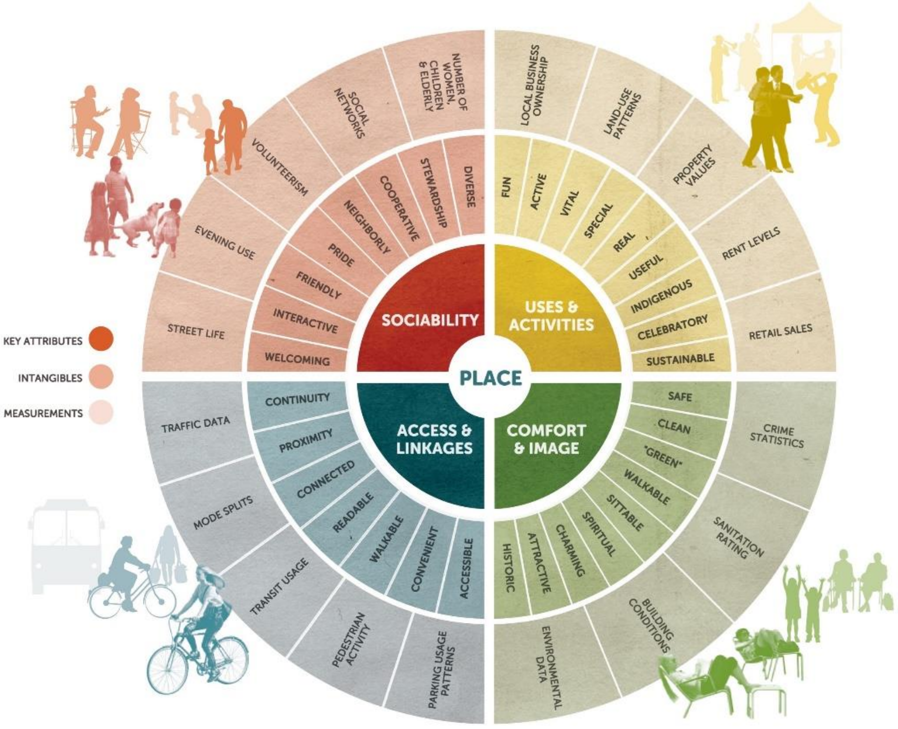
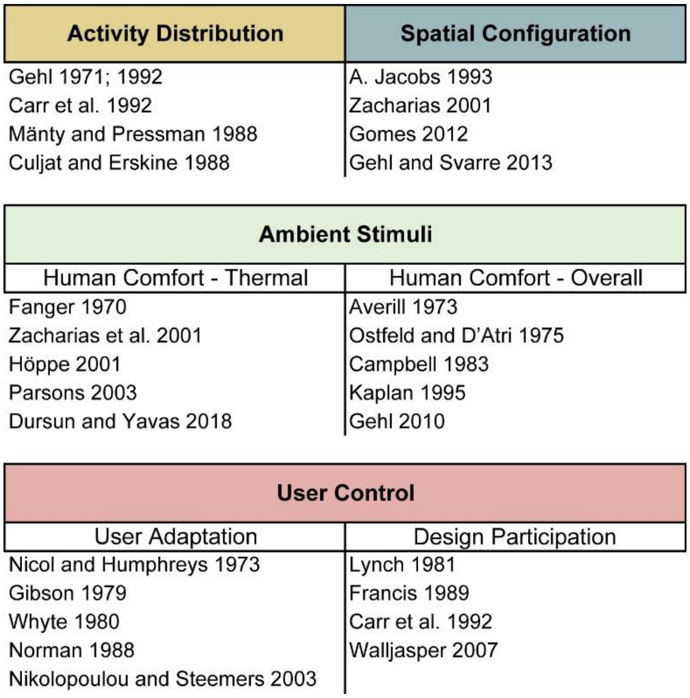


Figure 2.19 The Place Diagram by Project for Public Spaces. (PPS 2009)

The diagram refers to different terms—comfort and image; access and linkages; uses and activities; and sociability—to describe the characteristics of great places in common language. However, these characteristics are generally synonymous with design elements of *ambient stimuli*, *spatial configuration*, *activity distribution*, and *user control* in the academic literature on public spaces. Table 2-2 lists studies and monographs that address one or more of these four aspects of environmental design.



Activity Distribution	Spatial Configuration
Gehl 1971; 1992	A. Jacobs 1993
Carr et al. 1992	Zacharias 2001
Mänty and Pressman 1988	Gomes 2012
Culjat and Erskine 1988	Gehl and Svarre 2013

Ambient Stimuli	
Human Comfort - Thermal	Human Comfort - Overall
Fanger 1970	Averill 1973
Zacharias et al. 2001	Ostfeld and D'Atri 1975
Höppe 2001	Campbell 1983
Parsons 2003	Kaplan 1995
Dursun and Yavas 2018	Gehl 2010

User Control	
User Adaptation	Design Participation
Nicol and Humphreys 1973	Lynch 1981
Gibson 1979	Francis 1989
Whyte 1980	Carr et al. 1992
Norman 1988	Walljasper 2007
Nikolopoulou and Steemers 2003	

Table 2-2 Notable studies and monographs discussing one or more of the four design elements for successful public spaces.

For this thesis, *ambient stimuli* is characterized as all sensory information that can be perceived by humans at the microclimate level. It thus combines thermal, visual, auditory, olfactory, and any other types of sensory information which may influence human comfort or stress (see also "ambient stressor", "physical stimuli", "sensory environment", of "environmental stimulation"). The thermal component is elaborated in section 2.3. *Spatial configuration* refers to the geometric arrangement of public spaces (see also "form", "urban geometry", or "urban morphology"). *Activity distribution* refers to the distribution of various activities with respect to spatial configuration and ambient stimuli (see also "architectural programme", "functional program", or "zoning").

User control can refer to various meanings, such as control in the sense of individual or collective right to presence, use and action, appropriation, modification, and disposition (Lynch 1981). However, this thesis uses Averill's (1973) concept of "personal control" to define user control (see also "affordances" and, in short form, "control"). Averill identifies three types of control: decisional, behavioural, and cognitive. Decisional control refers to the range of environmental options available to an individual, where "environmental options" signifies the different combinations of ambient stimuli, spatial configuration, and activity distribution. Behavioural control—similar to behavioural thermal adaptation (see Nikolopoulou and Steemers 2003 in Section 2.3)—refers to an individual's available actions toward adjusting their exposure to ambient stimuli. Finally, cognitive control—similar to psychological thermal adaptation (Ibid. in Section 2.3)—refers to an individual's interpretation of ambient stimuli.

Since the activities and microclimate conditions within and surrounding public spaces are often subject to frequent and sudden changes, it is necessary to consider the four elements of environmental design for different users over time. The following anecdote highlights the importance of individual attention levels, perception of ambient stimuli, and exposure time:

> Consider the factory worker, racing off during the lunch period, fighting traffic and distractions [ambient stress and attention depletion], in search of a spot in the shade of a tree for a peaceful break. If the peaceful effects were to be worn off totally by the time the return trip is made at the end of the hour, would this ritual be repeated again the next day?
>
> (Kaplan 1995, 174)

Also, concerning the importance of compatibility between the four design elements and individual needs, preferences, and actions over time, Zacharias (2001) reports:

> Public presence in public spaces clearly depends on more than the internal organization of the space. Such places are perceived, evaluated, and related to particular purposes and people. The experience of space, architecture, activity, sound, and light has a cumulative effect on the desire to remain and to return. Such places will become associated with certain social characteristics and will affect joining behaviour. Routines and rituals develop both within individuals and across groups and populations.
>
> (Zacharias 2001, 15)

Measuring Public Space Quality

Weighting the relative influence of factors with respect to certain outcomes of human activity poses a significant challenge. Nevertheless, many design professionals conclude that levels of use and enjoyment over appropriate time intervals serve as useful performance indicators of public spaces (Gehl [1971] 2011; Francis 1989; Carr, Francis, Rivlin, and Stone 1992). A mixed methods approach is useful in this regard. The approach includes quantitative methods such as behavioural mapping, counting pedestrian volumes, and tracing, as well as qualitative methods such as street photography, questionnaires, interviews, usability testing of prototypes, and other types of user participation (Gehl and Svarre 2013; Nikolopoulou and Lykoudis 2007; Carr et al. 1992).

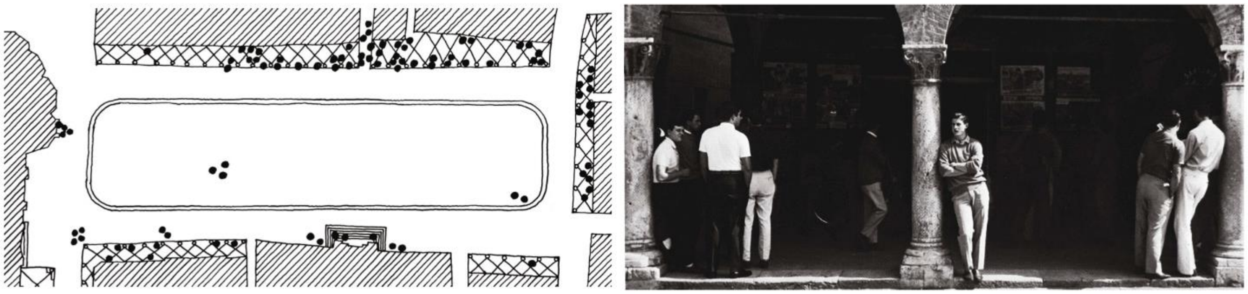


Figure 2.20 Behavioural map and street photography within Piazza del Popolo in Ascoli Piceno. (Stefan van der Spek, 1965 in Gehl and Svarre, 2013)

Using such methods can help identify factors that lead to greater use and enjoyment of public spaces, regardless of whether such factors were intentionally accounted in the design process. Consequently, designers can increase the likelihood of successful outcomes if critical factors are known and their effects are understood. As Zacharias (2001) maintains,

> The identification of environmental factors in collective decision making and their treatment in quasi-experiments tends the collected research toward a cataloguing of effects, rather than an explanation of underlying causes of such preferences. On the other hand, a cross-sectional reading of published results reveals few contradictions in clear results. Although a variety of methods of observation and analysis may not easily offer a basis for comparison, such approaches do enrich our reading of public space.
>
> (Zacharias 2001, 14)

For public spaces that frequently host extreme weather, the effect of ambient stimuli is evidently more critical to use and enjoyment than it is for public spaces located in temperate climates. To address this key aspect of public space quality, the next section expands on human responses to thermal environments.

2.3 Human Thermal Sensation, Comfort, and Adaptation

Human Responses to Thermal Environments

When heat transfer between the human body and the ambient environment is balanced, humans are in a steady state of thermal neutrality. Thermal physiologists name this state the thermoneutral zone (TNZ). Departure from the TNZ is termed thermal stress, which manifests as cold or heat stress (IUPS Thermal Commission 1987). When going from a state of heat or cold discomfort toward the TNZ, humans perceive sensations that can range from acceptable to comfortable, pleasant, or "super-comfort" as termed by Givoni et al. (2003). Since humans are exposed to variable microclimate conditions whenever they step outdoors, humans frequently shift between a neutral state and colder or warmer sensations.

When humans experience acute or prolonged discomfort, they may regulate their thermal exposure and perception via physiological, behavioural, or psychological adaptation (de Dear and Brager 1998). Physiological adaptation refers to physiological mechanisms such as sweating, vasodilation, vasoconstriction, shivering, acclimation, and acclimatization (Havenith 2005). Behavioural adaptation refers to actions taken by an individual to achieve thermal comfort, e.g., by changing location, changing clothing, or adjusting thermal control devices. Psychological adaptation refers to an individual's perception and interpretation of surrounding stimuli. Parameters of psychological adaptation include environmental preference, expectation, past experience, memory, exposure duration, perceived control, and perception of overall ambient stimuli (Nikolopoulou and Steemers 2003).

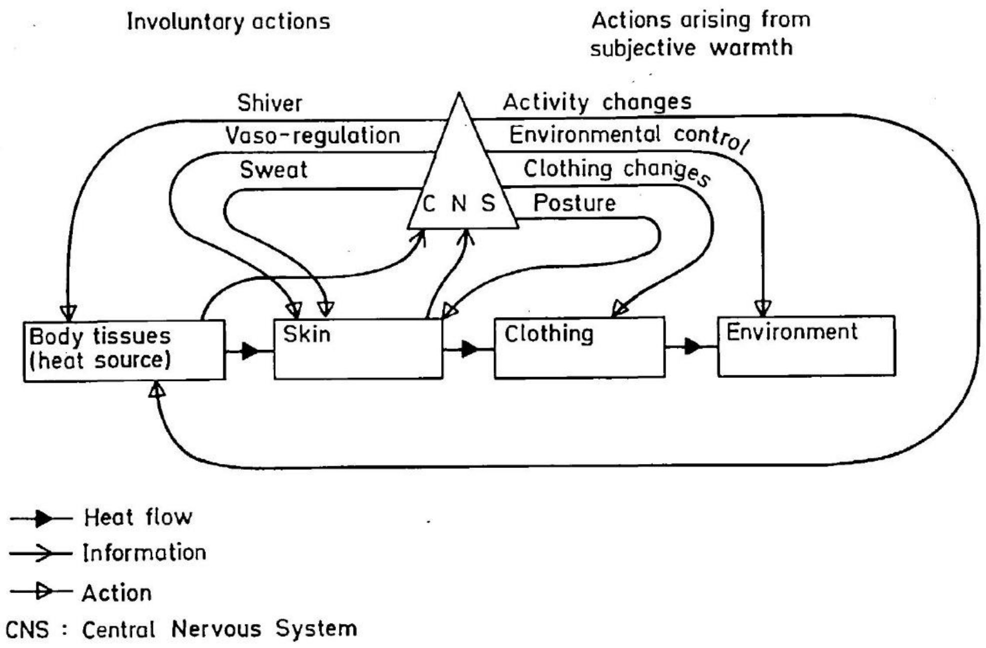


Figure 2.21 The human thermal regulatory system showing physiological adaptation on the left (involuntary actions), and behavioural adaptation on the right (voluntary actions). (Nicol and Humphreys 1973)

Defining Human Thermal Satisfaction

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) defines thermal comfort as "that condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." (ANSI/ASHRAE 2017, 3). However, "satisfaction with the thermal environment" refers to multiple conditions which vary as individuals each possess different thermal tolerance levels for specific goals, e.g., safety, productivity, well-being, or recreation.

One meaning refers to the TNZ described above. For safety and—depending on the task—productivity, a neutral state is often preferred. A second meaning of thermal satisfaction refers to the transient (i.e. changing, temporary) state achieved when an individual's thermal sensation shifts from stressful to pleasurable through physiological, behavioural, or psychological adaptation (Nikolopoulou and Steemers 2003). Thus, for well-being and recreational activities, a wider range of thermal conditions may be tolerable or even desirable.

As recalled for street canyons in section 2.1, a major challenge of design lies in resolving conflicting purposes with a single intervention. ASHRAE's current definition of thermal comfort then requires that "satisfaction with the thermal environment" be specified before any further use of the term. For this thesis, the second meaning of thermal satisfaction outlined above is particularly relevant as it relates to the concept of user control described in section 2.2. In this way, a high degree of control contributes to the user's perception of and agency over their thermal sensation, thereby influencing their overall satisfaction and desire to remain in colder- or warmer-than-neutral thermal environments (Ibid.; van Hoof 2008). By increasing users' duration of stay, the overall use of public space can be maintained, which in turn can invite greater use by oncoming passersby (Gehl and Svarre 2013, 19).

The following subsections summarize the evolution of human thermal assessment indices and models according to changing needs from safety to productivity and mental and physiological well-being.

Thermal Indices

Over the last century, several indices and models have been developed to predict the combined effect of multiple microclimate variables on human physiological sensation. Thermal indices provide single output values for specific applications, e.g., optimal temperature exposure for labour productivity in hot environments, or maximum exposure times for expeditions in extreme environments. Although many classifications exist, the indices can be grouped according to three major categories: direct indices, empirical indices, and rational indices (Parsons 2003).

Direct indices assess the combined effect of certain microclimate variables according to data that can be directly measured from the thermal environment. These do not consider subjective parameters, and therefore only provide objective information about the thermal stress posed by the physical environment to humans in general. In other words, direct indices combine two or more environmental variables to predict particular effects on human thermal sensation. For instance, the Wind Chill Factor (WCF) provides an output value that represents the skin temperature for a reference environment, i.e., low wind velocity with average levels of radiative and convective heat flow from the body, that would result from the combined effect of air temperature and elevated wind velocity in the measured environment (Siple and Passel 1945).

Empirical indices consider human physiological parameters by analyzing direct measurements of the thermal environment in relation to subjective ratings from participants in experimental settings. Examples of this type of index are Effective Temperature (ET) by Houghten and Yagloglou (1923 in Auliciems and Szokolay 2007) and Predicted Four-Hour Sweat Rate (P4SR) by McArdle et al. (1947 in Parsons 2003). While empirical indices factor both environmental and human physiological parameters, they remain limited as they do not comprehensively address all relevant physical and physiological parameters.

Human Heat Balance

Prior to the 1970s, thermal sensation could only be estimated using direct and empirical indices, which were based on knowledge of human physiology but did not reflect principles of heat transfer. This mainly physiological approach is known as the American School of environmental ergonomics. In 1970, Pavl Ole Fanger released the first human heat balance model, which provided HVAC engineers with a method to estimate energy loads and design requirements for specific situations. This event led to the emergence of a European School of environmental ergonomics that sought to assess thermal comfort using heat transfer principles. Consequently, rational indices emerged as the output values of heat balance models, which assess the combined effect of all relevant human and environmental variables according to heat transfer principles. (Fanger 1970). PMV and all other heat balance models are based on the following equation:

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \qquad (1)$$

Where: M is metabolic rate
W is physical work output
R is the body's net radiation
C is convective heat flow
E_D is latent heat flow by diffusion of water vapour through the skin
E_{Re} is latent heat flow by respiration
E_{Sw} is latent heat flow by sweat evaporation
S is the body mass storage of heat flow from cooling or heating

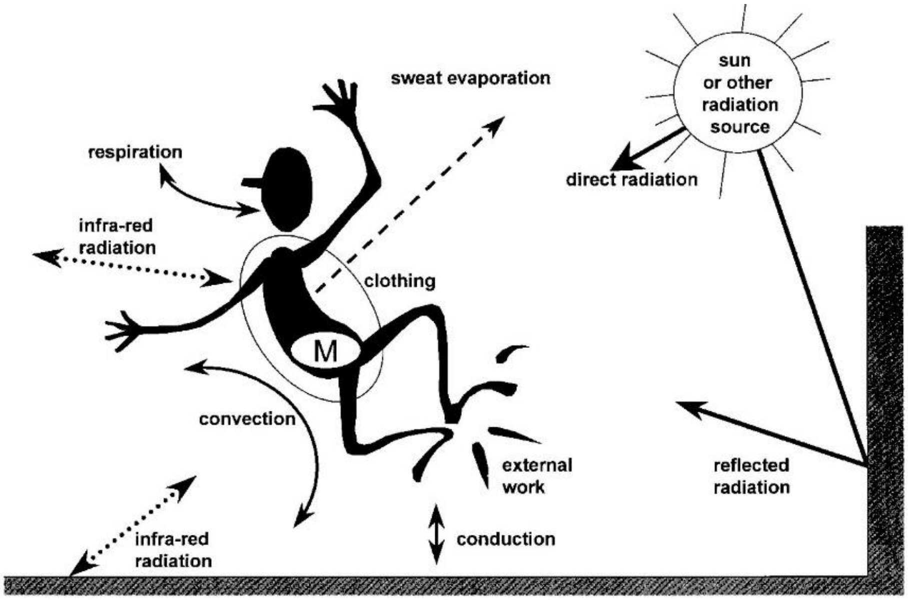


Figure 2.22 Schematic of human heat balance with the thermal environment. (Havenith 1999)

Input values for the equation are obtained from assessment of six essential environmental and personal parameters. Environmental parameters consist of air temperature (C, E_{Re}), relative humidity (E_{D}, E_{Re}, E_{Sw}), wind speed (C, E_{Sw}), and mean radiant temperature (R), while personal parameters are clothing thermal resistance and metabolic rate (Figure 2.22).

Predicted Mean Vote (PMV)

The PMV model aimed to provide a method for determining the thermal load requirements of HVAC systems for optimal levels of productivity and thermal comfort within steady-state indoor environments located in temperate climate zones. To develop the model, Fanger collected subjective comfort votes from 256 Danish subjects—64 female and 64 male college students (mean age = 23) and 64 female and 64 male elderly subjects (mean age = 68)—performing sedentary activity (approx. 50 $W \cdot m^{-2}$ or 1.0 MET) and wearing light clothing (0.6 clos) in a climate-controlled environment according to various combinations of air temperature, mean radiant temperature, and relative humidity, with air velocity maintained around 0.1 $m \cdot s^{-1}$. Earlier experiments by Nevins et al. (1966 in Fanger 1970) used the heat balance equation to predict thermal comfort for 720 American subjects—360 female and 360 male college students—and these served as the basis for comparison and analysis with the results from experiments for the PMV model. Fanger found that Danish and American subjects of all ages had very similar neutral temperatures, i.e., the ambient temperature at which an individual feels neither cool nor warm. Considering the lack of data relating human thermal adaptation to thermal comfort, Fanger asserted that the PMV equation could be used for indoor environments within temperate and tropical climates (Fanger 1970). Following its release, the model was eventually adopted by standards including ISO 7730 in 1984 and ASHRAE Standard 55 in 2004 (Enescu 2019; Olesen and Brager 2004).

While the PMV model effectively factors the six major physical variables of thermal comfort, it contains important geographic and physiological limitations. Studies find that the model underestimates personal factors such as metabolic rate and clothing insulation (Havenith et al. 2002) and does not account for user adaptation (Auliciems 1981; Nicol and Humphreys 1973; van Hoof 2008; Humphreys 1978; Chen et al. 2018).

Since PMV was developed from climate chamber research and was primarily intended for lightly clothed individuals performing moderate metabolic activity in steady-state indoor environments located within temperate climates, it does not apply for transient conditions in extreme thermal environments (van Hoof 2008). Moreover, as with many other earlier thermal indices, the PMV model was developed with the assumption that thermal comfort is identical to TNZ (Auliciems 1981). But while the PMV model was developed to assist in the design of steady state environments—i.e., conditions where thermal storage is maintained at 0 W·m^{-2}—as a sufficient condition for thermal comfort, field studies in environmental ergonomics show that individual neutral temperatures shift according to outdoor climate, time of year, and behavioural adaptation (Nicol and Humphreys 1973; Gerlach 1974; Humphreys 1978; Auliciems 1981; Nikolopoulou and Steemers 2003; Ning et al. 2016; Chen et al. 2018; Guo et al. 2018; Leng et al. 2019). Particularly in human biometeorology, field measurements of thermal sensation and comfort for cold and hot outdoor environments show considerable effects of behavioural and psychological factors (Höppe 2002; Nikolopoulou, Baker, and Steemers 2001; Ning et al. 2016; Chen et al. 2018).

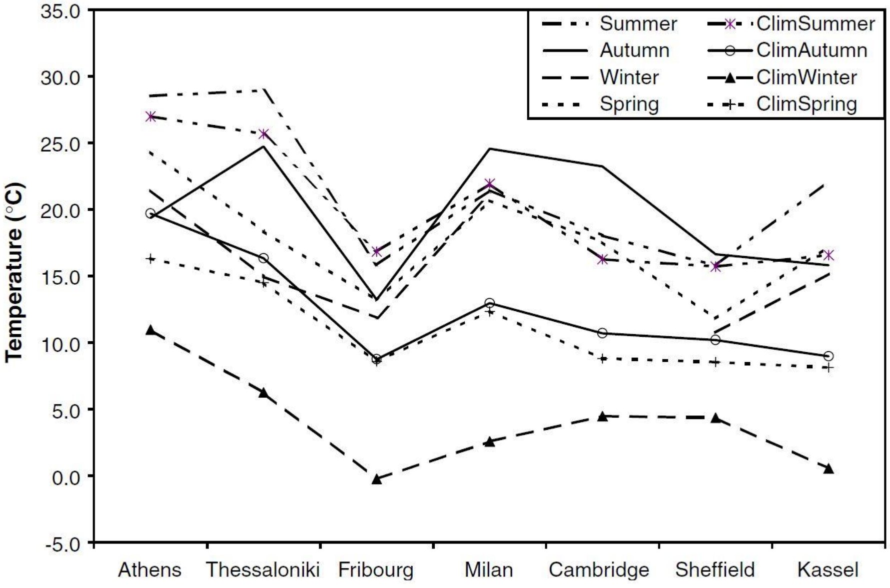


Figure 2.23 Variation of people's TNZ at measured local air temperatures for different seasons and locations. (Nikolopoulou and Lykoudis 2005)

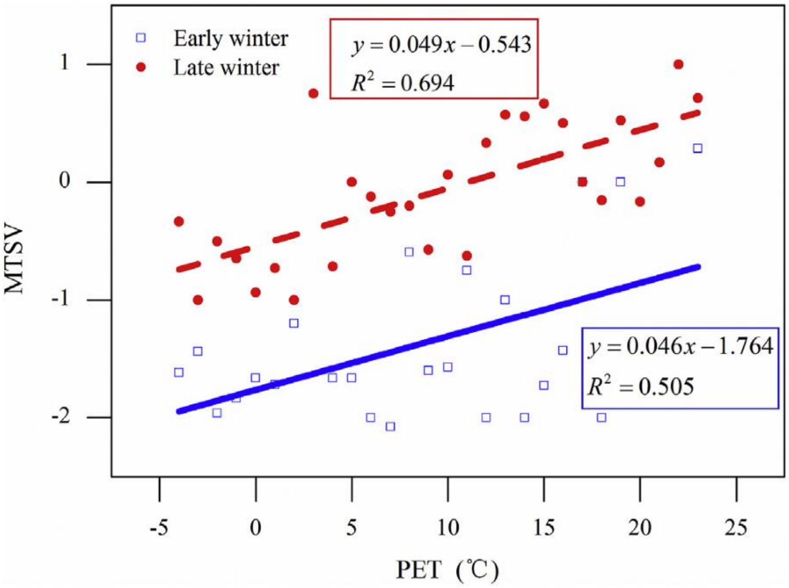


Figure 2.24 Mean Thermal Sensation Votes (MTSV) of 31 participants for early winter and late winter during an 11-month study in Harbin, China. Thermal Sensation Votes (TSV) were ranked on an 11-point scale, and within this chart "1" is slightly warm, "0" is neutral, "-1" is slightly cool, and "-2" is cool. (Chen et al. 2018)

This demonstrates the temporary nature of thermal comfort and the possibility for a wider range of thermal sensations over time and space in outdoor environments. From this, it is concluded that thermal comfort can extend beyond the TNZ and results from shifting perceptions of intensity, duration, and location of thermal stimuli over time. Consequently, rather than striving for steady state conditions, it is more critical for the design of outdoor microclimates to provide users with environmental options for appropriate lengths of time and space.

Subsequent Heat Budget Models

Over the last 50 years, heat budget models developed with increasing accuracy, relevance to human physiology, and range of application. Some include Standard Effective Temperature (SET) by Gagge et al. (1971), Klima-Michel-Modell (KMM) by Jendritzky et al. (1979), PMV* by Gagge et al. (1986), Munich Energy-Balance Model for Individuals (MEMI) by Höppe (1984), OUT_SET* by Pickup and de Dear (2000), and Universal Thermal Climate Index (UTCI) by Fiala et al. (2012). Although this section briefly overviews thermal indices, steady-state heat budget models, and transient multi-node heat budget models, Katić et al. (2016) and Enescu (2019) provide more comprehensive reviews of these models.

Standard Effective Temperature (SET)

While the PMV model considered human heat balance as a single transfer between the human body and the environment, subsequent models began integrating "nodes" to account for the layers beneath the skin. To better reflect human physiology and the heat transfer occurring between the skin and body core, Gagge et al. (1971) developed the Standard Effective Temperature (SET), also known as the Pierce Two-Node model. This model treats the human body as a two-layered cylinder, with the inner layer representing the core and the outer layer representing the skin.

Klima-Michel-Modell (KMM)

To expand the PMV model's range of application to include urban microclimates, Jendritzky and Nübler (1981) developed the Klima-Michel-Modell (KMM). This model brought greater representation of the bioclimate to the assessment of human heat balance by integrating urban climatological data and material properties into the calculation of mean radiant temperature (T_{mrt}).

Munich Energy-Balance Model for Individuals (MEMI)

KMM was later followed by Höppe's (1984) Munich Energy-Balance Model for Individuals (MEMI), which introduced equations for a two-node representation of the human body while also factoring the variables of outdoor microclimates. The equations are heat flow from the core to the skin F_{CS} (based on the Pierce Two-Node Model) and heat flow from the outer surface of the skin to the outer clothing surface F_{SC} (based on Fanger's PMV). They are expressed as:

$$F_{\mathrm{CS}} = v_{\mathrm{b}} \cdot \rho_{\mathrm{b}} \cdot c_{\mathrm{b}} \cdot (T_{\mathrm{c}} - T_{\mathrm{sk}}) \qquad (2)$$

$$F_{\mathrm{SC}} = (1 / I_{\mathrm{cl}}) \cdot (T_{\mathrm{sk}} - T_{\mathrm{cl}}) \qquad (3)$$

Where: v_{b} is blood flow from body core to skin ($\mathrm{ls^{-1}m^{-2}}$)
ρ_{b} is blood density (Kg/l)
c_{b} is specific heat capacity ($W\mathrm{s\,K^{-1}\,kg^{-1}}$)
T_{c} is core temperature
T_{sk} is mean skin temperature
I_{cl} is heat resistance of the clothing ($\mathrm{K\,m^2\,W^{-1}}$)
T_{cl} is clothing mean surface temperature

In relation to the human heat balance equation (1), parameters and their respective variables are:

air temperature (C, E_{Re})
mean radiant temperature (R)
air velocity (C, E_{Sw})
relative humidity (E_{D}, E_{Re}, E_{Sw})
clothing insulation (I_{cl})
metabolism (v_{b}, ρ_{b}, c_{b})

MEMI's output value is the Physiological Equivalent Temperature (PET) index (Mayer and Höppe 1987; Höppe 1999). The index uses an Equivalent Temperature (*ET*) approach, which estimates the temperature of a reference environment that would generate the same intensity of sensation as the combined effect of all other thermal comfort parameters in the measured environment. The reference environment is set to steady-state indoor conditions where air temperature (T_a) is equal to mean radiant temperature (T_{mrt}), vapour pressure (P_a) of the ambient air is 12hPa (50% relative humidity at 20 °C), air velocity (V_a) is 0.1 $m \cdot s^{-1}$, and the individual is performing sedentary metabolic work (W) at 80W while wearing light clothing (I_{cl}) of 0.9 clo.

Universal Thermal Climate Index (UTCI) – Fiala

Findings in human biometeorology revealed a need to better factor the transient, behavioural, and physiological aspects of human thermal sensation for the full spectrum of indoor and outdoor microclimate conditions. Through collaboration across experts in physiology, thermal physiology, modelling (thermo-physiological and radiation), biometeorology, occupational medicine, application development, and others, the Cooperation in Science and Technical Development (COST Action 730, supported by the EU RTD Framework Programme) along with the International Society on Biometeorology (ISB) followed with the development of a new thermal assessment model. This led to the Universal Thermal Climate Index (UTCI), which later merged with the Fiala model to become the UTCI-Fiala model. The model aims to meet the following requirements:

1. Thermo-physiologically responsive to all modes of heat exchange between body and environment
2. Applicable for whole-body calculations but also for local skin cooling (frost bite) (see Shitzer and Tikusis (2011)
3. Valid in all climates, seasons, and time and spatial scales
4. Appropriate for key applications in human biometeorology

(Jendritzky et al. 2012, 425)

Moreover, it considers:

1. the behavioural adaptation of clothing insulation observed for the general urban population in relation to the actual environmental temperature,
2. the distribution of the clothing over different body parts providing local insulation values for the different model segments, and
3. the reduction of thermal and evaporative clothing resistances caused by wind and limb movements of the wearer, who is assumed to be walking at a speed of 4 km/h on level ground (2.3 MET=135 W/m2).

(Ibid., 425)

Inline with these objectives, the UTCI-Fiala model builds on preceding models and recent studies by integrating input parameters for clothing adaptation and calculating heat exchange between multiple nodes, i.e., core, muscle tissue, fat, and skin for 12 body segments and 63 spatial sectors (see Figure 2.25). Combining greater accuracy in human physiology with the integration of behavioural responses over set time intervals, UTCI-Fiala is well suited for heat budget assessment within outdoor environments. In addition, it allows for the calculation of human heat budget for environments ranging from -40 to 46 °C (Blazejczyk et al. 2013).

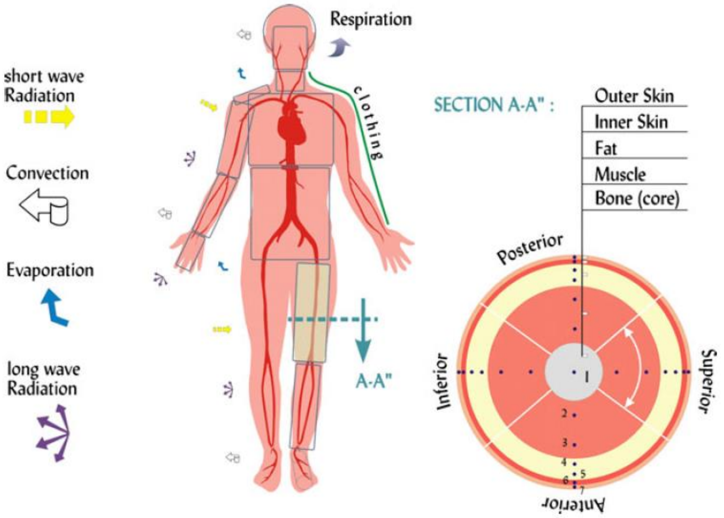


Figure 2.25 Schematic of UTCI-Fiala model body segments and nodes. (Fiala et al. 2012)

Assessing Psychological Factors

While several researchers maintain that psychological factors are highly influential to thermal comfort, there has yet to be a method for integrating the former into heat budget models (van Hoof 2007; Nicol, Humphreys, and Roaf 2012). Nikolopoulou and Steemers (2003) find that up to 50% of the variation between objective measurements and subjective comfort votes can not be explained by microclimate parameters and suggest that the remaining 50% could be attributed to psychological factors. Rohles (2007) also finds that in rooms with identical microclimate conditions, the visual perception of temperature resulted in different thermal sensation. This demonstrates that in a less comfortable environment, the perception of visual information pertaining to comfort can improve thermal comfort, e.g., through colours, materials, and symbols communicating warmth to the subject.

2.4 Conclusions

This chapter presented the elements of climate and weather with relevance to urban design, requirements for successful use and enjoyment of public spaces, and the human factors related to thermal environments.

Section 2.1 showed that local climate variability in the Northern Hemisphere is mainly determined by heat and moisture carried via macroscale air currents. Thus, local climate depends on a location's position relative to the westerly wind belt, and the influence of oceanic climate and land surface properties. Further, urban design at the micro scale is most challenging as the diverse needs of public spaces often require conflicting design configurations. User-friendly analytical tools such as the H/W ratio can assist designers in predicting possible outcomes for these conflicts.

Section 2.2 highlighted that the success of public spaces is primarily a function of the presence of people. This is demonstrated by Gehl's principle of necessary, optional, and social activities, which relates and synthesizes the elements of spatial configuration, activity distribution, and ambient stimuli toward the use and enjoyment of public spaces by people over time. This section also highlighted that user control has a significant influence on the quality of public spaces. Moreover, methods were presented for assessing the performance of public spaces, which include quantitative and qualitative methods. Levels of attendance do not imply enjoyment, and levels of enjoyment can be estimated by measuring the length of time people spend within public spaces and noting the presence of social activity.

Section 2.3 elaborated that "satisfaction with the thermal environment" depends on the purposes of specific individuals. The same definition may refer to a state of neutrality or a dynamic, transient state of thermal sensation. Thermal comfort can satisfy purposes such as safety, productivity, well-being, and recreation, which all possess specific thermal tolerance ranges per individual needs, preferences, activities, and exposure times. This section also showed that physiological, behavioural, and psychological adaptation considerably influence the perception and sensation of thermal comfort. From this, it was concluded that perceived control (see cognitive control in section 2.2) is a function of microclimate severity, exposure time, and proximity to nearby retreat thermal environments. The evolution of human thermal indices and heat budget models shows growing attention to questions of well-being in extreme outdoor thermal environments. Among these, the UTCI-Fiala shows the most compatibility for addressing issues of outdoor thermal comfort in WiSR environments. However, while the indices and models are effective tools for factoring the physiological components related to the use and enjoyment of public spaces, they remain limited in their ability to factor thermal adaptation. Nevertheless, thermal adaptation can be more readily addressed through the design elements of spatial configuration, activity distribution, and ambient stimuli.

The following chapter elaborates on the challenge of public space design in mid- to high-latitude cities.

3. The Challenge of WiSR Public Space Design

Chapter 2 reviewed the factors that contribute to the use and enjoyment of public spaces in general, emphasizing that different configurations of ambient stimuli, activity distribution, and space will lead to specific uses by different people at various intervals of time. In this chapter, these elements are reviewed with respect to use and enjoyment within public spaces that are exposed to extreme seasonal variation.

This thesis purposely refrains from using terms such as “winter city”, “cold climate”, or “boreal climate”, as these terms are ineffective in describing the problem under investigation. Instead, Wide Seasonal Range (WiSR) is proposed as a term for urban climates which experience both severe cold winters and hot summers within the same year. The rationale for WiSR is further elaborated in Section 3.3, but first, the following section describes the existing knowledge on urban design responses to winter climate in mid- to high latitude cities.

3.1 Existing Knowledge on Winter-Related Urban Design Issues

While great progress has been made on the study of human spatial behaviour in public spaces in general, early research did not provide explicit strategies to address the effects of severe winter climate on human activity. In the early 1980s, the Winter City movement emerged with the goal of improving the wintertime quality of pedestrian environments for cities with winter climate that is severe, prolonged, or both (Neal and Coles 1989). The movement began in 1982 when Takeshi Itagaki, then mayor of Sapporo, invited mayors and civic officials from Edmonton, Harbin, Shenyang, Helsinki, Munich, Anchorage, Minneapolis, Portland, Sapporo, and 18 other Japanese cities to attend the “First Mayor’s Conference” by the Northern Intercity Conference, an international research hub targeting urban winter-related problems.

From that point on, the movement gained traction through multidisciplinary conferences and research investigating strategies for all cities above the 45th parallel with mean monthly temperature for January below 0 °C (Rogers and Hanson 1980 in Pressman 1988). A major outcome of the 1982 conference was the founding of the Winter Cities Association (WCA), which sought to reinforce the ongoing work of the Northern Intercity Conference (WWCAM.org, accessed October 4th, 2020). The WCA was founded by Norman Pressman, who is arguably the most cited researcher in winter-related urban design literature. Pressman’s research consists of multiple books and articles written between the years of 1985-1996, culminating with his most recent monograph in 2004 (Stout et al. 2018).

Despite the climbing number of publications from the 1980s into the early 1990s, there were fewer studies following the turn of the new millennium. In 2004, the Northern Intercity Conference changed its name to the World Winter Cities Association for Mayors (WWCAM) in attempt to stimulate further research (WWCAM.org). But in 2005, Winter City studies nearly halted as the WCA could no longer sustain itself as a non-profit organization (Davies 2015). To carry forward the objectives of the Winter City movement, Patrick Coleman followed by founding the Winter Cities Institute (wintercities.com, accessed October 6th, 2020). However, the level of academic attention that was present in the late 1980s never returned. Nevertheless, in recent years—likely due to the growing awareness on the interrelated effects of human behaviour and climate—there is growing interest on the study of public spaces within extreme hot and cold climates.

To describe the broad scope of effects incurred by long and severe winters on human activities, Culjat and Erskine (1988) categorize *direct* and *indirect* influences. *Direct* influences of climate are those that immediately impact the fulfilment of certain human activities due to harsh weather conditions at the time of such activities. Examples of direct influences include frigid cold air temperature, high wind speed, reduced daylight, heavy snowfall, blowing snow, or freezing precipitation. The stated examples can directly influence thermal comfort, mobility, safety, and voluntary outdoor exposure.

Consequently, *indirect* influences are those that either support or impede the fulfilment of certain activities through humans' responses to direct influences of climate. The responses in question refer to urban planning decisions made in anticipation of the climate. In WiSR cities, these include building and infrastructural modifications such as enlarged sidewalks for snowbanks; enlarged roads for snow clearing; the construction of transit shelters and canopies; the construction and renovation of enclosures above, below, and at grade; or the addition of vegetation or structures as windbreaks. The consequences of poor planning responses to climate may include a narrowed range of optional activities, discontent for the winter season (Phillips 1986; Stout et al. 2018), promoted sedentary behaviour (Toronto Public Health 2012), reduced street-level economic activity (Zacharias 2001), and greater environmental stress—e.g., from extended walking distances and waiting times in severe cold and increased exposure to poor air quality, noise, and strong winds.

3.2 Case Studies: Permanent, Convertible, and Ephemeral

After studying various winter city strategies and policies around the world, Pressman (1985) noted two prevailing approaches. He defines the first approach as "do not overprotect man from nature" (Ibid., xiii), which treats city dwellers as highly resilient and adaptive to the effects of winter climate, and relies on passive design strategies such as climate-sensitive street layouts, building geometry, and vegetation to extend outdoor human activity. The second approach, "offer as much protection from the elements as possible" (Ibid.), aims to fully shelter pedestrians from outdoor thermal environments and maintain all-year indoor economic activity through a connected pedestrian network of overhead, underground, or street-level passages. These approaches could be termed "permanent", as they imply a single spatial configuration to be maintained throughout the entire year. But other design approaches have also been noted but have yet to be studied at depth in relation to winter-related issues. One is the "convertible" approach, which implies semi-outdoor or semi-indoor structures with enclosures that adjust to seasonal climate (see also adaptable, modulable, adjustable). Another approach is termed “ephemeral”, and implies lightweight, movable, and mountable/dismountable structures intended for temporary events of numerous types. The following subsections compare and contrast precedents for WiSR cities according to these notable approaches.

3.2.1 Permanent Approach: Summer-based

This first approach could be termed as the “Copenhagen model”, as it mostly stems from principles developed by Danish architects and urbanists for public spaces in Northern Europe. Despite its origin, however, many public space designers around the world rely on this model as it contains universal principles for generating greater social and economic activity—e.g., Gehl’s principle of necessary, optional, and social activities. The model essentially seeks to maximise the beneficial aspects of nature and the built environment for human senses and activities. It places particular emphasis on low-cost, passive strategies that prioritize the quality of public spaces during ideal outdoor climate. Some strategies from this approach include shaping natural elements such as planting, water, and hard surfaces so as to afford public space users with shade in the summer, wind protection and sunshine on colder days, and visual connections with people and natural scenery throughout the city.

Regarding all-season urban design for Nordic cities, Gehl (1992) argues that the summertime performance of public spaces is most conducive to their year-long use and enjoyment. Concurrently, the prescription “endure the winter in order to have a really enjoyable summer” (Gehl 1990, 28 in Li 1994, 96) does not seem problematic for northern cities where the average January temperature is moderate.

But while this approach remains effective for the temperate maritime climate of Northern Europe, it is not suitable for WiSR cities as it does not consider the effects of severe and prolonged cold. Hence, the Scandinavian proverb “‘If the city works well in the summer, we can form the networks that will take us through the winter’” (Gehl 1992, 16) would take on different meanings for city dwellers who frequently experience wind chill below -20 °C than for those living where extreme cold is less problematic and the lack of solar radiation is a much greater concern. As Culjat and Erskine (1988) report: “Being a basic element of the natural environment, climate *is* one of the parameters of all architectural and urban design. The more extreme the climate is, the more necessary it becomes to respond to it” (Culjat and Erskine 1988, 348).

In addition, there are few successful documented examples of this approach in WiSR cities. This then makes it seem arbitrary to classify WiSR public spaces according to the Copenhagen model. Nevertheless, most public spaces in WiSR cities show greater levels of use and enjoyment for the summertime than during the colder seasons. Considering that some public spaces operate on the basis of their summertime quality, these are considered as attempts for the Copenhagen model in a WiSR climate.

Sparks Pedestrian Street, Ottawa

One example of such attempts is Sparks Street in Ottawa. The project, designed by Balharrie Helmer and Morin Architects and built in 1967, emerged as a response to declining retail activity in the downtown core over the 1950s. The space attracted greater summer use by providing optional activities such as outdoor cafés, canopies, seating areas, play structures, planting, and street art (Cook 2008). By taking the street's entire width, the open space also allowed for a greater variety of temporary events and activities.

On the other hand, there are important drawbacks to the design of the street and its surrounding buildings. First, the ground-level indoor environments mainly accommodate necessary activities or private indoor spaces. As a result, there is poor compatibility between the optional activities of the outdoor public space and indoor optional activities. Second, the street, oriented East-West, is interrupted at every intersection with North-South vehicular roads. As such, the areas near intersections have high noise levels and require greater caution for both pedestrians and drivers. Finally, the urban geometry is not ideal for street-level human activities. On one hand, the street's orientation leaves the South portion of the space in constant shade. On the other hand, the edge conditions at the base of buildings offer few opportunities for human interaction over extended lengths. During suboptimal weather conditions, pedestrian thermal comfort is exacerbated by reduced solar radiation, and a lack of warmth or shelter from cold drafts and wet surfaces.

In the end, it is likely that the Copenhagen model's lack of explicit solutions for severe winter climate challenges leads urban planners and designers to regard it as incompatible for WiSR public space design. However, further research is needed to determine the Copenhagen model's effectiveness at all-season use and enjoyment, since there are few documented projects that substantially apply its principles and strategies in WiSR settings.

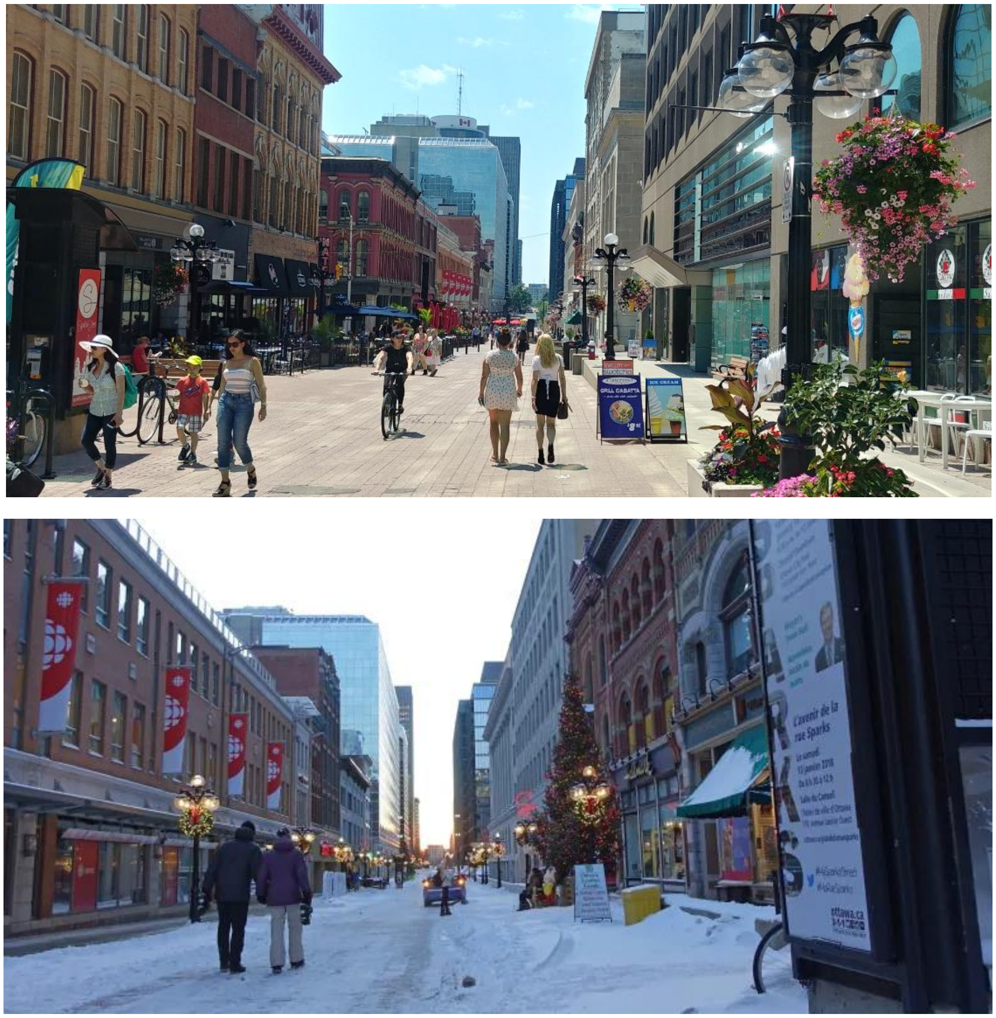


Figure 3.1 Sparks pedestrian street, Ottawa on July 2nd, 2019 (above: Leroux 2019) and January 13, 2019 (below: Pritchard 2019)

3.2.2 Permanent Approach: Winter-based

A considerable number of privately operated indoor pedestrian spaces exist, and these can provide relief from harsh winter climate within certain time intervals, and for certain users and activities (Gehl 1989; Pressman 1995). Under these conditions, many assert that indoor pedestrian networks should not be considered public, underscoring that these spaces narrow the possible range of activities and do not offer users the same degree of sociability and access as street-level pedestrian outdoor spaces (Boddy 1992; Gehl 1989; Nash 1981; Robertson 1988; Whyte 1980). But although this approach may not apply directly to public spaces, it is important to consider its influence on the overall public realm.

*Plus 15 Pedestrian System, Calgary**

Calgary's +15 pedestrian system attempts to separate pedestrian activity from vehicular traffic and outdoor weather (Pressman 1995). Its name refers to enclosed walkways connecting buildings at 15 feet above ground level. Proposed by the City Planning Department in 1966 and built in 1970, the project resulted in 8.5 kilometres of indoor pedestrian walkways connecting various offices, retail, and institutional uses via 38 overhead bridges as of 1986 (Ibid.; Rushman 1977). As a commercial project, the +15 succeeded in increasing horizontal mobility for building users on the second floor, providing comfortable shopping environments throughout the year, and increasing retail activity for merchants connected to the +15 system.

Despite the benefits to some users within working hours, overhead pedestrian networks often lead to an overall decrease in the use and enjoyment of public spaces. The system effectively shelters from climate but does not satisfy needs for collective social activity as found within successful public spaces. Interestingly, studies find that underground pedestrian networks can maintain levels of outdoor public activity if they are well connected to the urban transit system (Zacharias 1993; Pressman 1988). Unfortunately, however, the current studies suggest that the overhead type of pedestrian systems is insufficient in extending the all-year use and enjoyment in WiSR public spaces.

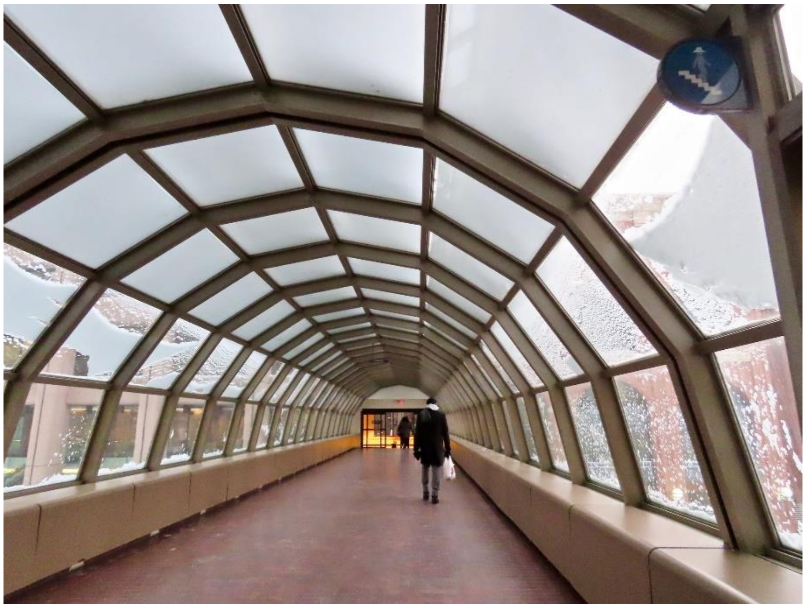


Figure 3.2 Indoor snapshot of the +15 pedestrian network in Calgary, February 11. (Ben 2019)

Figure 3.3 View toward the +15 in Calgary, July 17. (Urban Grammar 2005)

*Allen Lambert Galleria, Toronto**

Another example of privately-operated indoor pedestrian spaces is the Allen Lambert Galleria in Toronto. Designed by Santiago Calatrava and built in 1992, the galleria sought to connect Bay Street to Garden Court and Heritage Court via the Canada Trust Lobby. The space mainly serves as a connection between necessary activities ("Brookfield Place (Formerly BCE Place)" n.d.). As with the +15, the project effectively shelters certain city dwellers from outdoor weather during working hours. However, in this case, the lack of elevated pedestrian connections benefits the quality of the surrounding public spaces. As Whyte (1980) states, indoor pedestrian networks can contribute to street vitality provided they possess a strong physical and symbolic (e.g., visual, formal) connection to the street. Figure 3.4 shows that the galleria creates a usable sheltered space in an otherwise vacant space between buildings and asserts a strong visual connection to the street without interfering with the street's microclimate and views. Still, the galleria remains semi-private, which can only partially address the question of extending the use and enjoyment of public spaces.

From a first analysis of these two approaches, the limitations of WiSR become clear. In areas that do not possess a strong connection between the indoor transit system and outdoor public spaces, users are left with only two options for sociable spaces when outdoor conditions are below an acceptable thermal range. One option is indoor spaces, which are only partially public and typically reduce all-year pedestrian activity. The other option is outdoor public spaces, which only offer a limited range of activities due to a lack of safety, comfort, and mobility. For either of these options, the opportunities for collective social activities are limited.

Figure 3.4 Allen Lambert Galleria, Toronto (left: tpyj September 19, 2008; right: Evgeny June 11, 2010). Despite that the space is fully enclosed, the extension of the awning and transparency of the entrance reinforces the connection to the street.

3.2.3 Permanent Approach: All-Season

Noting these two approaches, Pressman (1985) concludes that a third approach could be envisioned through the "provision of choice. [...] embracing positive aspects of winter and protecting against the negative ones". Other researchers also stress the value of this approach (Gutheim 1979; Gehl 1992; Li 1994). It essentially aims to create a well-connected system of indoor and outdoor public spaces offering sustained social and economic activity throughout the year. But as Li (1994) notes, there is yet to be a documented example of this approach being applied city-wide in WiSR regions.

*Galleria Vittorio Emanuele II, Milan**

Although there are few documented precedents for WiSR cities, some examples from temperate climate setting can provide insight on sheltered public spaces. The Galleria Vittorio Emanuele II in Milan is one of these examples. Designed by Giuseppe Mengoni in 1861 and built in 1877, the galleria provides public access to a pedestrian retail mall sheltered by a glazed arcade (Stoyanova 2015; “Galleria Vittorio Emanuele - Giuseppe Mengoni - Great Buildings Architecture” n.d.). While the space is located in a densely populated area, which automatically raises the likelihood of public space attendance, the galleria shows good conformity with the Copenhagen model while offering the necessary shelter for days where weather is less ideal.

For instance, the level of public accessibility to the space allows it to host a greater range of optional and social activities, and in combination with the embedded retail shops, this leads to an even higher rate of attendance. Once users are in the galleria, the glazed canopy can extend their stay by offering shelter from rain and snow. By contrast to the Allen Lambert Galleria, only the roof remains covered, which creates a transitional space between the steady state indoor environments of the retail shops and the transient outdoor conditions of the surrounding public space. Depending on the prevailing wind direction and the geometry of the galleria’s openings, the space could also provide shelter from cold drafts. This last point is particularly important for WiSR public spaces, as an inadequate orientation of a covered pedestrian street could constrict and accelerate wind flow.

Figure 3.5 Archway entrance to Galleria Vittorio Emanuele II from Piazza del Duomo (left: Bresciani 2016; right: Brown 2007)

Figure 3.6 Interior views of the Galleria Vittorio Emanuele II. (left: Tisseghem 2019; right: Expat Alli n.d.)

Figure 3.7 Interior snapshot along the galleria's long axis on a cold day. The space is teeming with pedestrian activity, afforded by optional activities, the presence of other people, people's own behavioural adaptation (clothing insulation), and the glazed vault enclosure, which shelters from wind drafts, rain, and snow. (John Straube, n.d.)

3.2.4 Convertible Approach: All-Season

Upon recognizing the limitations of a permanent summer- or winter-based approach, and without any precedent on a permanent strategy for both seasons, attempts were made to implement structures that could convert to meet seasonal needs. Some projects, such as the Rideau Transit Mall of 1983, perform poorly and tend toward a winter-based approach rather than a fully all-season convertible structure. Other projects, such as the recently completed glazed canopy in Zaryadye Park, show a great rate of success and operate as partial enclosures optimized for wide seasonal variations.

Rideau Sidewalk Enclosure, Ottawa

Designed by Sankey Partnership Architects and built in 1983, the Rideau sidewalk enclosure was designed to maintain adequate levels of pedestrian activity for retail merchants of Rideau Street following the construction of the Rideau Centre, which would contain 188 new stores. The Rideau Transit Mall sought to achieve this by providing a convertible enclosure along the North and South sides of Rideau Street for use by transit users and patrons of existing store merchants and the new shopping centre (Chen 1986).

From a thermal comfort standpoint, the enclosed space provided shelter from wind, rain, snow, and overhead radiant heaters were programmed to maintain temperature at 10 °C during the period where outdoor conditions were below freezing. These conditions were estimated to provide adequate shelter for temporary use by transit riders wearing winter clothing. During the hot season, 30% of the enclosure's wall surfaces could open to allow for natural ventilation using sliding glass panels.

But in spite of these strategies, the built enclosure had an uneven distribution of heat. The radiant heaters could not account for the heat loss from frequently opened doors at high pedestrian volumes, and thus thermal conditions in the space were often unpredictable. In addition, the wide variation in the amount of solar exposure for north and south enclosures (See Figure 3.14) could result in air temperature differences up to 10 °C.

The radiant heat emitted by infrared heaters would also melt snow and ice on the higher portion of the glass roof. As the melted snow and ice dripped toward the lower end of the roof, freezing would occur and ice would accumulate on the lower edge of the roof. This necessitated the installation of electrical heating cables to prevent the build up of ice in affected zones. The short distance of the enclosure to the street (0.6 meters) also demanded unforeseen maintenance as passing buses frequently splashed dirt, snow, and ice against the glazed surfaces, which also degraded the enclosure's public image.

In terms of spatial and activity distribution, the enclosure's undulating shape adds multiple physical boundaries to the space, and this limits the possible range of uses. In Milan's galleria, the space is large enough to accommodate high volumes of pedestrians while also providing temporary uses such as semi-outdoor patios, displays, or any other temporary installation.

As a result, the sidewalk enclosure had a low rate of use and perception by the general public. The combined effect of low ceiling height, dim lighting, poor choice of materials, uneven temperature distribution, and a narrow range of possible uses resulted in an unattractive environment. Many also perceived that the space had become less safe as an increasing number of homeless people occupied the space for unintended uses (Chen 1986). Eventually, decreased use by patrons and elevated number of the homeless led to its dismantlement in 1993 (N.d. 2012). As Gordon (2012) of the Rideau Board of Management recalls, "The area was in decline but there's no doubt that this shelter system killed it much faster. These bus shelters smelled, they became homeless shelters, and within five years almost all the shops on that part of the street failed" (Ottawa Citizen 2012).

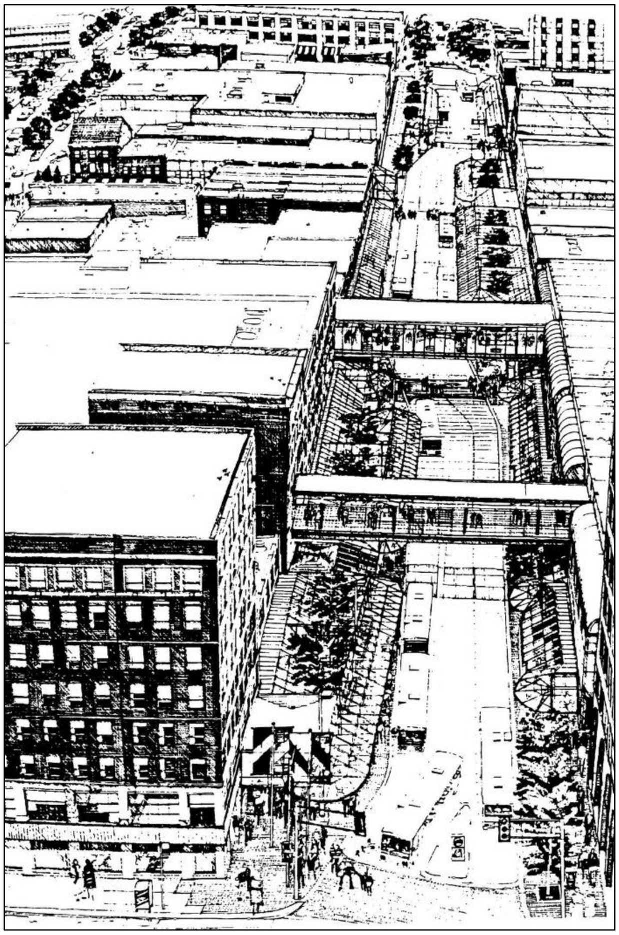


Figure 3.8 Bird's eye view of the Rideau Transit Mall proposal, with sidewalk enclosures (Sankey Partnership Architects in Pressman 1988)

Figure 3.9 Snapshot of the sidewalk enclosures in 1989 and in 2014, following dismantlement in 1993 (top: Robert Smythe 1989; bottom: Ibid. 2014)

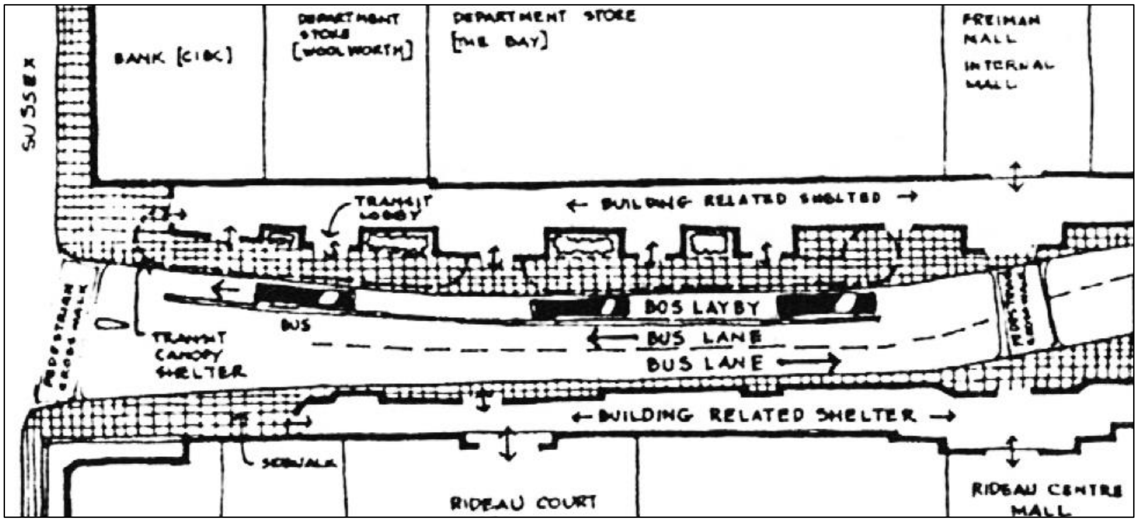


Figure 3.10 "As Built" plan of the Rideau Transit Mall at Rideau and Sussex St (Chen 1986)

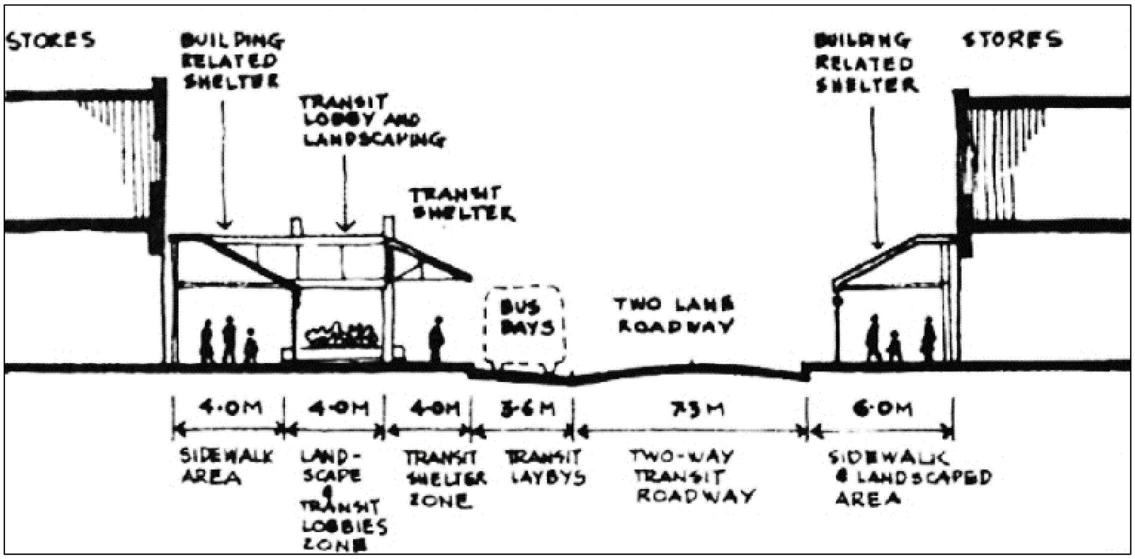


Figure 3.11 "As Built" cross-section of the Rideau sidewalk enclosures (Chen 1986)

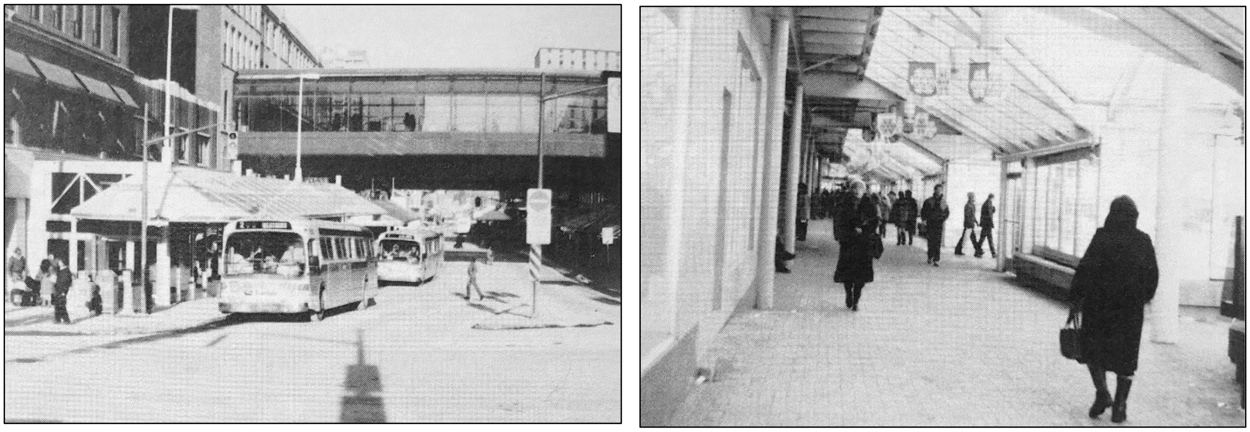


Figure 3.12 Exterior and Interior views of the Rideau sidewalk enclosures. (Patrick Chen 1988)

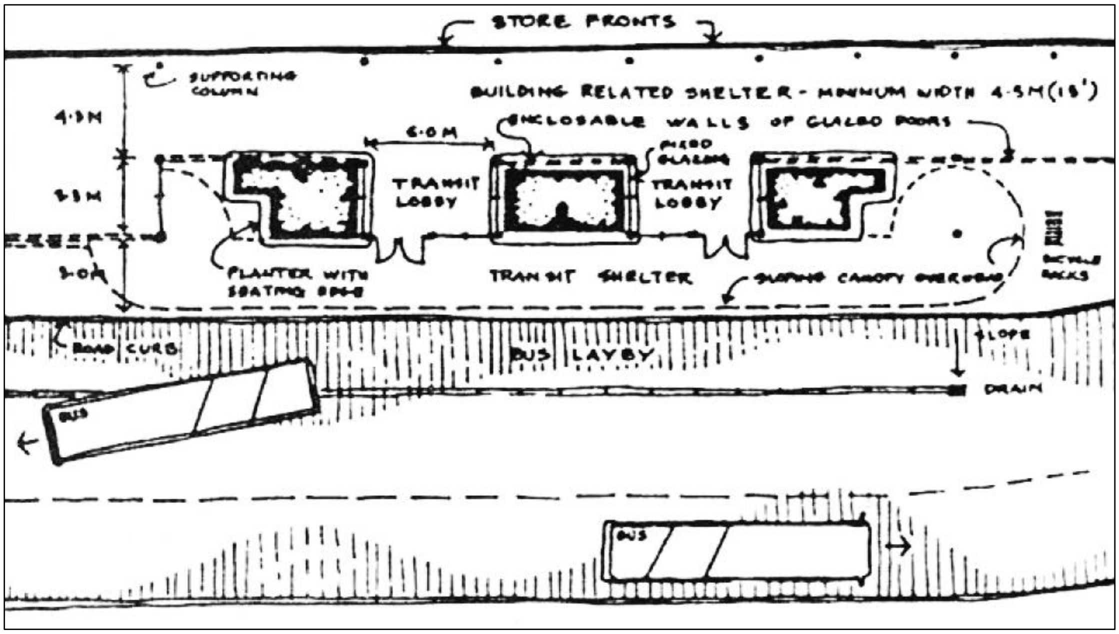


Figure 3.13 "As Built" typical area plan of the sidewalk enclosure. This view shows the convertible glazed doors in double dashed lines and the outdoor transit canopies in single dotted lines. (Chen 1986)

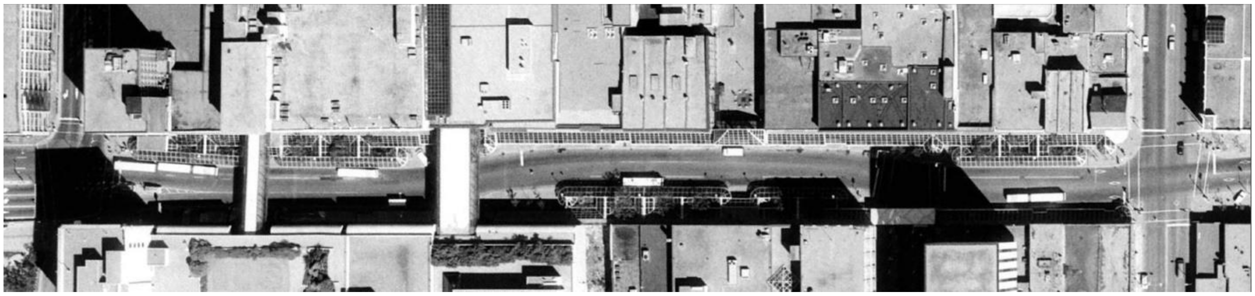


Figure 3.14 Aerial view showing the effect of an East-West street orientation on shading. The North side enclosures receives solar radiation for a considerable part of the year while the south side remains shaded most of the time. (Google Earth 1991)

Zaryadye Park, Moscow

By contrast, some large-scale projects provide convertible shelters that can be adjusted for hot and cold seasons while continuing to provide flexible year-round use of the space. Zaryadye Park's Glass Crust is a recent example and the first successful prototype of its kind in a WiSR city. Designed by Diller Scofidio + Renfro in collaboration with Transsolar and built in 2017 (“Zaryadye Park” n.d.), the Glass Crust is one of many components that constitute the 10.2-hectare park (“Zaryadye Park – the New Symbol of Moscow” n.d.). As a whole, the park condenses the physical features of Russia's four major climate types into a single space, offering—in elevating order—wetland, steppe, forest, and tundra landscapes (see Figure 3.17). The Glass Crust covers the mound-like roof of the philharmonic theatre to generate microclimate conditions that support all-season use of the space for gathering, interacting, and resting. The structure also partially covers the Large Amphitheatre, which holds a seating capacity of 1600 for festivals, concerts, and other programmed activities. On hot days, the canopy converts to allow for passive cooling via natural ventilation and active cooling through humidification (“Zaryadye Park: A New Ecological Heart for Moscow” n.d.). This is made possible by the canopy's height and geometry, operable glazed panels, a misting water irrigation system, and the roof's sloped topography. During the cold season, the glazed panels are closed to allow passive solar heat gains, and additional warmth is supplied via radiant floor heating (see Figure 3.16, Figure **3.18**, Figure **3.20**, and Figure **3.22**). Despite the lack of enclosing walls, the canopy’s geometry is shaped and positioned to prevent the penetration of wind flow during winter, which allows the space to be warmer than the surrounding unsheltered outdoor spaces (“Diller Scofidio + Renfro - Zaryadye Park in Moscow, Nature and Architecture Act as One | The Plan” n.d.).

Regarding levels of use and enjoyment, there were over 10 million visitors over the year that followed the park’s opening, and these attendance levels are expected to remain for years to come (Ibid.; “Zaryadye Park – the New Symbol of Moscow”). Many have also photographed the park during its use, and this highlights the presence of social activities during both hot and cold seasons (see Figure 3.16; Figure **3.18**; Figure **3.21**–Figure **3.23**). One of the most attractive features of the park lies in the grand views afforded by its topographic arrangement (Ibid.). At the top of the Large Amphitheatre—and sheltered by the Glass Crust—users get a broad view of the city, which includes the Moskva River, St-Basil’s Cathedral, the Red Square, the Kremlin, and the park itself.

Considering that Moscow experiences a wide range of thermal conditions throughout the year, Zaryadye Park’s Glass Crust can serve as a model for public space design in similar WiSR urban climates. First, it is important to note that the project benefits from its location, size, and minimal shade from elements surrounding the site. As in the Galleria Vittorio Emanuele II, the project makes use of its proximity to nearby necessary and optional activities and distributes activities so as to support those within the site and the broader local area. Whether such a prototype could be adapted for small-scale, higher density locations in other WiSR cities remains to be known. Further research and design will also reveal the possible uses which can be supported by this new public space prototype, as well as its impact on optional and social activities surrounding it.

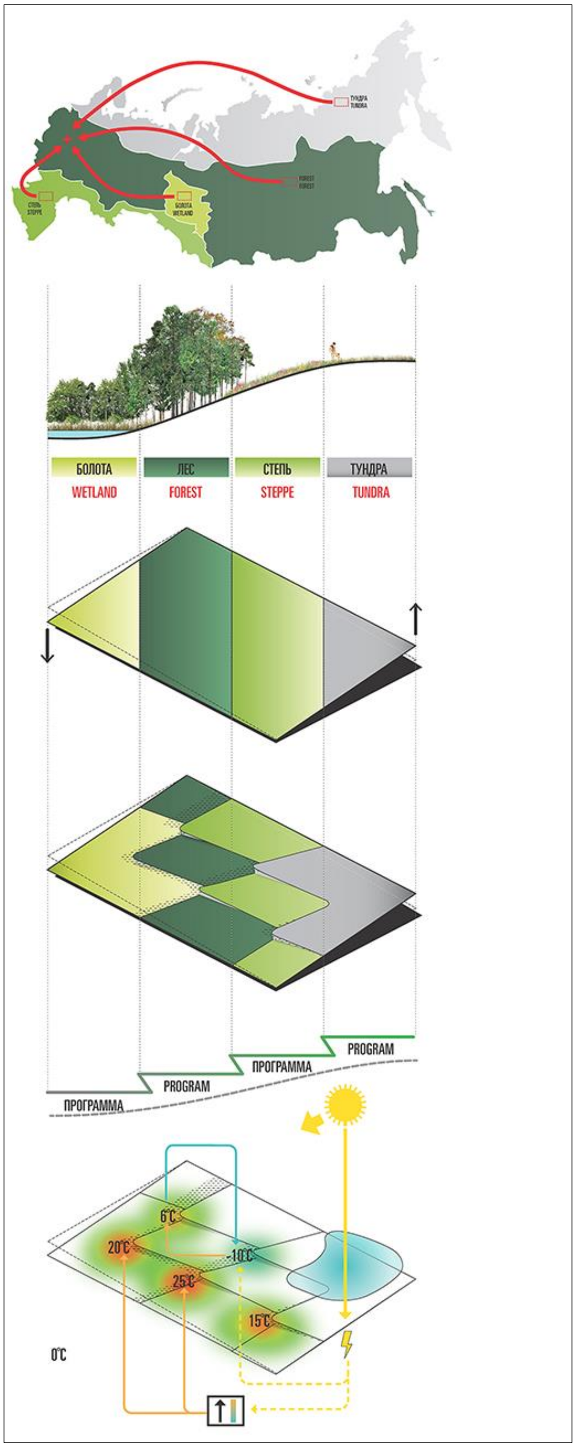


Figure 3.17 Concept diagram for Zaryadye Park's microclimate design. (Diller Scofidio + Renfro, n.d.)

Figure 3.15 View from the top of the Large Amphitheatre. (Phillippe Ruault, n.d.)

Figure 3.16 View of the Large Amphitheatre and Glass Crust. (Iwan Baan, n.d.)

Figure 3.18 View from the top of the Large Amphitheatre. (Phillippe Ruault, n.d.)

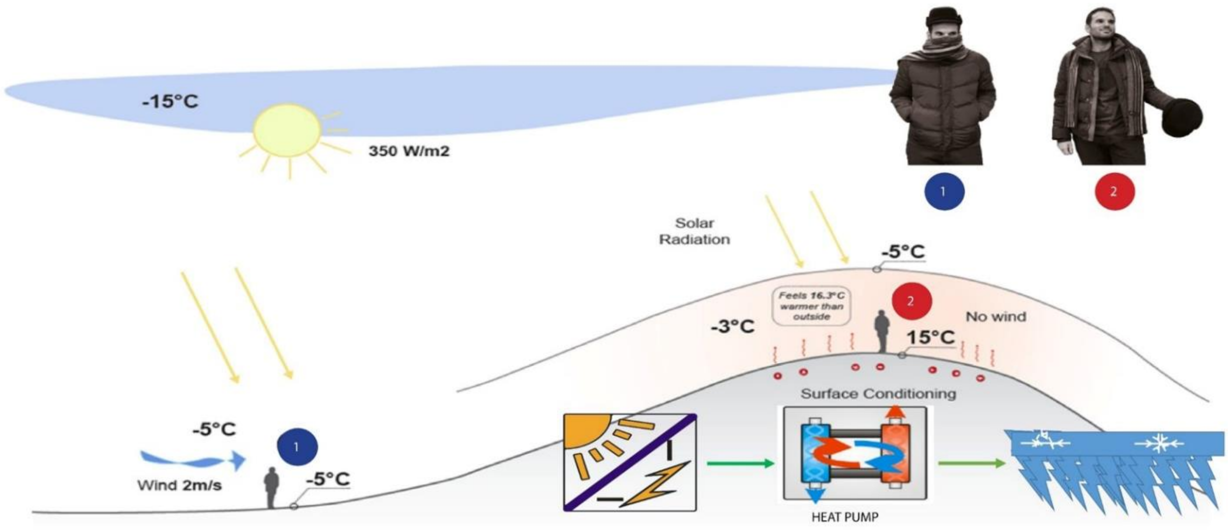


Figure 3.19 Snapshot under the Glass Crust during cold outdoor conditions. In addition to a warmer microclimate, this space offers people the opportunity to sit on grass while most of the city is covered in snow, as seen in the background of this view. (Ibid.)

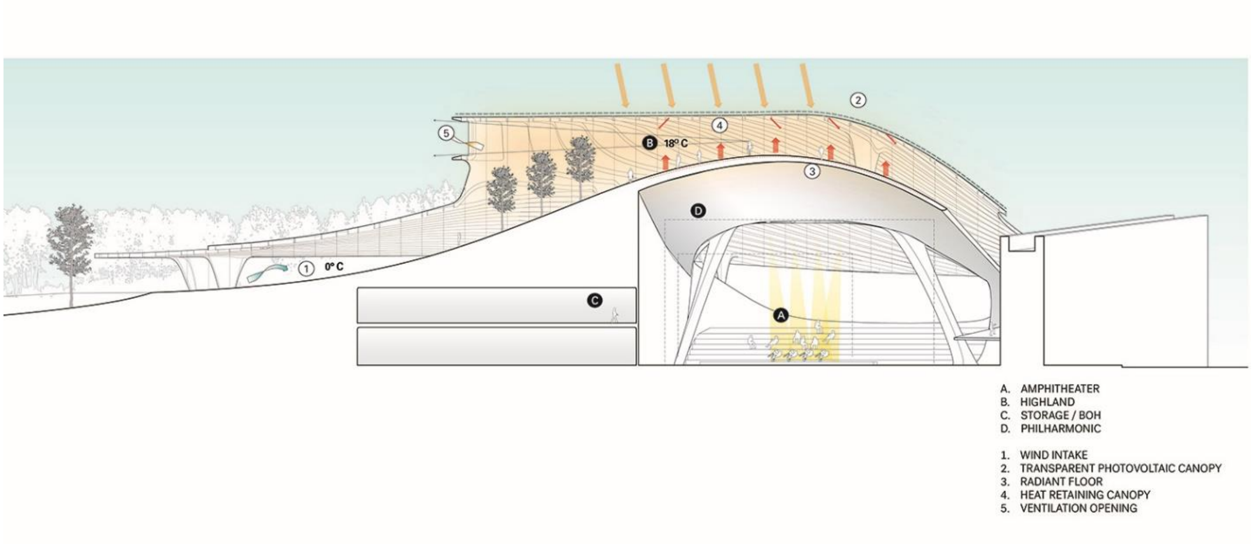


Figure 3.20 Cross-section through the Philharmonic Theatre. (Diller Scofidio + Renfro, n.d.)

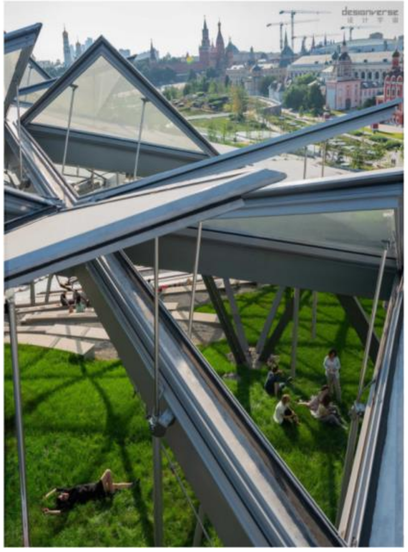


Figure 3.21 View of the opened glazed panels allowing the Glass Crust's summer configuration (Matthew Monteith, n.d.)

Figure 3.22 Snapshot under the Glass Crust during cold outdoor conditions. In addition to a warmer microclimate, this space offers people the opportunity to sit on grass while most of the city is covered in snow, as seen in the background of this view. (Ibid.)

Figure 3.23 Winter scene of kids sledding at Zaryadye Park with the Glass Crust in the background (Ibid.)

3.2.5 Ephemeral Approach: All-Season

So far, the discussion on use and enjoyment has focused on permanent or convertible structures. However, human activities are essentially ephemeral, i.e., perpetually changing over time and space. As such, a main benefit of the summer-based approach lies in its ability to support ephemeral activities in all seasons. In this way, another design approach emerges, which is the conscious integration of ephemeral activities within public spaces' annual life cycle. Consistently, the most successful public spaces for this purpose are those following the first approach, i.e. oriented for summer use. For purposes of the present chapter, the ephemeral approach is limited to activities that persist between a day up to a season in length, and it is subdivided into frost-related activities, winter festivals, temporary markets, programmed events, and seasonal installations.

Frost-Related Activities

Frost-related activities refer to unplanned or minimally planned outdoor winter activities that can only occur when temperatures are below freezing. Such activities include ice-skating, cross-country skiing, freestyle snowboarding, sledding, or sliding, to name a few. Waterloo's Public Square and Ottawa's Rideau Canal represent popular WiSR public spaces that support frost-related activities. Waterloo's square is notable as it stands as a relatively small public space that receives high levels of use in both summer and winter. Thus, the space is highly enjoyable in summer and in winter, and the combination of these conditions generates an all-year experience that is much more successful than a public space that would only receive either high summer use or high winter use. As a result, the all-season use of the square makes it a *destination*, rather than another space for similar experiences as any other public space—or worse, a space used only for walking to another destination.

Figure 3.24 Waterloo Public Square during summer and winter. (left: Wylie Poon, 2019; right: Enterprise Canada, 2017)

In Ottawa, a WiSR city that experiences severe cold and wet winter conditions, it is common to witness many enjoying themselves in public spaces at very cold temperatures. Figure 3.25 shows masses skating on the Rideau Canal at temperatures between -14 °C and -18°C ("Historical Weather on Saturday, January 31, 2015 at Ottawa Macdonald-Cartier International Airport, Canada - Weather Spark" n.d.). This is ensured by the fact that optional activities, i.e., warming areas, changing facilities, skating areas, and food stands are provided that suit user needs for behavioural adaptation to the cold. Most importantly, this recurring situation shows evidence of Gehl and Whyte's conclusion that people are most attracted to places that include seeing and being with other people. Many are willing to adapt behaviourally through clothing change and activity levels to enjoy optional and social activities. During the summer, however, the canal's sidewalks cater more to walking, jogging, or cycling, as the available optional activities are limited to such uses. In this way, the public square typology offers greater flexibility for all-year use as the winter skating area can more readily accommodate summer activities.

Figure 3.25 View of the Rideau Canal in mid-summer and mid-winter. (left: lezumbalaberenjena, July 19, 2017; right: Brian Leon, January 31, 2015)

Winter Festivals

Winter festivals refer to themed events that occur for a short period in the cold season—typically between 2 days and 2 weeks in length. They often combine the other ephemeral activities mentioned in this section and may be connected to temporary markets or programmed events. The Sapporo Snow Festival is one of the world's largest and most successful winter festivals. It was initiated in 1950, as middle and high school students made snow sculptures in Odori Park, which unexpectedly attracted over 50 thousand attendees. Following the success of the first trial, the festival became a winter tradition for all consecutive years. In 1984, due to its continuing success, the festival went from a 2-day to a week-long event ("The History" n.d.). In 2019, the festival hosted roughly 2.74 million people (Kyodo News n.d.). While many WiSR cities host similar festivals, the Sapporo example benefits from the city's high population density, the park's large area and location in the downtown core, and extensive snowfall.

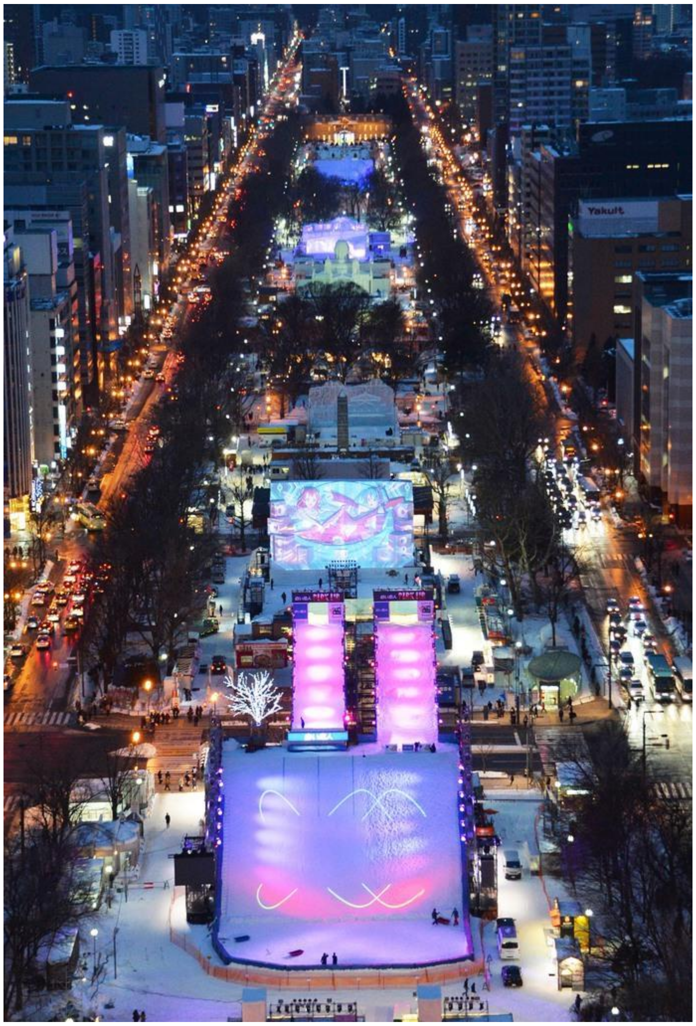


Figure 3.27 Bird's eye view of Sapporo* Snow Festival in Odori Park (Takashi Noguchi, February 2nd, 2020)

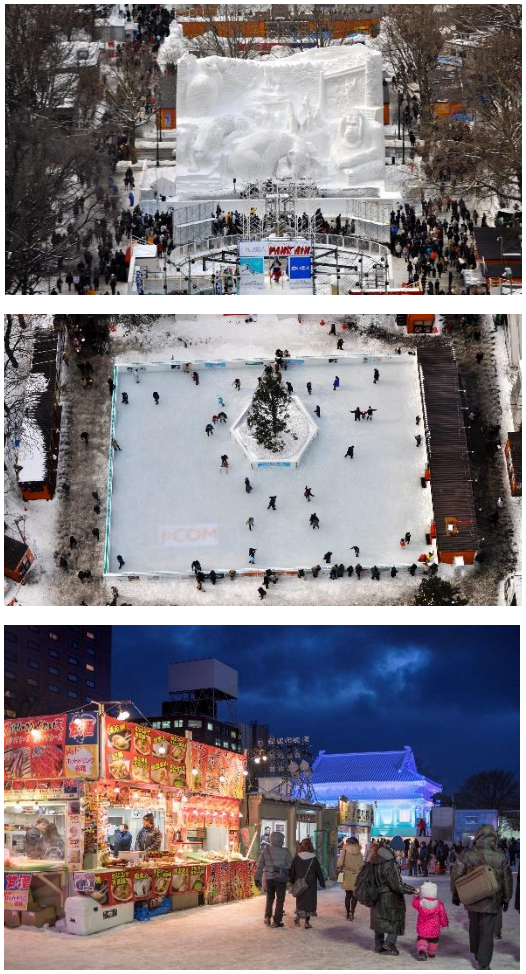


Figure 3.26 Snapshots and aerial view of the festival (top: David McKelvey, February 8, 2010; middle: Ibid.; bottom: Britt Leckman, February 7, 2018)

Temporary Markets

Temporary markets are smaller than festivals and typically follow a certain holiday theme. They often run for a week or longer, depending on the city, and may change locations from one year to the next. Kitchener hosts the Christkindl market, an annual German Christmas tradition that typically runs for four days in early December. Figure 3.28 and Figure **3.29** show different configurations of the market: along King Street and at City Hall's public square, respectively. The City Hall configuration excels as it provides users with a dense concentration of optional activities near the high pedestrian and vehicular traffic of King Street. However, the configuration on King Street offers lower use density as it scatters vendors along the street. Moreover, this configuration turns its back to the skating rink which generally receives great levels of use. In this way, Waterloo's public square outperforms Kitchener's City Hall in terms of all-year use and enjoyment.

Figure 3.28 Christkindl Market in Kitchener; King Street configuration. (Simon Leroux, December 6th, 2018)

Figure 3.29 Christkindl German Christmas Market; City Hall configuration. (left: Christkindl.ca, n.d.; right: CTV News, n.d.)

Programmed Events

Programmed events refer to events usually lasting between 1 hour and 3 days in length and generally gathering large crowds in one or more public spaces. Such events include recreational activities such as concerts, planned social gatherings, exhibits, or gastronomic experiences. The event “Montréal en Lumière”, which roughly translates to the Montreal Highlights Festival, benefits from the city’s connected network of outdoor public spaces to scatter events throughout the downtown core. By doing so, a large portion of the public realm is temporarily transformed, thereby providing an alternative urban winter experience to be enjoyed by nearby city dwellers.

Figure 3.30 Snapshot of Braseros RBC warming station and urban slide at the “Montréal en Lumière” event. (Montrealenlumiere.com, n.d.)

Figure 3.31 Bird’s eye view of the Place des Arts portion of the “Montréal en Lumière” event. (Ibid.)

Figure 3.32 Igloofest Concert Event in Montréal. (Peter Ryaux Larsen, January 2018)

Figure 3.33 Bird’s eye view of Sparks Street on New Year’s Eve. (Ottawa Magazine, 2013)

Seasonal Installations

Seasonal installations refer to experimental projects that seek to improve the user experience of public spaces during an extended part of the cold season. Some of these may be successful and be reused for consecutive years, while others can serve to measure the effectiveness of certain prototypes toward improving the pedestrian experience in WiSR public spaces.

Figure 3.34 Warming Huts competition winners; top-left: Jellyfish by Patkau Architects, 2011; top-right: The Ha(y)ven by n.d., 2011; bottom-left: Greetings from Bubble Beach by Team 888: Site Design Group and SMP Group Design Associates, 2017; bottom-right: Woodpile, 2011. (Source: warminghuts.com)

Figure 3.35 Bus shelter designed by Colle + McVoy providing heating for Minnesotan transit users and advertising for Caribou Café. (Stafford Photography, n.d.)

3.3 Conclusions

In sum, the few successful examples of the permanent summer-based approach are rarely documented. However, in general, WiSR public spaces that follow the Copenhagen model show good levels of summertime use.

Concerning the permanent winter-based approach, semi-public indoor pedestrian networks can either support or decrease the use of public spaces. An overabundance of overhead indoor networks tends to limit views and the range of summer uses of outdoor public spaces. During winter, indoor pedestrian bridges can also harshen microclimate conditions by channelling wind flow at street level. These effects therefore limit the possibility for increasing the all-year use and enjoyment of public spaces. On the other hand, some studies show examples of ground-level and underground networks that support both indoor and outdoor activity by reinforcing their connection to the street and transit system.

While many scholars agree that a better approach strives for a well-connected network of indoor and outdoor spaces, the current knowledge of successful projects using such an approach within WiSR cities remains limited. Nonetheless, the Galleria Vittorio Emanuele II in Milan provides a successful example of a partial enclosure that could extend the use and enjoyment in WiSR public spaces during harsh weather in all seasons, if properly calibrated to local microclimate extremes.

The convertible approach shows both cautions and great opportunities. The case of the Rideau sidewalk enclosures shows the consequences of narrowing the range of possible spatial and activity configurations of a public space. In addition, it sheds light on the challenges of maintain a constant indoor temperature across a narrow, linear space that receives high pedestrian volumes during severe cold outdoor conditions. By contrast, Zaryadye Park’s Glass Crust presents itself as a first prototype of a glazed canopy that can support all-season use and enjoyment in a WiSR public space.

Lastly, the ephemeral approach provides a method of increasing all-year use and enjoyment in public spaces by relying on the permanent summer-based approach. This includes spontaneous and programmed temporary activities which all range in timespan, area, location, and target demographic range. Public spaces that host high levels of use and enjoyment in both cold and hot seasons thus not only extend all-year social activities, but also contribute to strengthening collective identity through recurring experiences in memorable destinations.

While this chapter provided a qualitative assessment on four approaches to WiSR public space design, there is no current quantitative basis to compare, evaluate, and design WiSR public spaces toward greater use and enjoyment. The next chapter reviews existing classifications, indices, and other metrics that inform pre-design analyses of public spaces.

4. Current Climate Metrics for Urban Design

Chapter 3 elaborated on the challenge of designing public spaces for regions that experience opposing needs for hot and cold seasons. But it is also a considerable challenge to develop accurate concepts, classifications, and predicting tools for public space design in WiSR climates. Moreover, some terms used to describe urban climates in mid- to high latitude regions, e.g., “Winter City”, “cold climate”, “snow climate”, are now widely used, despite the fact that many of those climates also have hot summers. The common use of these terms only adds to the challenge of understanding and developing an accurate definition for WiSR cities.

This chapter elaborates on the climate metrics used to inform public space design, which are especially critical for climates with wide seasonal range. To do so, it is divided into two parts. Section 4.1 describes the challenge of defining WiSR climates and developing design metrics that accurately address its key elements. It follows by stating the limitations of existing climate metrics for purposes of early-stage planning and design in WiSR cities. Section 4.2 briefly presents early climate and microclimate metrics which began to integrate human behaviour for different time scales.

As recalled in Chapter 2, macroclimate processes influence local scale conditions, and local climate processes are modified by microclimate conditions. Therefore, if the goal is to enrich all-year collective use and enjoyment, it is necessary that public space design in WiSR cities be appropriately informed by local climate challenges. The following section describes the current issue of defining local climate challenges in WiSR climates.

4.1 The Challenge of Defining Wide Seasonal Range (WiSR)

Upon reviewing the literature on winter- and cold-related issues in general, it becomes evident that many significant misconceptions persist. This not only impacts urban planning and design in general, but also impinges on the study and design of public spaces located in WiSR cities. The present section clarifies some of these misconceptions by comparing historical climate data for 13 cities in a broad range of conditions contained by the current Winter City criteria, i.e. cities that experience sub-zero temperatures for over two months per year. Although Reykjavik’s population count does not fit within the defined scope of this thesis, it is included as it remains a popular tourist destination and offers greater clarity to the argument of this chapter.

Figure 4.1 13 Cities Selected for Analysis of Local Climate.

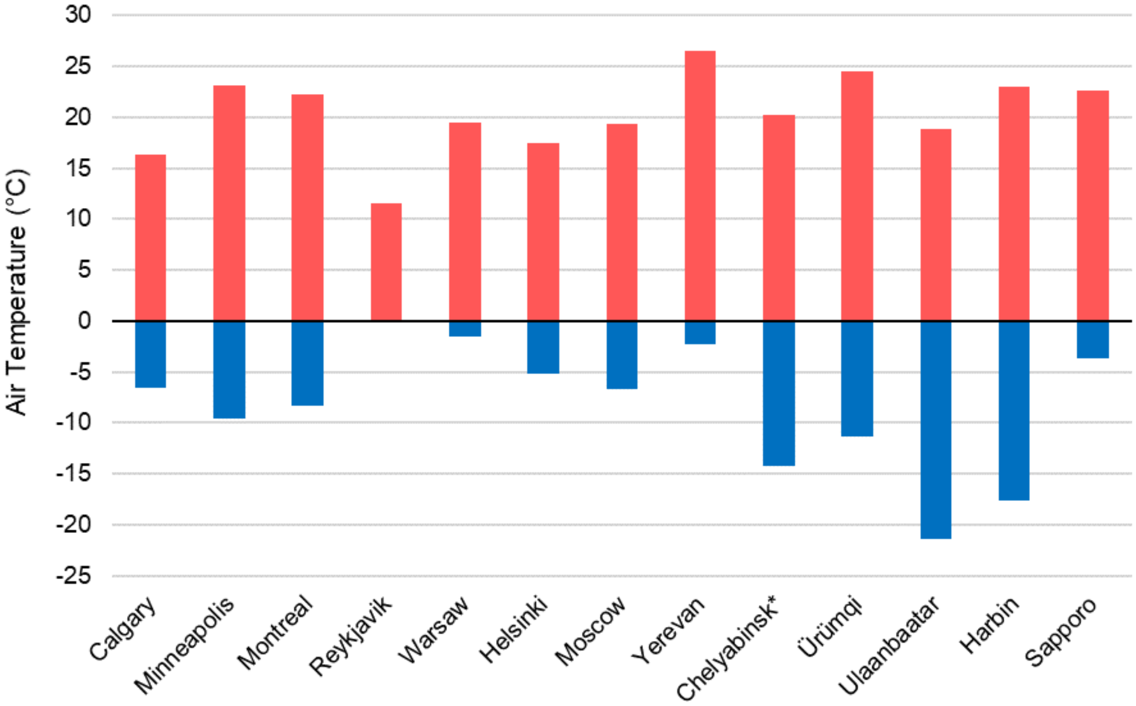


Figure 4.2 Annual temperature range between coldest and hottest monthly averages. (Data source: Menne et al. 2018)

northern latitude $\neq$ severe cold winter

northern latitude $\neq$ wide seasonal range

cold summer $\neq$ severe cold winter

Winter City advocates have frequently emphasized issues related to high latitude (Gutheim 1979; Pressman 1988; 1995). However, as pointed out in Section 2.2, latitude does not indicate climate severity, and so it should not be considered as a basis for categorizing winter- and cold-related planning issues. Unfortunately, widely cited studies often generalize local climate differences into a single category of "winter". The issue with this is that two very different types of winter climates are categorized as identical. The first type is high-latitude cities with a narrow thermal range, e.g., Reykjavik, Copenhagen, Stockholm, or Oslo, and the second type is mid- to high-latitude cities a wide thermal range, e.g., Minneapolis, Ottawa, Novosibirsk, Ulaanbaatar, or Harbin (Menne et al. 2018). Figure 4.3 plots average monthly temperature data for the 13 analysed cities. In the first type, winters are long but moderately cool and issues are largely due to the lack of winter solar radiation and a short summer season. On the other hand, the second type experiences significantly colder winters and hotter summers. This is challenging because summer and winter bring highly opposing design needs, and strategies responding explicitly to one season usually conflict with planning needs of other seasons.

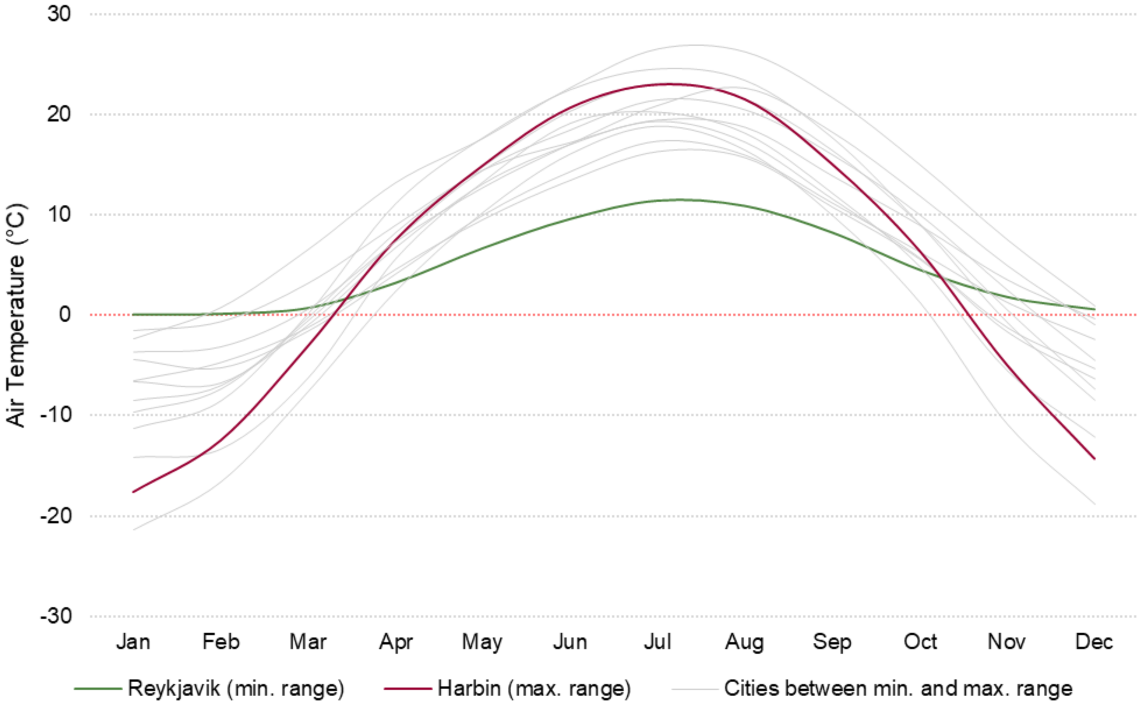


Figure 4.3 Annual distribution of average monthly temperature. (Data source : Menne et al. 2018)

severe winter climate ≠ severe summer climate ≠ wide seasonal range

winter design needs ≠ summer design needs ≠ all-year design needs

So, although Northern regions in general face severe limitations in the amount of sunshine over the year, the temperate climate of these maritime cities requires different interventions for all-year planning than cities that experience a wide range of thermal conditions for winter and summer seasons.

severe winter ≠ long winter ≠ dark winter ≠ snowy winter ≠ severe cold winter

When discussing winter severity, there is no clear indication on which aspect of winter is severe. It may be widely acknowledged that winter severity results from the combination of various effects, but it remains unknown how much local bias can influence perceptions of winter. Figure 4.4 to Figure **4.8** show the range of possible variations in average winter wind speed, sunshine hours, and precipitation.

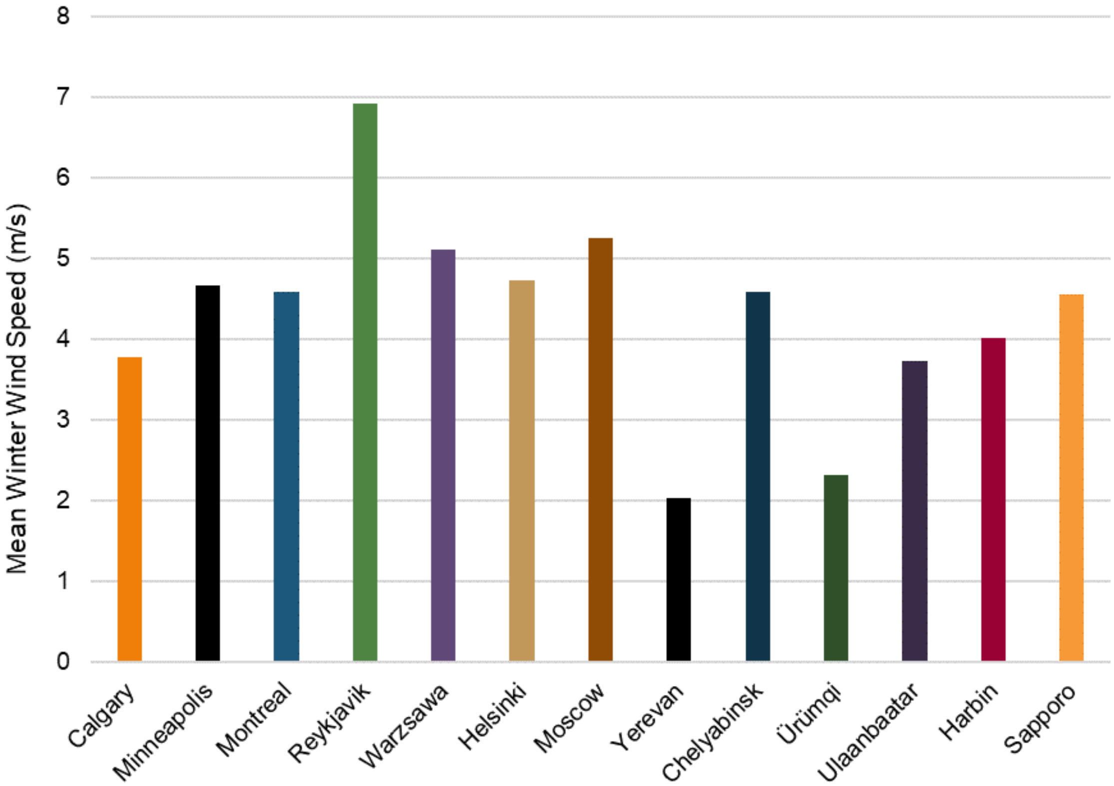


Figure 4.4 Average wind speed for months December to February, measured at 10m above ground for period between 1980-2016. (Data source: Cedar Lake Ventures Inc.)

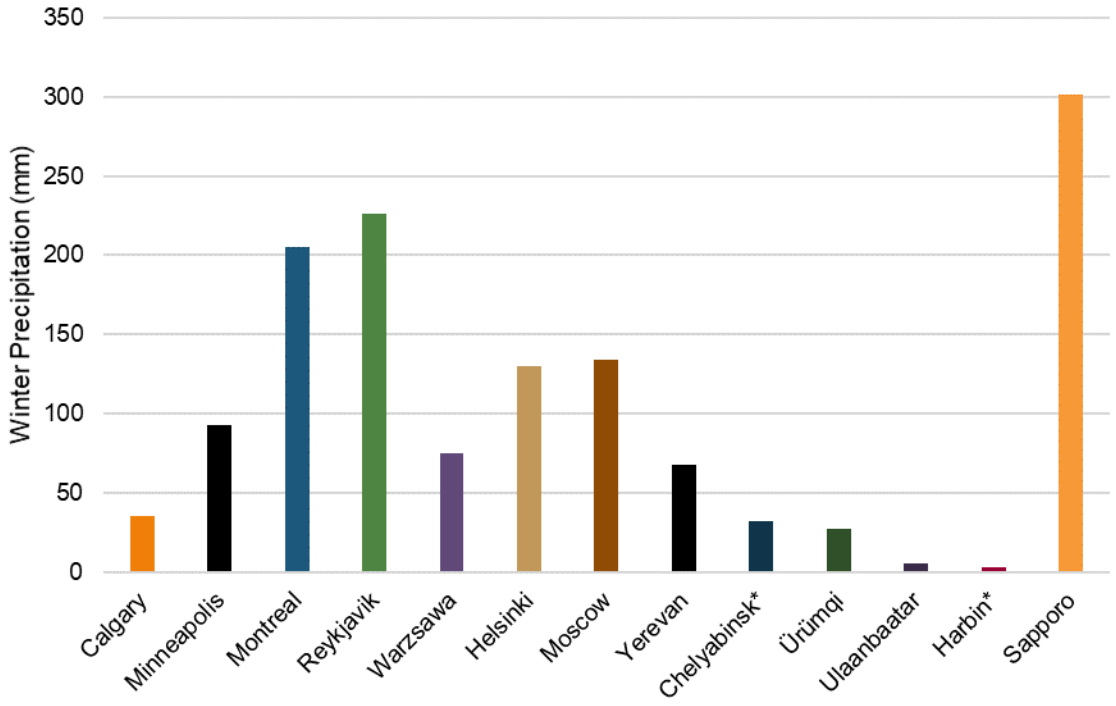


Figure 4.5 Mean total precipitation for December, January, and February for period between 1961-1990. (Data source: WMO; DWD; *1980-2016 period, Cedar Lake Ventures Inc.)

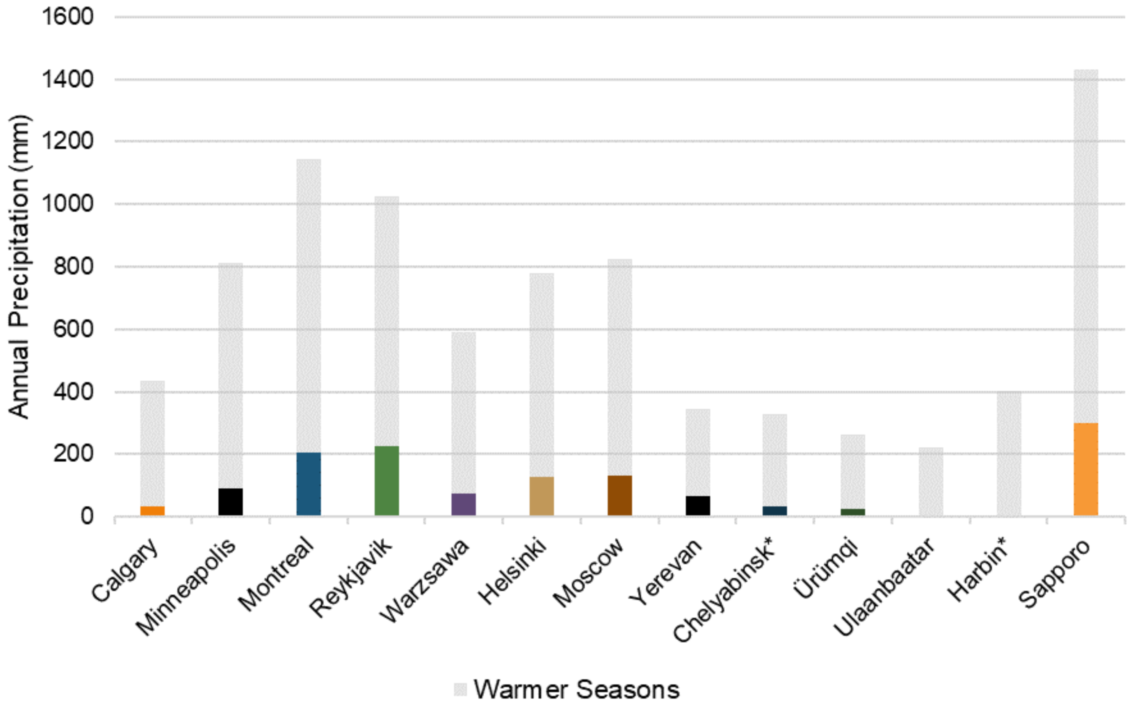


Figure 4.6 Mean total precipitation for all seasons (grey) and for December, January, and February (colour) for 1961-1990 period. (Data source: WMO; DWD; *1980-2016 period, Cedar Lake Ventures Inc.)

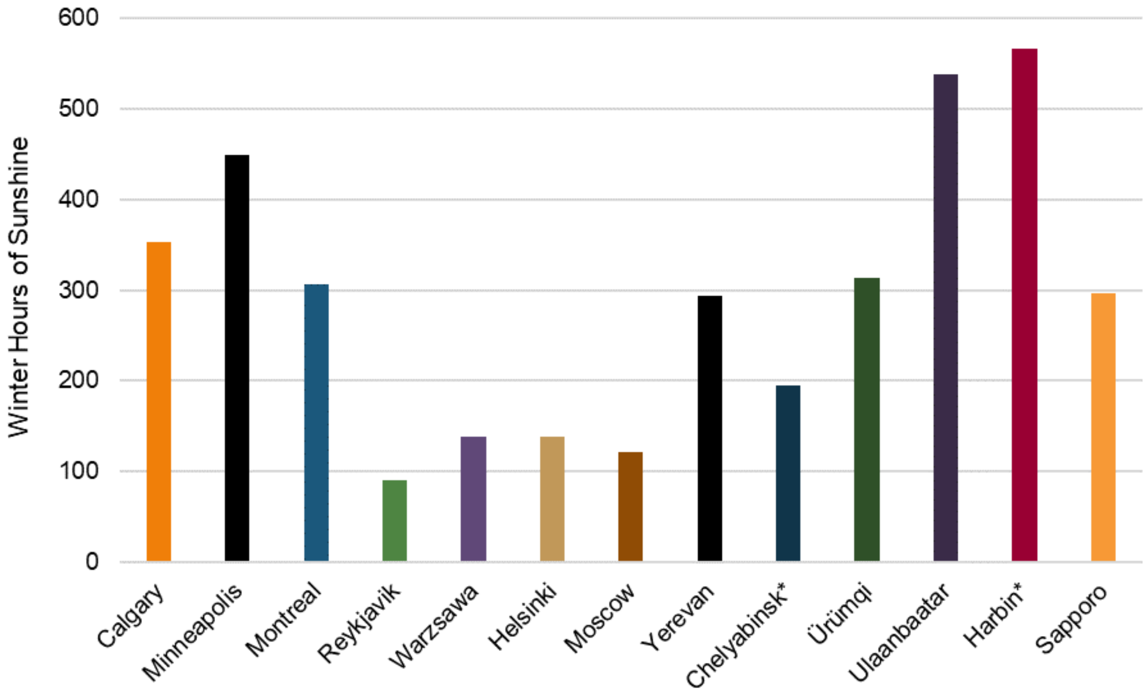


Figure 4.7 Mean total sunshine hours for December, January, and February for period between 1961-1990. (Data source: WMO; NOAA)

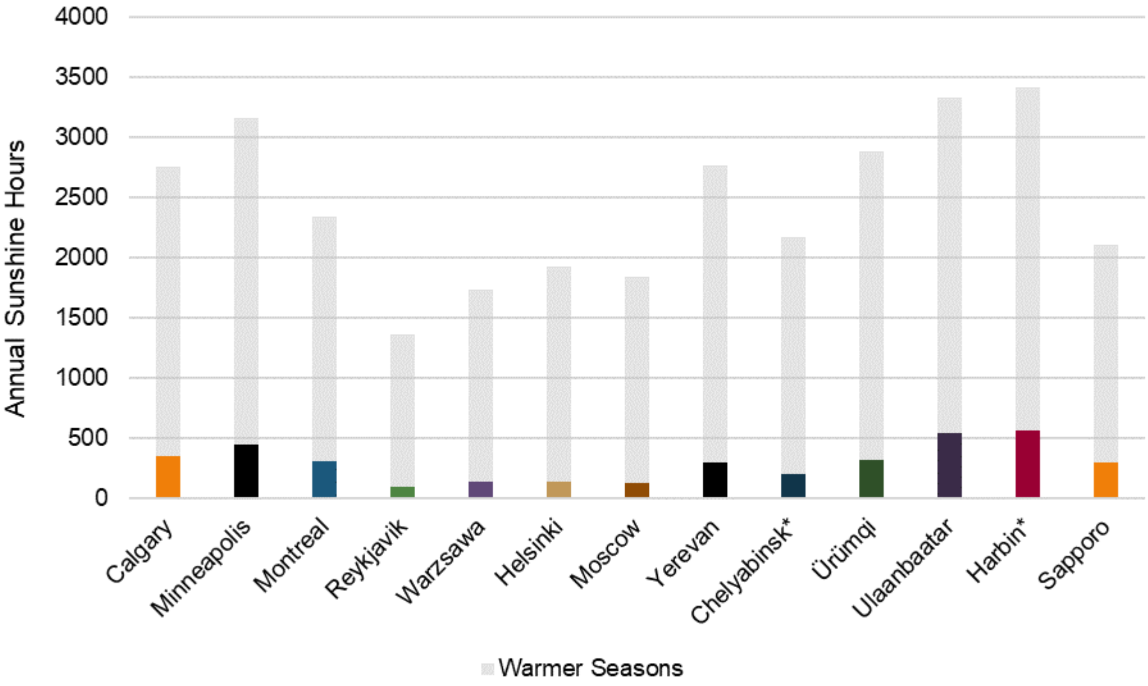


Figure 4.8 Mean total sunshine hours for all seasons (grey) and for December, January, and February (colour) for period between 1961-1990. (Data source: WMO; NOAA)

4.1.1 Issues of the Winter City Concept and Criteria

It is argued that the ongoing definition of "Winter City", along with similar terms focusing on single winter weather aspects such as "cold climate", or "snow climate" continue to propagate misconceptions about the needs for planning and climate in WiSR cities in all seasons, winter included. In an effort to account for all-year needs, Pressman and Zepic (1986) make frequent notes on the importance of maintaining an all-year perspective. However, such mentions do little to compensate for the effect of continuing to use the term "Winter City", which still refers to a narrow approach to urban planning.

The term "Winter City" was effective insofar as it connected planners and researchers from all cities that experience some form of winter. But although the Winter City movement succeeded in gathering and stimulating research on winter-related urban issues, the concept lacks precision and takes a narrow perspective on all-year planning needs. As Phillips (1988) shows, there are many ways to define winter, i.e., by length, severity, frequency, or type of various winter elements (See Table 4-1). Yet the Winter City concept draws no distinction between key differences for the various winter climates it defines.

Definition of Winter	***Average***	***Longest***	***Shortest***
Astronomical	*89 days 22 Dec — 21 March*	—	—
Climatological	*91 days 1 Dec — 28 Feb*	—	—
Freeze-over period (ice)	*153 days Nov 16 — Apr 18*	*177 days Nov 13—May 8/1966*	*126 days Dec 8—Apr 2/1951*
Frost period	*225 days Sept 24 — May 6*	*301 days Aug 29/1886—June 25/1887*	*184 days Dec 8—Apr 2/1951*
Snow-season (recreational winter)	*170 days Oct 27 — Apr 14*	*215 days (1965—66)*	*81 days (1976—77)*
Coldest 91-day period	*91 days Dec 2 — March 2*	—	—
Mean maximum temperature below freezing	*122 days Nov 16 — March 17*	—	—
Wind chill reading of 1200 (analysis from 1975-1984)	*95 days Nov 20 — March 4*	*148 days Nov 9/1978—April 5/1977*	*111 days Nov 25/1983—March 15/1984*

Table 4-1 List of definitions of winter for Edmonton, Canada for different purposes. (Adapted from Phillips 1988)

Early on, Winter Cities were defined as places located above the 45th parallel with average January temperature equal or below 0 °C (Winter Cities Forum 1986, ii in Pressman 1995). Later, somewhat vague criteria were added (Pressman 1988, 21).

1. temperature — normally below freezing
2. precipitation — usually in the form of snow
3. restricted hours of sunshine/daylight
4. prolonged periods of the first three elements cited above
5. seasonal variation

Eventually, this led to a slightly more specific criterion (Ibid.).

> […] A "winter city" is one in which the average maximum daytime temperatures are 0 °C (32 °F) for a period of approximately two months or longer.

It can be assumed that the author intends to say 0 °C or colder. Even so, this definition remains both narrow and imprecise. From a cross-seasonal perspective, using the term "winter city" to characterize a four-season city is misleading. Even if some cities experience winter conditions for most of the year, many cities experience both severe cold winter and hot summer conditions within the same year. Designers and city dwellers of WiSR cities are evidently aware of their region's climate variability, and numerous architects and urban designers assert that designing with too much focus on the effects of winter can result in missed opportunities for the year-round quality of public spaces (Gehl 1992; Whyte 1980; Robertson 1988; Peñalosa in Willing 2009).

From a winter-only perspective, "winter city" encompasses a great number of cities according to the mere fact that they experience "winter", but this does little to convey the specific climate challenges for different locations. Taken as it stands, the term refers to cities that possess any combination of climate variables that range in type, extent, and severity. To demonstrate the range implied by what constitutes a "Winter City", the period below 0 °C for some cities can span from 77 days, as in Chicago, up to 143 days, as in Harbin (Data source: Menne et al. 2012). Further, it can refer to cities with vastly ranging severity of air temperature, wind speed, and solar radiation. A winter city's average air temperature for the coldest month can range from -2.8 °C in Stockholm down to -24.6 °C in Ulaanbataar (National Oceanic and Atmospheric Administration and World Meteorological Organization 2018). Thus, cities with such different winter climate conditions can not be compared as they each require different local planning considerations.

Without conveying the specific type of local winter challenge, e.g., frigid cold, extended snow cover, frequent freeze/thaw events, frequent severe precipitation, or low solar radiation, one has difficulty identifying the relevance of design strategies without additional review or modification. It is important to note that presenting clear information on all these elements in a useful manner presents a significant challenge. The WiSR definition and classification elaborated in Chapter 5 presents a working classification of seasonal range based solely on temperature, and so it does not yet offer information on all other important meteorological factors. However, it needs to be highlighted that other weather elements—e.g., snowfall, snow cover, or sunshine hours—contribute to winter climate severity and the classification is developed to accommodate future integration of these elements.

4.1.2 Limitations of the Winter Climate Severity Index (WCSI)

To classify Canadian cities according to the effects of severe winter climate on human outdoor activity, Phillips and Crowe (1984) developed the Climate Severity Index (CSI). Two years later, Phillips (1986) introduced the Winter Climate Severity Index (WCSI) to account for all cities with severe cold winter climates around the world. The WCSI uses a points system to weigh the effects of four components of severe winter climate on human outdoor activity. These are categorized as discomfort, outdoor mobility, hazardousness, and psychological factors (See Table 4-2 on next page).

Due to current constraints, it was not possible to obtain the formula for WCSI, but Phillips (1988) explains that the same principles were applied for development of CSI as for WCSI. The CSI formula is defined as:

$$\mathrm{CSI} = \frac{5\mathrm{A} + 2\mathrm{B} + 2\mathrm{C} + \mathrm{D}}{7.5}$$

where, A = discomfort
B = psychological state
C = hazardousness
D = outdoor immobility

(Phillips and Crowe 1984 in Pressman and Zepic 1986)

One issue with these categories is that psychological factors are considered as the result of darkness and wetness, yet prolonged cold stress, reduced outdoor mobility, and hazardousness have important psychological effects as well. However, the index seems to account for those effects indirectly by assigning greater weight to the discomfort category.

		Points
A.	**Discomfort Factor (400 points)**	
	Wind Chill Mean percentage of the time in January that wind chill exceeds 1400 W/m²	170
	Length of Winter Number of months with mean daily temperature less than 0 °C	115
	Severity of Winter Mean daily temperature of coldest month	115
B.	**Psychological Factor (100 points)**	
	Darkness Increasing darkness factor with increasing latitude	55
	Wet Days Average number of days with measurable precipitation (rain and/or snow) in December, January, and February	45
C.	**Hazardousness (100 points)**	
	Strong Winds Mean percentage frequency of January wind speed equal to or greater than 30 km/h	34
	Blowing Snow Absolute frequency in 10 years of the number of hours with blowing snow	44
	Snowfall Mean winter snowfall (cm)	22
D.	**Outdoor Immobility (100 points)**	
	Freezing Precipitation Absolute frequency in 10 years of the number of hours with freezing precipitation	67
	Snowfall Mean winter snowfall (cm)	33

Table 4-2 Assigned weighting factors of the WCSI for different components and their respective variables. (Phillips 1986)

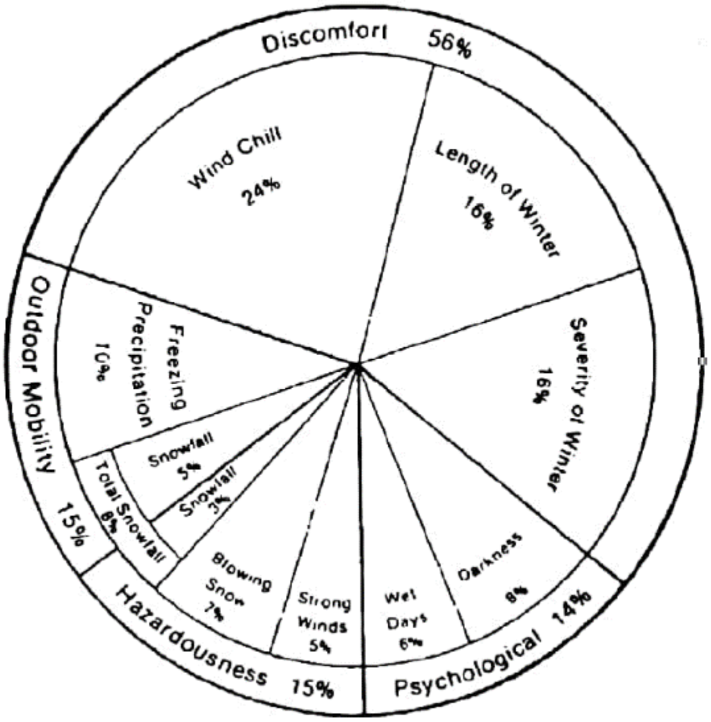


Figure 4.9 Percentage distribution of the different factors comprising WCSI. (Phillips 1986)

Points attributed from these factors estimate climate severity on a scale of 0-100. The author later demonstrated that among Canadian metropolitan cities, Edmonton, Montreal, and Ottawa had the most severe winter climates with values of 49, 49, and 50, respectively. Later, the WCSI index showed values (shown here in parentheses) for cities internationally, including those of Harbin (51), Helsinki (48), Kiev (50), Saint-Petersburg (50), Novosibirsk (59), and Omsk (58) (Phillips 1988). Figure 4.10 shows isolines for the winter climate severity in the northern hemisphere, which rises unevenly toward the North pole. It is important to note that although the WCSI attempted to provide an accurate assessment of the climate's effect on humans, it remains subjective. Thus, the isolines shown in Figure 4.10 do not represent climate severity in a consistent manner, and this signifies that the same value in one area could be more influenced by, e.g., darkness and precipitation while another can be more influenced by, e.g., frigid cold. This can easily lead one to perceive that locations along the same isoline experience similar conditions, which is not the case. Hence, the WCSI does not assist one in identifying which climate factor has the most influence.

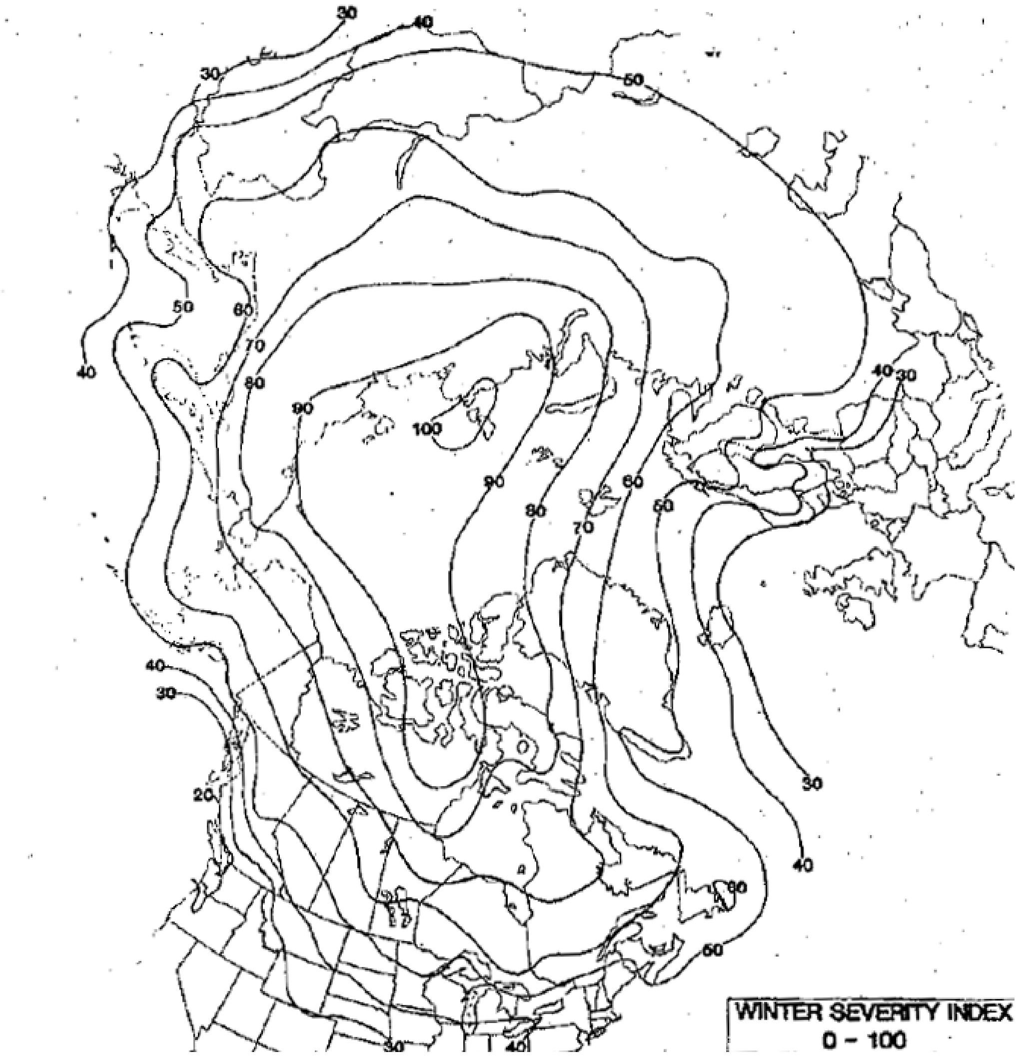


Figure 4.10 Isolines of WCSI for Northern Hemisphere. (Phillips 1988)

City	**WCSI**				
Beijing	22	Oslo	42	Ottawa	50
Copenhagen	25	Toronto	43	Harbin	51
Chicago	34	Calgary	44	Moscow	52
Detroit	36	Milwaukee	44	Minsk	53
Stockholm	36	Minneapolis	46	Québec	54
Cleveland	38	Buffalo	48	Saskatoon	55
Indianapolis	38	Helsinki	48	Sverdlovsk	55
Reykjavik	38	Edmonton	49	Winnipeg	56
Changghun	41	Montréal	49	Omsk	58
Sapporo	41	Kiev	50	Irkutsk	59
Anchorage	42	Leningrad	50	Novosibirsk	59

Table 4-3 Cities and their associated WCSI values, arranged low to high. (adapted from Phillips 1988)

Moreover, while the WCSI has served as a valuable guide for applications such as identifying areas with moderate climates, ensuring fair wages for outdoor work in extreme climate regions, or estimating safe exposure limits in various zones (Phillips 1988), it offers little use for urban planning as its output values are not tangible and do not indicate the particular climate variables that guide planning decisions for different locations. Rather, the WCSI compresses information on specific local climate conditions into an index that only conveys that one location has greater or lesser impact on human activity. This informs the design professional that they should conduct further analysis to determine the effect of specific climate factors. This might be useful if planners could perform such an assessment, but ongoing practice in planning reveals that multiple constraints do not currently allow for this additional step (Eliasson 2000; Oke 1984; 2006; Dursun and Yavas 2016).

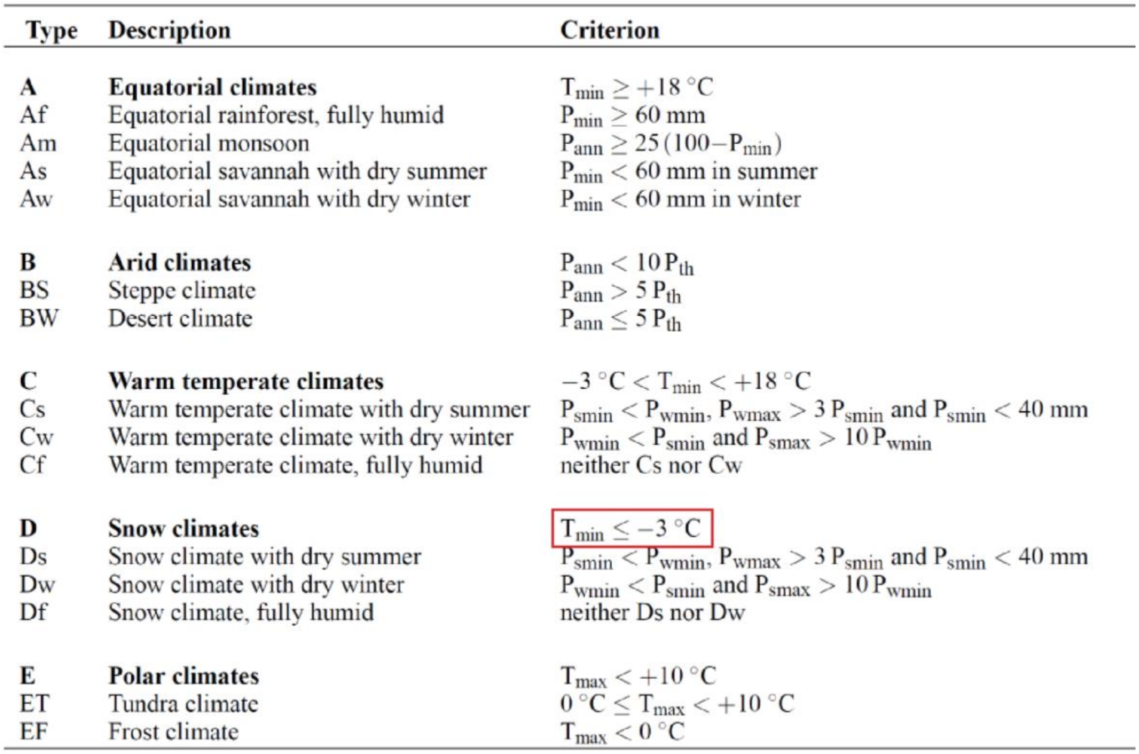
4.1.3 Limitations of the Köppen-Geiger Climate Classification System

While WCSI method provides no tangible values, climatologists commonly use the Köppen-Geiger Climate Classification System a reference for identifying and analysing climates from a macroscale perspective. However, despite the low accuracy of the system for describing local scale variations, it is commonly used for microclimate studies investigating human activity within public spaces. This is problematic as the system was not developed for such uses, and thus it reduces the transferability of findings on local challenges for human activity.

German plant physiologist Wladimir Koeppen developed the first quantitative classification for the world's climates in 1900. He based it on temperature and precipitation data and categorized climate zones according to French botanist De Candolle, who derived five vegetation groups based on observations by ancient Greek philosophers such as Parmenides, Pythagoras, and Aristotle (Sanderson 1999). It was revised by Rudolf Geiger and Wolfgang Pohl in 1954, who included amendments for better coverage of arid climates (Geiger and Pohl 1954). Table 4-4 and Table **4-5** present the nomenclature for the five major climate classes and their subtypes. These amount to 31 classes, which can be seen on a world map (Kottek et al. 2006).

The classification offers little use for planners and designers, however, since it does not assist in identifying key challenges for public space design. In particular, the zones are too broadly delimited to directly discern seasonal extremes for different locations. E.g., in the warm temperate fully humid warm summer zone (Cfb), Helsinki has an average temperature of the coldest month (T_{min}) of -5.7 °C, while Zürich's T_{min} is only -0.6 °C. In the fully humid continental warm summer zone (Dfb), T_{min} can vary from -3.7 °C in Sapporo down to -16.1 °C in Krasnoyarsk. Cities in the cold arid steppe zone (BSk) can experience T_{min} from -4.3 °C, as in Beijing, down to -15 °C in Ürümqi (National Oceanic and Atmospheric Administration and World Meteorological Organization 2018).

Further, seasonal extremes for arid (B) climates are only defined by precipitation. For temperature, the only distinction made is whether average annual temperature (T_{ann}) is hot ($T_{ann} \geq 18$ °C) or cold ($T_{ann} <$ 18 °C). Hence, simply knowing that a city is within a cold arid climate—e.g., cold steppe (BSk)—does not provide any direct information on summer and winter temperatures or the annual temperature range.

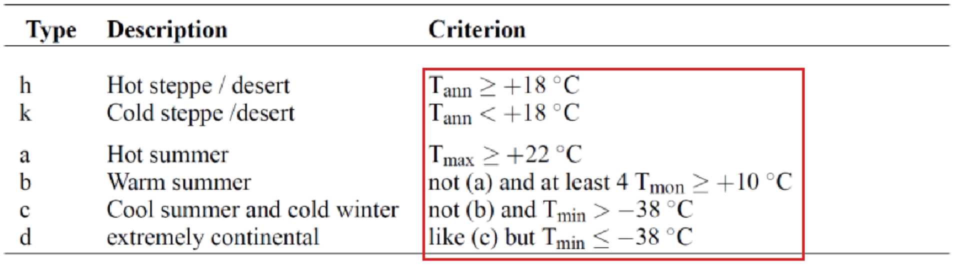


Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18\ ^{\circ}C$
Af	Equatorial rainforest, fully humid	$P_{min} \geq 60$ mm
Am	Equatorial monsoon	$P_{ann} \geq 25\,(100-P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60$ mm in summer
Aw	Equatorial savannah with dry winter	$P_{min} < 60$ mm in winter
B	**Arid climates**	$P_{ann} < 10\,P_{th}$
BS	Steppe climate	$P_{ann} > 5\,P_{th}$
BW	Desert climate	$P_{ann} \leq 5\,P_{th}$
C	**Warm temperate climates**	$-3\ ^{\circ}C < T_{min} < +18\ ^{\circ}C$
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Cw	Warm temperate climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Cf	Warm temperate climate, fully humid	neither Cs nor Cw
D	**Snow climates**	$T_{min} \leq -3\ ^{\circ}C$
Ds	Snow climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Dw	Snow climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Df	Snow climate, fully humid	neither Ds nor Dw
E	**Polar climates**	$T_{max} < +10\ ^{\circ}C$
ET	Tundra climate	$0\ ^{\circ}C \leq T_{max} < +10\ ^{\circ}C$
EF	Frost climate	$T_{max} < 0\ ^{\circ}C$

T_{ann} = annual mean near-surface (2 m) temperature
T_{min} = average temperature of the coldest month
T_{max} = average temperature of the hottest month
P_{ann} = accumulated annual precipitation
P_{min} = precipitation of the driest month
P_{smin} = lowest monthly precipitation for summer half-years on the hemisphere considered
P_{smax} = highest monthly precipitation for summer half-years on the hemisphere considered
P_{wmin} = lowest monthly precipitation for winter half-years on the hemisphere considered
P_{wmax} = highest monthly precipitation for winter half-years on the hemisphere considered

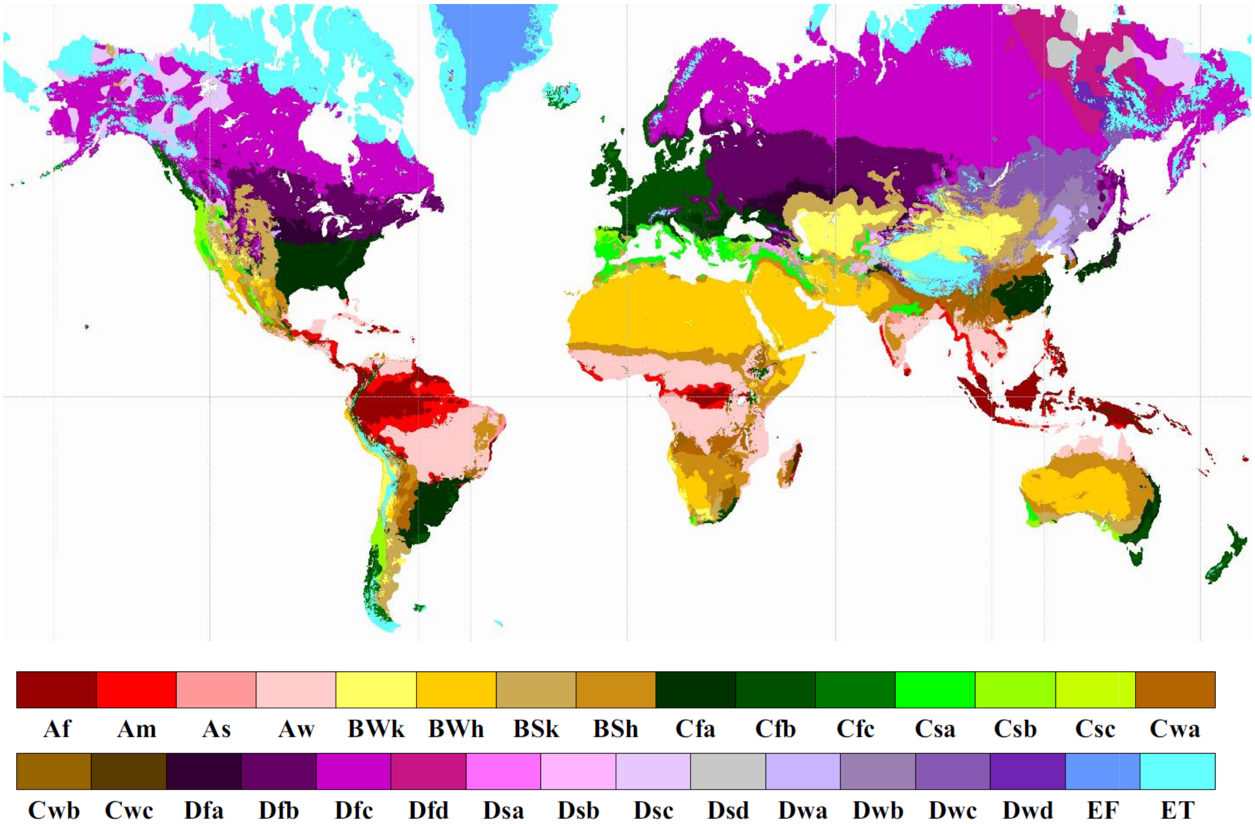
$$P_{th} = \begin{cases} 2\{T_{ann}\} & \text{if at least 2/3 of the annual precipitation occurs in winter,} \\ 2\{T_{ann}\}+28 & \text{if at least 2/3 of the annual precipitation occurs in summer,} \\ 2\{T_{ann}\}+14 & \text{otherwise.} \end{cases}$$

Table 4-4 Five major groups (first letter) of the Köppen-Geiger Climate Classification and their respective precipitation (second letter) and temperature (third letter) denominations. The red boxes outline criteria that are too broad to offer relevant climate information for use in early stages of public space design. (Kottek et al. 2006)



Type	Description	Criterion
h	Hot steppe / desert	$T_{ann} \geq +18\ ^{\circ}C$
k	Cold steppe /desert	$T_{ann} < +18\ ^{\circ}C$
a	Hot summer	$T_{max} \geq +22\ ^{\circ}C$
b	Warm summer	not (a) and at least 4 $T_{mon} \geq +10\ ^{\circ}C$
c	Cool summer and cold winter	not (b) and $T_{min} > -38\ ^{\circ}C$
d	extremely continental	like (c) but $T_{min} \leq -38\ ^{\circ}C$

Table 4-5 Temperature criteria denominators for different Köppen-Geiger climate zones. The highlighted criteria are too broad to offer any specific climate information for use in early-stage planning and design. (Ibid.)



Main climates	**Precipitation**	**Temperature**	
A: equatorial	**W: desert**	**h: hot arid**	**F: polar frost**
B: arid	**S: steppe**	**k: cold arid**	**T: polar tundra**
C: warm temperate	**f: fully humid**	**a: hot summer**	
D: snow	**s: summer dry**	**b: warm summer**	
E: polar	**w: winter dry**	**c: cool summer**	
	m: monsoonal	**d: extremely continental**	

Figure 4.11 World map of the Köppen-Geiger Climate Classification System, with Arctic and Antarctica cropped. (Kottek et al. 2006, using 1986-2010 data from Kottek et al. 2006; Rubel et al. 2017; and koeppen-geiger.vu-wien.ac.at, retrieved August 9 2020)

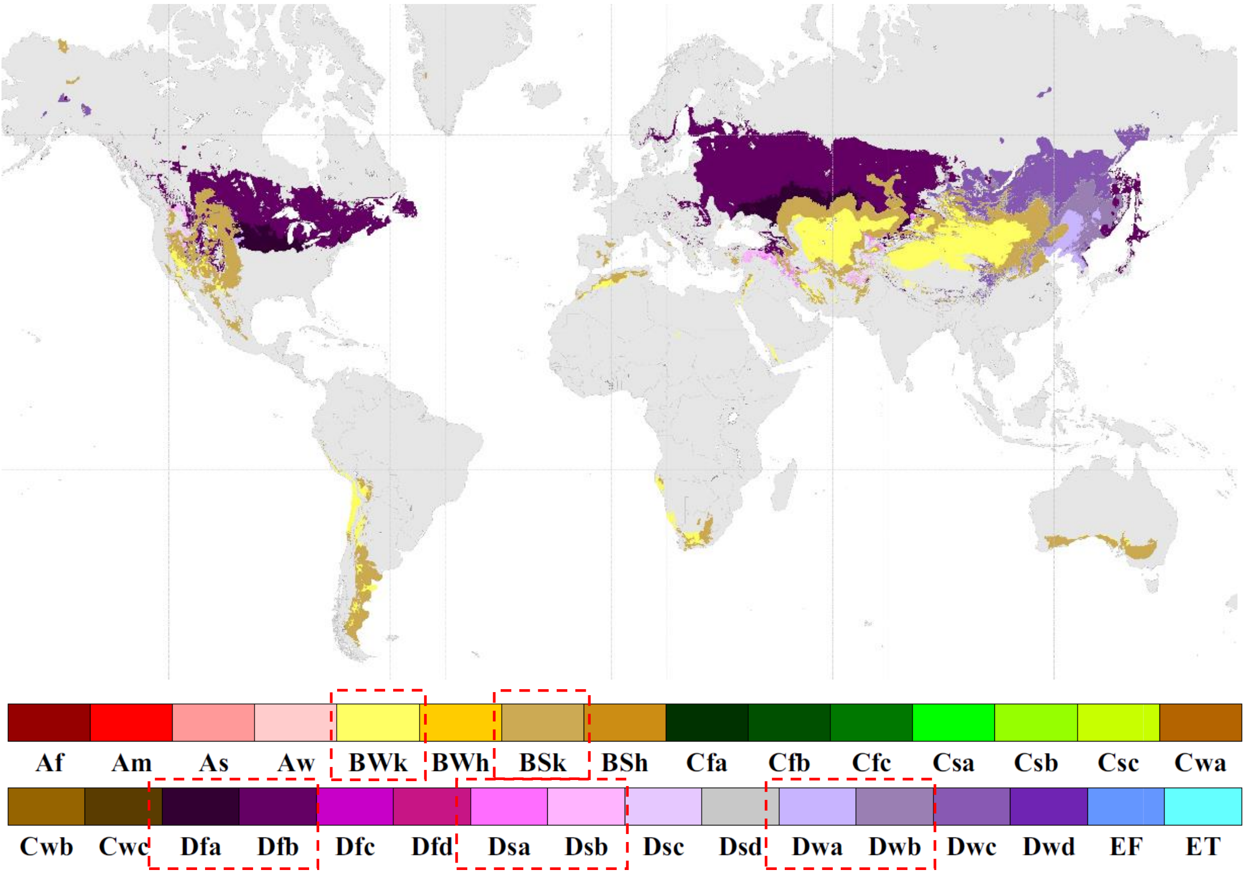


Figure 4.12 World map showing only cold arid and continental climate zones of the Köppen-Geiger Climate Classification System. These zones generally contain WiSR cities, but as will be shown in Chapter 5, a classification of seasonal range can provide greater accuracy and precision for purposes of public space design. (Adapted from ibid.)

4.1.4 Conclusions

This section demonstrated the complexity of winter and describing its attributes in a succinct manner. Generalizing the wide range of possible local winter climates as a single condition can lead to misinformed planning outcomes. It is concluded that “Winter City”, “cold climate”, and similar terms are too narrow and imprecise in the climatic sense to effectively communicate design strategies for all-year WiSR needs. The challenge remains communicating these differences verbally and visually so that key findings of public space design studies in one location can be transferred to cities with similar climates, which may or may not apply to cities of other continents.

Phillips developed the WCSI with the underlying notion that climate variability is ubiquitous in Canada. But noticing that the WCSI’s output value only provides a relative measure of severity which does not specify the type, location, time interval, or frequency of weather elements, this method could be useful for planning and design if it could quantify climate variability with the variables of element type, extent, and severity included as part of the output value.

The climate zones of the Köppen-Geiger Classification are not suitable for purposes of comparing and communicating key differences in meso, local, and microclimate among urban climatologists, planners, and designers. The Köppen-Geiger system is important for studies requiring knowledge on the certain range of vegetation species for different areas, and this is evidently useful to understanding the macroscale effects of human activity on global changes in biodiversity. But in its current state, the Köppen-Geiger classification system does not communicate relevant information for urban planning and design purposes. At the same time, there has yet to be a method for representing advective components, i.e., air temperature, wind speed, sunshine hours, precipitation, in a manner that captures the range of all-year local climate conditions. Representing these components graphically and quantitatively would allow urban design and climatology professionals to better relate the significance of local knowledge for uses in parts of the world with similar needs.

In sum, it is currently difficult for planners and designers to globally compare and relate climate data, because the climate metrics in place do not clearly convey the key challenges of various local climates around the world. Consequently, planners and designers have no simple method for locating and assessing similar research and design precedents around the world. This issue relates to problems of low use and enjoyment of public spaces in WiSR cities as current metrics WiSR cities are either narrowed to a single-season perspective or do not respond to human needs. So, while strategies exist to treat specific winter-related problems, the challenge for WiSR urban design is not of simply determining *which* strategies can extend wintertime use and enjoyment in WiSR cities, but also *how, how many, how long,* and *at which scales* should strategies be implemented to increase all-year use and enjoyment of public spaces? Such questions can only be addressed if the context for implementation is sufficiently known. Climate metrics can facilitate comprehension if they provide key information in a clear, direct, and accurate manner.

4.2 Climate and Microclimate Metrics Integrating Time and Human Behaviour

This section recalls the important climate and behaviour elements stated in previous chapters and describes some of the existing metrics that allow for their integration within public space design. As stated in Section 2.3, previous thermal assessment models did not address outdoor climate and human behaviour. As a result, prior to development of MEMI and similar models after 1984 (Höppe 1984 in Mayer and Höppe 1987), attempts to apply a quantitative approach to urban design were limited by heat-balance models that were designed for steady state conditions—which are difficult to achieve in outdoor and semi-outdoor environments. For some semi-indoor public spaces, such as the Rideau sidewalk enclosure built in 1983, the continuous flow of pedestrian traffic made it impossible to maintain steady state conditions, and the narrow range of activities attracted unintended uses of the space by itinerants which limited its use for other users. However, as shown by the summertime and wintertime use of public spaces in Waterloo and Ottawa, many are willing to remain in cold, non-steady state environments when outdoor activities are suited to user preferences. Coincidentally, for the last 40 years the general focus of research in human biometeorology has tended toward studying the psycho- and physiological effects of non-steady state environments. As a result, heat budget models that were originally developed to estimate neutral steady state indoor conditions were expanded to allow estimation of transient conditions in extreme outdoor environments. Recent heat-budget models, along with field investigations and 3D simulation models, not only provide greater accuracy for human physiology and local climate but are now beginning to offer methods for assessing factors such as behavioural and psychological adaptation (Chen and Ng 2012). Still, however, these demand a significant amount of time, costs, and knowledge that do not easily fit within existing planning and design practice, as many other important constraints require sustained attention (Eliasson 2000; Oke 2006).

Section 2.2 also showed that the use of public spaces depends first upon the spatial distribution of necessary activities in the area. But even with the most ideal distribution, cold stress remains severe for a significant portion of the year in WiSR cities. In particular, Chapter 2 emphasized the importance of time of exposure toward cold sensation. Time becomes much more critical to human activity in severe cold environments, as people must either increase their metabolic rate, wear appropriate clothing, or do both to compensate for accelerated heat loss, and thus avoid discomfort or injury in prolonged cases.

Further, Nikolopoulou and Steemers (2003) note that exposure time is connected to “perceived control”, among other parameters of psychological adaptation to thermal environments. From this viewpoint, extending use and enjoyment within public spaces during the cold season can be achieved if restorative environments—e.g., accessible indoor spaces or warming areas in outdoor and semi-outdoor spaces—are nearby and both environments contain activities that are compatible with user needs and preferences. So, simply having access to nearby sources of warmth can increase users' perceived control over their exposure duration, and this can invite longer stays in nearby public spaces during the long cold season. An example of this in rural settings could be an ice fishing hut or a ski lodge, whose function is primarily to extend outdoor recreational activity. On the other hand, urban outdoor and semi-outdoor examples—such as the Glass Crust in Zaryadye Park—can also provide temporary relief from cold stress and thus extend the length of outdoor exposure in urban settings. And since extended outdoor exposure times lead to greater attendance levels, public spaces benefit from greater use and enjoyment (Gehl 2010; Zacharias 2001).

Considering that public spaces are cold for a major part of the year in WiSR cities, the length of exposure to cold stress is highly influential to outdoor use and enjoyment of WiSR public spaces. To this end, climate metrics that assess human thermal sensation in relation to time and behaviour can be especially useful as they allow designers to predict ideal exposure times for different types of activities—and their associated metabolic rates—at different times of year. And while such metrics apply to climate in general, they can be particularly useful for determining design needs for the microclimates of public spaces.

Outdoors Season

To determine the effect of air temperature of human activities at daily, seasonal, and annual timescales, Culjat and Erskine (1988) point to the "outdoors season" concept developed by Bjørktø (1965) to measure "that period of the year when it is comfortable to be outdoors without heavy clothing (i.e., with only indoor-type clothing) (Culjat and Erskine 1988, 350). They report that in Oslo, temperature thresholds that meet this requirement were above 9 °C in the spring and above 11 °C in the fall (Ibid.). This finding is consistent with similar studies conducted during marginal seasons, which found that cold sensation varied according to perceptions and expectations of local climate before and after winter (Chen et al. 2018; Gehl 1968 in Gehl and Svarre 2013; Nikolopoulou and Lykoudis 2006; Leng et al. 2019).

Sub-marginal Season

Despite its ability to delimit a certain cold season, the "outdoors season" concept suggests that ideal outdoor activity times only occur on days when individuals can be comfortable wearing indoor clothing outdoors. This is clearly not the case as many Scandinavians continue enjoy the outdoors long after winter clothing has become required. Similarly, Li (1994) found that in New York, public space used dropped most significantly below a threshold of 4 °C. To define the period of the year below this temperature, Li suggested the term "sub-marginal season", and further added that designers in should focus on improving conditions during this period. Consistent with the Copenhagen model of public space design, the study highlighted that the wintertime use of public spaces was not necessarily determined by microclimate conditions, but that land use distribution, management, materials and visual information, cultural aspects, and perceptions toward winter also held considerable influence on levels of use. Figure 4.13 shows that use levels for four of the public spaces studied drop significantly below the 4 °C threshold, but that the Rockefeller Center and General Motors plazas were not significantly influenced by temperature or time of year.

Thus, a limitation of these two season-based climate metrics remains that they rely solely on air temperature, which does not provide a complete assessment of human thermal needs. Greater accuracy could be achieved if the other five parameters of the human heat budget were integrated, as well as activity distribution, spatial configuration, and user control.

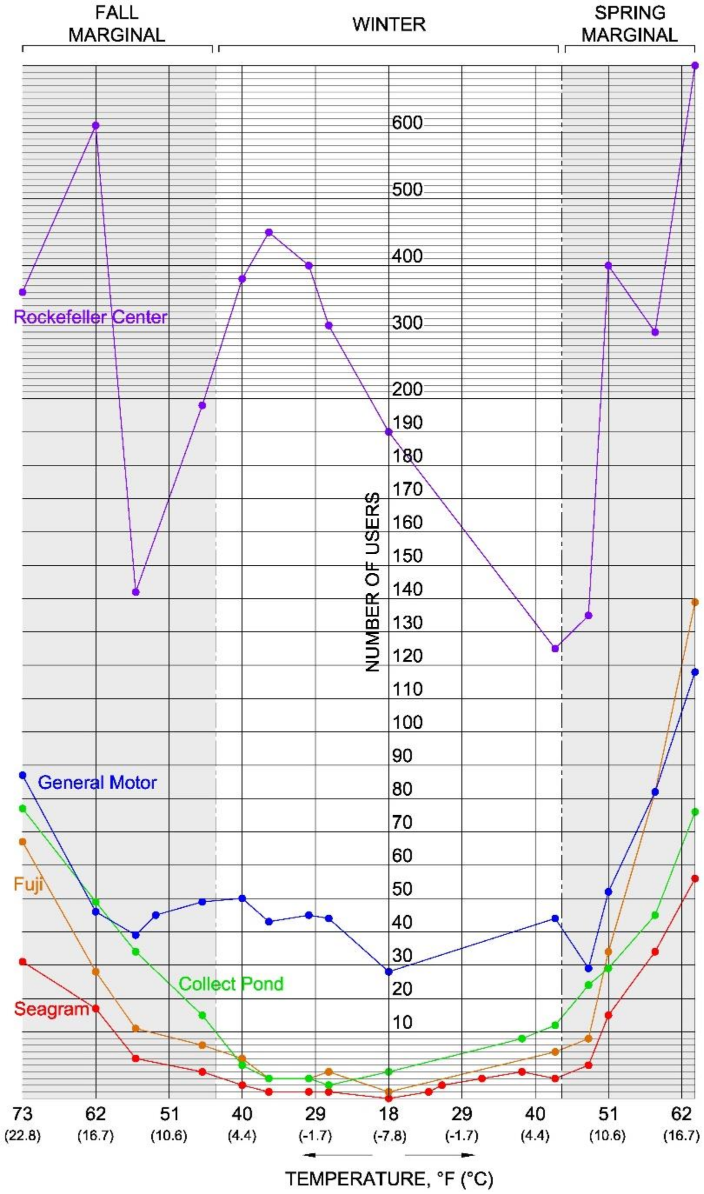


Figure 4.13 Observed attendance levels in relation to air temperature for six public spaces in New York 1989 and 1993. Temperatures are presented left to right, from Fall, to Winter, and finally to Spring temperatures. (Adapted from Li 1994)

4.3 Conclusions

The current metrics in place for urban planning and design do not suit the purposes of public space design in WiSR range cities. Definitions such as “Winter City”, “cold climate”, or “snow climate” are too narrow and imprecise for the planning needs of Wide Seasonal Range (WiSR) climates. Moreover, this chapter showed that certain climate metrics such as the Winter Climate Severity Index (WCSI) and the Köppen-Geiger Climate Classification System do not suit the needs of early stage decision making for public space design in WiSR cities. The WCSI puts too much emphasis on the aspect of “winter misery” in a broad sense and too little emphasis on key winter variables for different locations. On the other hand, Köppen-Geiger climate zones are still categorized by five groups of flora and fauna, which have different needs and sensitivity to climate than human activities. The most recent version of the classification system provides high-resolution gridded data for present (1980-2016) and projected future (2071-2100) conditions (Beck et al. 2018), but the minimum thresholds used to delimit climate zones remain too general for a meaningful comparison of local climates of WiSR cities.

Climate metrics such as the “outdoors season”, “sub-marginal season” are key as they point to a simple method of integrating climate and human behaviour—which have shown to be especially important in cold environments—within early-stage urban design. However, future development is needed to attain metrics that provide simple, tangible information for early-stage decision making which factor all six parameters of human heat budget for specific scenarios of activity distribution and spatial configuration.

Considering the important seasonal variations in microclimate throughout the year in WiSR cities, the effects of public space design on use and enjoyment are best revealed through time in a cross-seasonal perspective. Since urban planning and design concern factors that go beyond solely human comfort, cities with severe and variable climate would benefit from a simple climate metric that describes local climate in terms of the severity, duration, and frequency for each of the relevant weather variables. This could then allow designers to better assess the influence of other important parameters such as activity distribution, spatial configuration, user control, and other non-thermal aspects of ambient stimuli. The following chapter presents a method for classifying cities according to seasonal range.

5. Proposed WiSR Climate Classification

So far, Chapter 3 concluded that there are currently very few documented examples of WiSR public spaces that attract use in all seasons. Public spaces that support ephemeral activities tend to be more successful due to their ability to provide greater control over optional activities, microclimate conditions, and spatial configurations for different seasons and user preferences. Further, there remain few studies on winter- and cold-related issues for public space design, and even less on designing public spaces for cities that experience severe cold to hot conditions within the same year.

While Winter City studies drew considerable attention to winter-related urban planning issues in the 1980s and 1990s, few studies acknowledge the specific climate challenges to be addressed for different locations. Instead, local climate challenges continue to be treated as relative or general (Pressman 2004, 5; Stout et al. 2018, 5), and thus local issues and their associated strategies remain unclear. There is also an overemphasis on Northern latitudes. This becomes problematic as challenges related to latitude are frequently associated to other winter-related challenges which are more closely tied to macroscale air currents, proximity to land and water bodies, and precipitation. As shown by land surface temperatures of the world for January and July, high latitude regions of Europe, including Iceland, experience relatively warm winters and cool summers compared to lower latitudes regions in North America, Siberia, and Northeast Asia (see Figure 5.1).

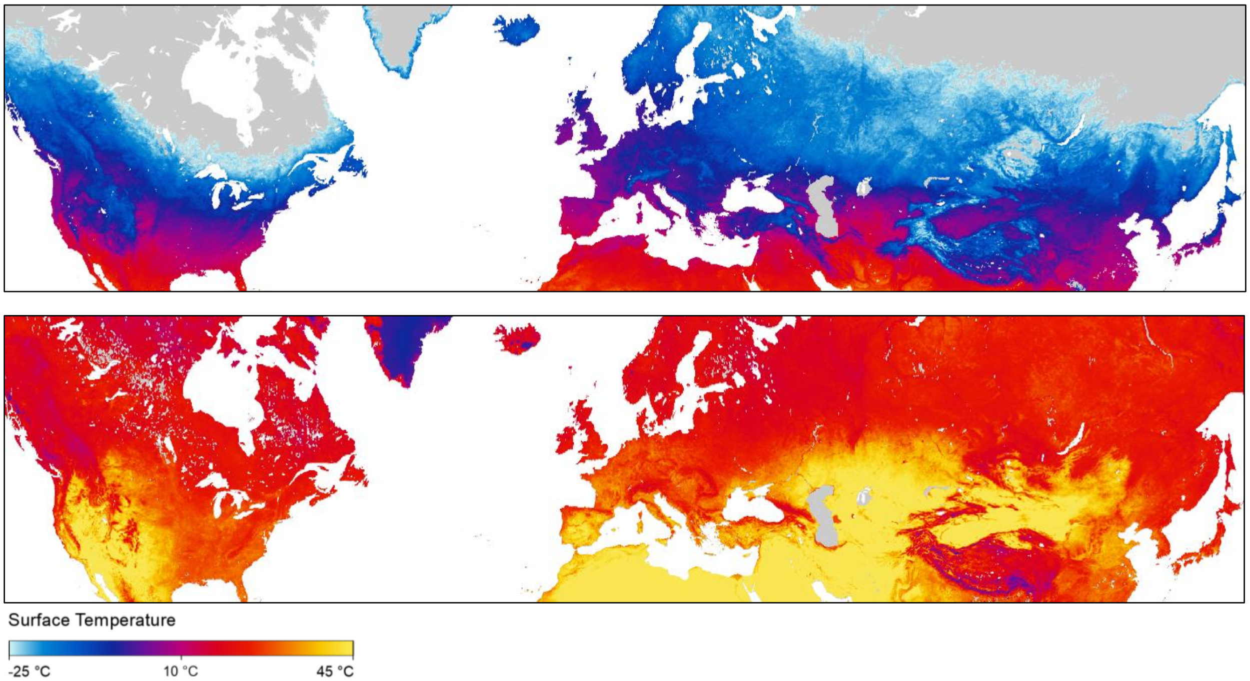


Figure 5.1 Average Land Surface Temperature for January 2019 (Top) and July 2019 (Bottom). (Adapted from NASA Earth Observations (NEO) using data courtesy of the Land Processes Distributed Active Archive Center (LPDAAC) and the MODIS Land Science Team; Wan et al. 2015)

Beyond issues in existing research, there is also no useful metric for assessing and comparing all-year local climate needs for public space design in cities that experience severe winters. One issue with existing metrics and definitions is that they often focus on single aspects to describe a broad range of conditions. Terms such as “winter city”, “northern city”, “cold climate”, or “snow climate” are all used to describe places that experience a wide range of conditions throughout the year, which can include severe cold and hot, humid summers. These terms place a narrow focus on winter planning needs, yet many practitioners and researchers agree that summer conditions are more critical for all-year use and enjoyment (Whyte 1980; Gehl 1992; Gehl and Gemzøe 1999; Li 1994). With current terms in use not suited for conveying local climate and planning challenges, it remains challenging to collectively address specific challenges of urban climates through an all-season perspective. As a result, it is common for public space designers in WiSR cities to rely on design approaches developed either for summertime activities or solely for winter needs.

The WCSI offers a relative measure of winter climate severity, but it does not provide tangible output values on both cold and hot seasons in a manner that can be directly factored in planning and design. On the other hand, the Köppen-Geiger Classification System does provide a measurable basis for comparison, but climates are zoned according to plant physiology, making it difficult to relate cities according to the needs of human physiology and behaviour. Hence, these metrics do not provide the key information needed for early-stage design at meso, local, and micro scales.

In line with the need to identify local climate challenges at the pre-design stage, the WiSR Climate Classification System is proposed. The classification provides tangible information that allows for simple assessment of seasonal range for different cities of the world. It is based on the hypothesis that by facilitating access to key information on local climate pertaining to urban planning and design—in this case, the average temperature of the coldest month (T_{min}), average temperature of the hottest month (T_{max}), and annual temperature range (T_{range})—planners and designers can more directly assess and compare urban climates and their associated public space design strategies. By doing so, it not only informs planners and designers on specific winter needs, but also summer needs. It then becomes evident that some cities have the challenge of severe winter *and* summer, while others are more challenged by either winter *or* summer conditions.

5.1 Chapter Structure

The following sections of this chapter begin by describing the process used to develop the classification. Then, the classification is applied to assess the relationship between of various winter-related climate parameters. In particular, it is used to analyse the influences of latitude, snow cover for the coldest month, average temperature of the coldest month (T_{min}), average temperature of the hottest month (T_{max}), annual temperature range (T_{range}), and the proposed Seasonal Range (SR) criteria on all-year climate for different cities. Subsequently, findings of this chapter are related to the objective of increasing the use and enjoyment of public spaces in WiSR cities. Lastly, a comparison of the Köppen-Geiger and WiSR system show the practical uses of a criteria measuring both the *coldest month* of the year and the *range* between coldest and hottest months toward pre-design comparison and analysis of WiSR cities.

5.2 Development of WiSR Classification System

5.2.1 Selection of Cities for Analysis

The classification system was developed by calculating 30-year climate normals (1981-2010) obtained from weather stations of the Global Historical Climate Network (GHCN). The GHCN gathers weather data accumulated over several decades from thermometers located 2 metres above ground level at available weather stations around the world (Menne et al. 2018). To determine the cities to be considered for analysis, it was deemed useful to narrow the scope of selection to all large metropolitan urban agglomerations that could—or have been suggested to—host elements of winter weather. This chapter focuses on data for large cities to allow for greater analysis of climates from a global perspective. But, as mentioned in Section 1.4, many smaller cities and town centres could also benefit from the proposed classification system.

While the definition of a large city can range widely, the United Nations often uses the criterion of urban agglomerations with 1 million or more inhabitants to define large cities (see Figure 5.2). As such, all cities with population equal or greater than 1 million were identified using approximate population data acquired from urban agglomerations for latest available census data between 1999-2015 (United Nations Department for Economic and Social Affairs 2018; United Nations 2018). This revealed roughly over 500 cities (see Figure 5.3).

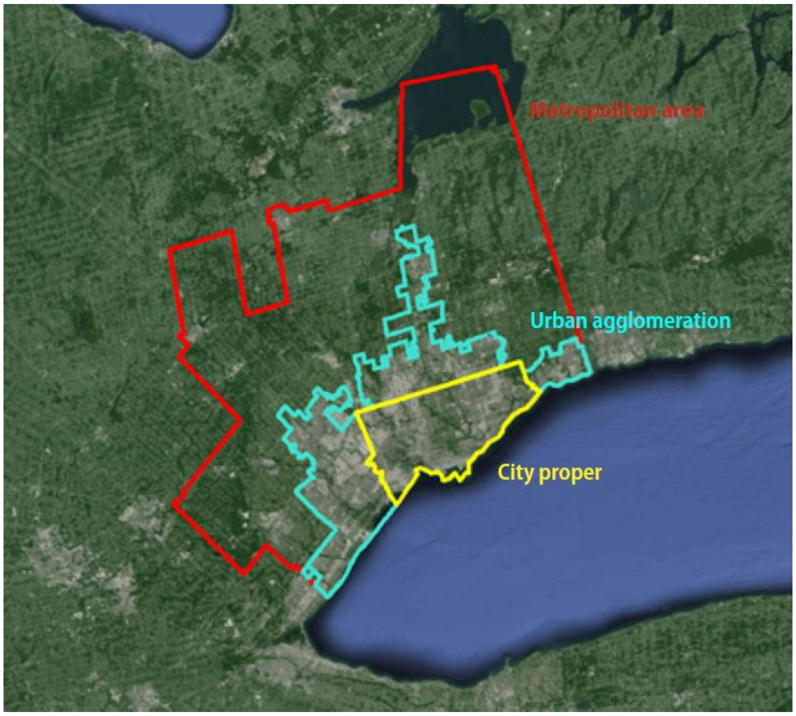


Figure 5.2 Boundaries of metropolitan, urban agglomeration, and city proper areas for the city of Toronto. (Image provided by United Nations 2018, which uses population data and boundaries taken from Statistics Canada, and satellite imagery taken from Google Image)

Figure 5.3 Global Map of Metropolitan Cities with over 1 Million Inhabitants. (Data Source: United Nations Department for Economic and Social Affairs 2018; United Nations 2018)

To determine the effect of latitude on local climate severity, all cities above latitude 45 °N were retained. Figure 5.4 shows that cities above latitude 45 °N are distributed across a wide range of climates. Moreover, many cities above 45 °N are not very cold during winter. E.g., Vancouver, London, or Amsterdam do not experience severe cold winter conditions, nor do they experience severe hot summer conditions. These cities were included in the analysis as Narrow Seasonal Range (NSR) to allow better comparison of these climates in relation to those of WiSR cities.

To account for all metropolitan cities that could potentially experience harsh winter climate, world metropolitan cities were further narrowed to all cities below latitude 45 °N that contain average temperature for the coldest day equal or below 0 °C. This temperature was chosen as a less restrictive criterion with the intent of including all potential metropolitan cities that experience a wide seasonal range. The parameter "average temperature of the coldest month (T_{min})", on the other hand, is more restrictive and allows for a more robust basis for comparison of local climates. Figure 5.5 shows these cities in relation to climate zones of the Köppen-Geiger Classification. With both conditions satisfied, the selection resulted in 128 cities, all of which are located between latitudes 34 °N and 61 °N (see Figure 5.7).

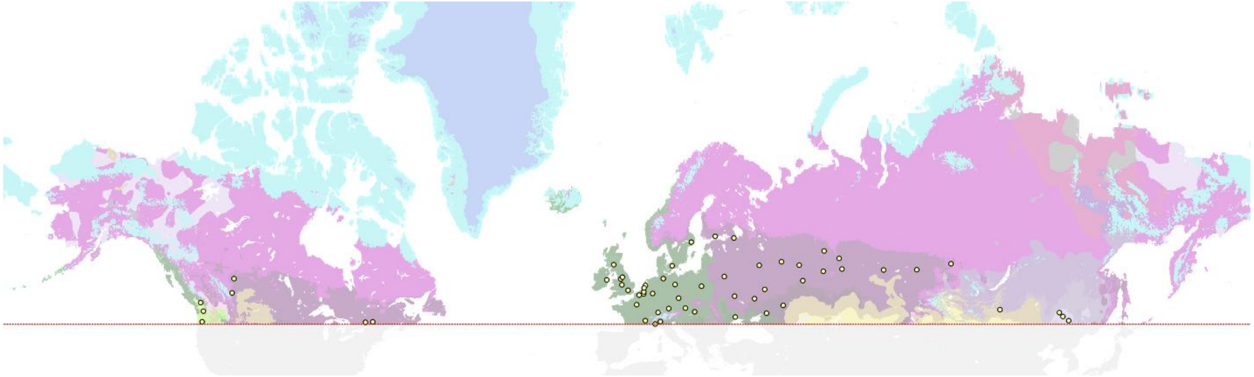


Figure 5.4 Metropolitan Cities at latitudes equal or above 45 °N. (Population Data: UN 2018; Climate Zone Data: Kottek et al. 2006; Rubel et al. 2017; and koeppen-geiger.vu-wien.ac.at, retrieved August 9 2020)

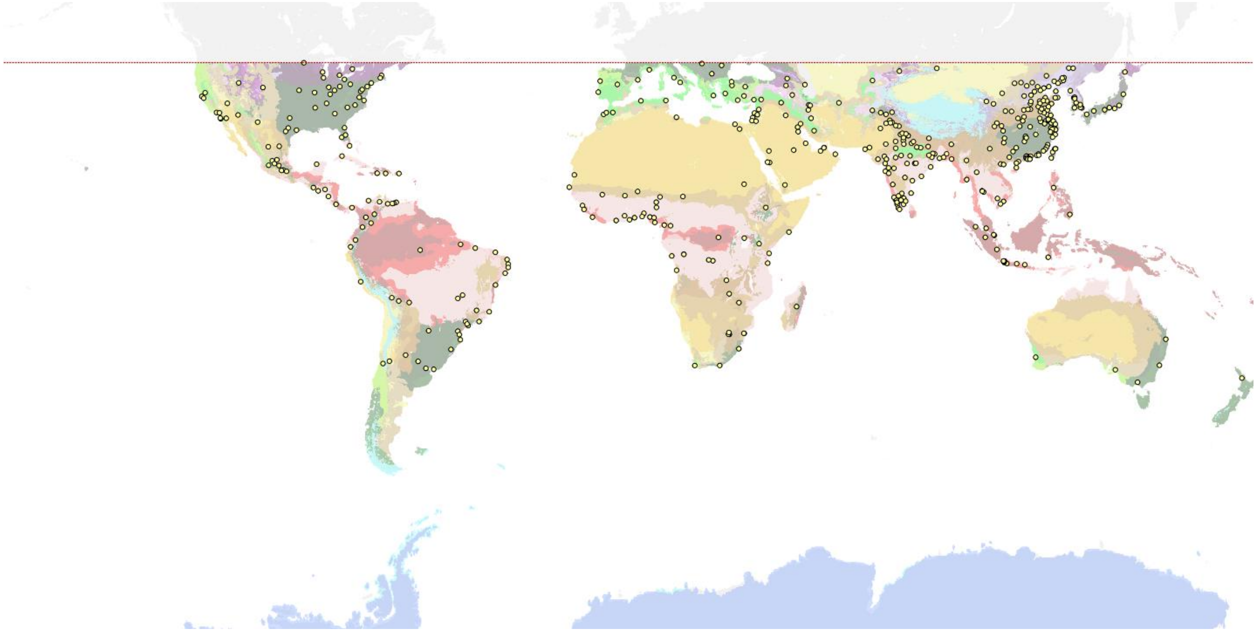


Figure 5.5 Metropolitan Cities at latitudes below 45 °N. (Ibid.)

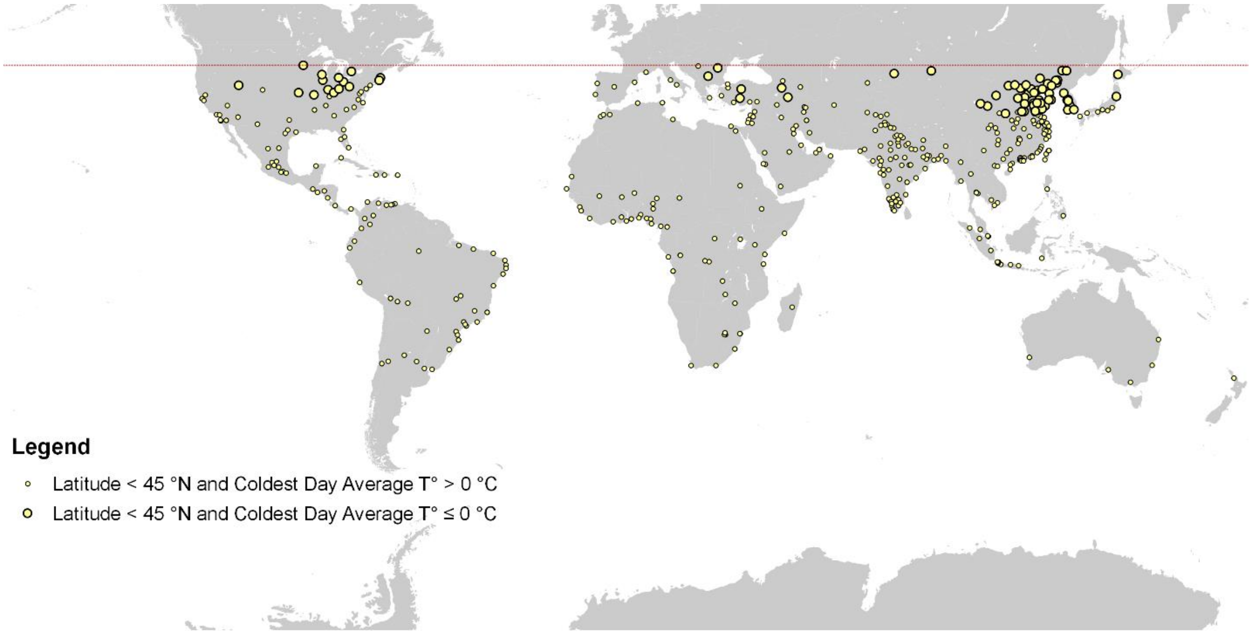


Figure 5.6 Metropolitan Cities at latitudes below 45 °N with Average Temperature (Mean of High and Low) of the Coldest Day equal or below 0 °C (magnified) and above 0 °C. (UN 2018; Cedar Lake Ventures Inc., retrieved October 22 2020)

Figure 5.7 Illustration of the 128 Cities Selected for Analysis. (Ibid.)

5.2.2 Determination of Thresholds

As concluded in Chapter 3, winter and summer seasons are both important to the year-round success of public spaces in WiSR cities. However, there have been few attempts to develop climate metrics that accounts for these opposing needs. To determine different classes of "cold" for the cold season, the average temperature of the coldest month (T_{min}) should be low enough to allow for snowfall, i.e., equal or below 0 °C. However, there is nothing about snowfall in winter that indicates whether a certain location also experiences hot summer conditions. The parameter annual temperature range (T_{range}) then becomes useful to indicate the range of conditions between coldest and hottest periods. Analysing the T_{min} and T_{range} values for selected cities reveals that colder winters are generally accompanied by greater T_{range} (see Figure 5.19). Considering this close relationship between T_{min} and T_{range}, it becomes possible to establish criteria that simultaneously considers both parameters. In other words, cities in mid- to high latitudes can be classed according to specific ranges of T_{min} and T_{range}. This section describes the rationale for determining thresholds of T_{min} and T_{range} used to determine WiSR classes.

Initially, the thresholds for different classes of T_{min} and T_{range} were set at regular, round-number increments of 5 °C. This step is arbitrary, but it does offer certain benefits. On one hand, it provides clear and simple points of reference. On the other hand, the allotted spacing of 5 °C ensures that a fair number of cities are included within each category of T_{min} and T_{range}, and that for each category, T_{min} thresholds correspond to similar T_{range} thresholds.

Figures 5.8 and 5.9 show the distribution of cities according to their T_{min} and T_{range} values, respectively. The S-shaped pattern demonstrates that values in the middle range have more comparable cities, while those at the high end of T_{range} and low end of T_{min}, e.g., Ulaanbaatar, Harbin, and Daqing, have fewer comparable climates. Cities at the low end of T_{range} and high end of T_{min} are not significantly challenged by a wide seasonal range and share a similar climate as many other metropolitan cities which are not in the scope of this analysis. After inspecting general climate conditions for recognizable cities in each category, it was noticed that some refinements were needed.

To account for sharp transitions in climate severity, two adjustments were made for thresholds near extremely high T_{range} and extremely low T_{min}, respectively. To account for exceptionally large differences of cities with extremely cold T_{min}, a first adjustment was made by raising the threshold between severe and extreme T_{range} from 35 °C to 37 °C . This was decided as it would seem inappropriate to place cities similar to Ulaanbaatar—which is right at the edge of the 40 °C T_{range}, with a T_{min} of -21.4 °C and T_{range} of 40.2 °C—in the same category as cities such as Novosibirsk—which in fact is severely cold with T_{min} of -16.1 °C and a T_{range} of 35.6 °C, but not sufficiently severe and seasonally variable to seem comparable to Ulaanbaatar. From a thermal comfort standpoint, it could be argued that the implications for T_{min} of -16.1 and -21.4 °C are not very different. But from the standpoint of energy consumption and technical requirements, this difference could have considerable consequences.

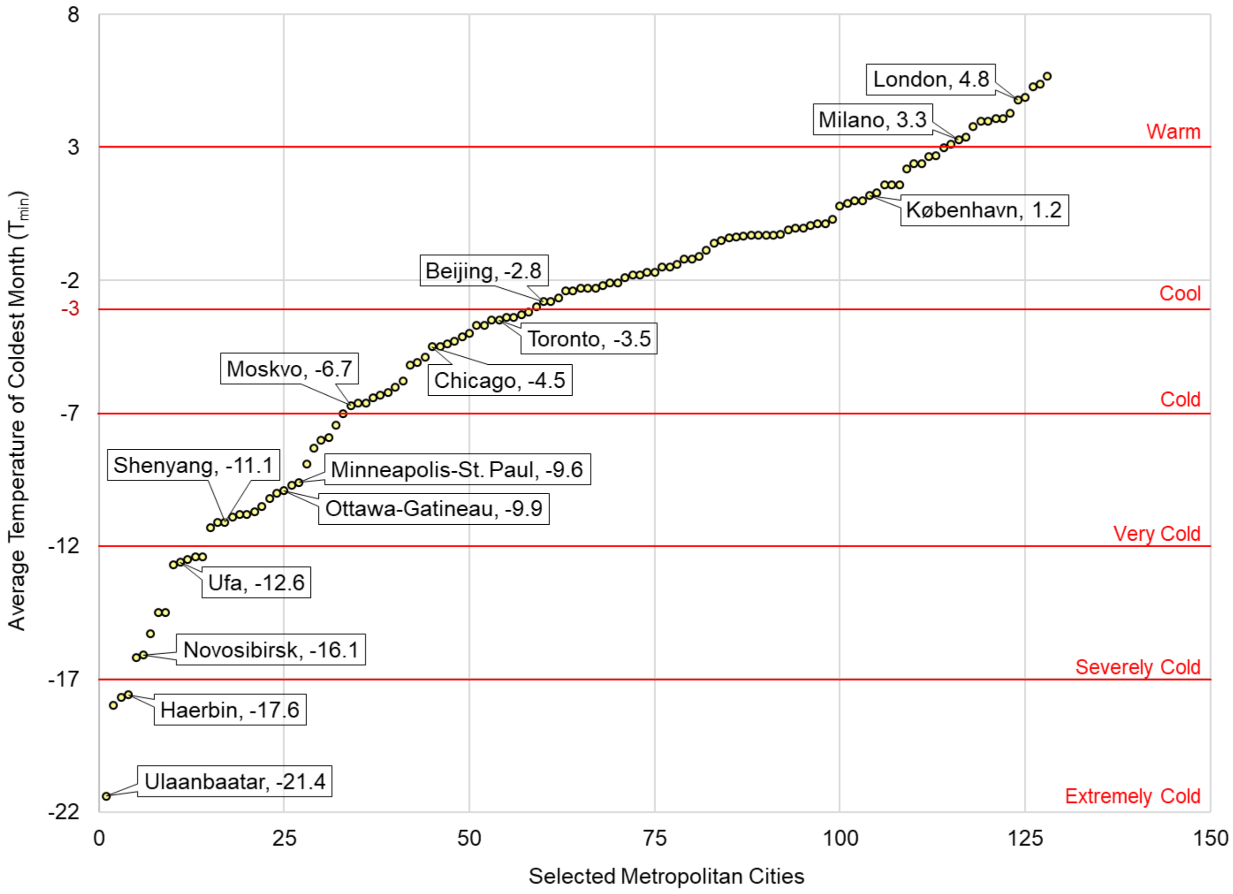


Figure 5.8 Average Temperature of the Coldest Month (T_{min}) for the 128 Selected Cities.

T_{min} increments were also mostly maintained at 5 °C for extreme low temperatures by starting at the lowest round number of -22°C, and proceeding upward by 5°C. Cities between thresholds -17 and -12 include … seems appropriate since... Cities between thresholds -12 and -7 include … seems appropriate since... At -3 °C, a second adjustment was made since some cities with T_{min} between 3 °C and 2 °C can have remarkably different winter conditions than those with T_{min} between 3 °C and 7 °C. E.g., maintaining a threshold of -2 °C would place cities such as Beijing (T_{min}: -2.8 °C) and Moscow (T_{min}: -6.7 °C) within the same category, while cities with very similar climates, such as Oslo (T_{min}: -2.8 °C) and Stockholm (T_{min}: -1.7 °C) would belong to different categories. At 3°C the threshold is maintained because it realigns with the general rule of 5°C increment. It could be higher or lower but raising it too high might begin to include cities that experience only moderately cold winters, such as Vancouver, London, or Amsterdam. Placing this threshold too low might exclude cities that do experience fairly cold winters, such as Changwon.

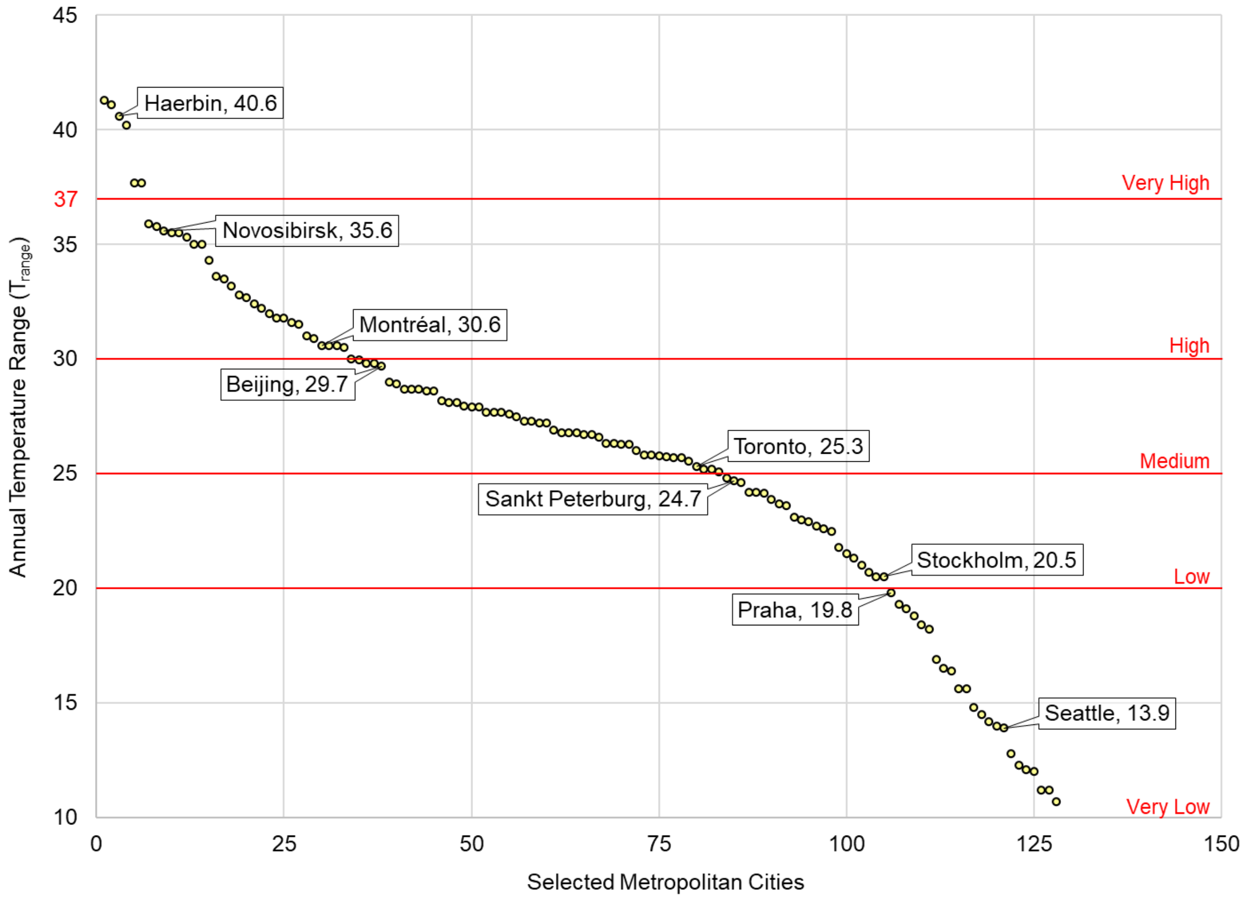


Figure 5.9 Average Annual Temperature Range (T_{range}) for the 128 Selected Cities.

Cities with T_{range} below 20 are not severely challenged by seasonal range because the lowest T_{min} value is -1.4 °C, which indicates that winter is moderately cold while summer is between cool and moderately warm. Further, it was considered that cities with T_{range} below 20 are not much more challenged by seasonal variation as cities with T_{range} below 15. At most, a city below 20 °C T_{range} experiences moderately cold winters (T_{min} between -1.4 °C and 5.7 °C) and cool to warm summers (T_{max} between 15 °C and 21.9 °C).

In the end, different combinations of T_{min} and T_{range} thresholds were trialed, and the chosen thresholds seem most appropriate classes for purposes related to seasonal range and urban planning and design. In general, the rationale for determining thresholds can be summed up by the need to maintain a fair number of cities per group, account for sharp changes in T_{min} and T_{range}, and ensure that no cities with very different conditions fall within the same category, or that cities with very similar conditions fall within different categories.

It is important to note that these remain proposed thresholds. While they are determined by the author's own judgement and knowledge on cold- and winter-related architecture and design, they do not reflect empirical measurements as with acceptable thermal range or other climate-behaviour metrics. This classification would ideally be informed by such metrics, but instead a first attempt is made to create a working classification system that can revised as more evidence is published.

For T_{range}, regular intervals of 5 °C were also used, going upward from 20 °C. An annual temperature range below 20 °C is considered low because it does not allow for a great range of conditions between winter and summer. At most, a city below this threshold will experience moderately cold winters (T_{min} between -2.8 °C and 5.7 °C) and cool to warm summers (T_{max} between 15 °C and 21.9 °C) (Data source: Menne et al. 2018). To account for exceptionally large differences in T_{range} at higher extremes, the higher threshold for T_{range} is raised to 37 °C. It is important to note that these remain proposed thresholds. While they are informed by existing knowledge on cold- and winter-related research, they do not reflect empirical measurements as with acceptable thermal range or other climate-behaviour metrics.

5.2.3 Proposed Criteria

The system assigns WiSR cities of the world to six classes of Seasonal Range (SR), which include Low (LSR), Moderate (MSR), High (HSR), Severe (SSR) and Extreme (ESR). The sixth class, Narrow (NSR) is proposed for all cities that are not significantly challenged by seasonal variation. The selected cities and their respective climate data and SR class are listed in the Appendix. All six classes are determined by specific criteria for parameters T_{min} and T_{range}. Table 5-1 shows Seasonal Range (SR) classes and their respective criteria.

Criteria for Seasonal Range (SR)	
Extreme (ESR)	$T_{range} \geq 37$ AND $T_{min} \leq -17°C$
Severe (SSR)	$T_{range} \geq 30$ AND T_{min} between $> -17°C$ and $\leq -12°C$
High (HSR)	$T_{range} \geq 25$ AND T_{min} between $> -12°C$ and $\leq -7°C$
Moderate (MSR)	$T_{range} \geq 20$ AND T_{min} between $> -7°C$ and $\leq -3°C$
Low (LSR)	$T_{range} \geq 20$ AND T_{min} between $> -3°C$ and $\leq 3°C$
Narrow* (NSR)	$T_{range} < 20$ OR $T_{min} > 3°C$

Table 5-1 Proposed Criteria for WiSR Cities. *Narrow Seasonal Range (NSR) denotes climates where seasonal variation is not a significant factor for urban planning and design.

5.3 Results

Among the 128 selected cities, there are 100 cities that meet the minimum requirement of average temperature for the coldest day ≤ 0 °C (32 °F). Of these, 44 are located above 45 °N, while the other 66 are between 34 °N and 45 °N. For both eastern and western hemispheres, NSR cities, i.e., those containing highest T_{min} and lowest T_{range}, are located in the westernmost part of the continent (see Figure 5.13). The overall distribution of WiSR cities is congruent with Hare's (1997) observations, who states that local climate variability in the Northern Hemisphere is largely influenced by the westerlies, the expanse of water bodies, and land surface geography. The areas with sharp variations in SR include North-western and North-eastern parts of North America and Northeast Asia (see Figure 5.12 and Figure **5.14**). By contrast, there is a smooth gradation of Narrow (NSR) to Severe Seasonal Range (SSR) going from Western Europe to the central part of the Eurasian continent (Figure 5.13).

Among the six classes of SR, Low Seasonal Range (LSR) cities span across the broadest range of latitudes, i.e., between 34 °N and 61 °N. Cities of this class extend throughout the Northern part of United-States, Southern parts of Scandinavia, Eastern Europe, North-western parts of the Middle East, Northeast China, South Korea, and Northeast Japan. In this class, it is most remarkable that high latitude cities of Northern Europe share similar T_{min} as cities at latitude as low as 36 °N, such as Daejeon or Lanzhou.

Moderate (MSR) and High Seasonal Range (HSR) cities are generally spread North and East of LSR cities. But again, it would be inaccurate to qualify all of these as northern cities—as frequently stated in Winter City studies—as they are distributed unevenly between latitudes 36 °N and 61 °N. In addition to the areas mentioned for LSR cities, MSR and HSR cities also include cities of Western and Eastern Canada, North-eastern parts of the Middle East, North Korea, and Northern Japan.

The two highest classes of WiSR, Severe (SSR) and Extreme (ESR), are in Volga, Ural, and Siberian Russia, Mongolia, and Northeast China. The WiSR city with lowest average temperature for the coldest month (T_{min}) is Ulaanbaatar, and the one with highest annual temperature range (T_{range}) is Daqing.

Figure 5.15, Figure 5.16, and Figure 5.17 show the global distribution for T_{min}, T_{range}, and T_{max}, respectively. As expected, maps for T_{min}, T_{range}, and WiSR show similar results. These maps show that on average, a wide range of T_{min} and T_{range} values are fully covered by snow for the month of January. Consequently, snow cover is not a suitable basis for climate severity at meso, local, and micro scales. They also provide more evidence that latitude is not a reliable basis for local winter climate severity, as snow cover is noticeably lower in North America and Asia than in Europe.

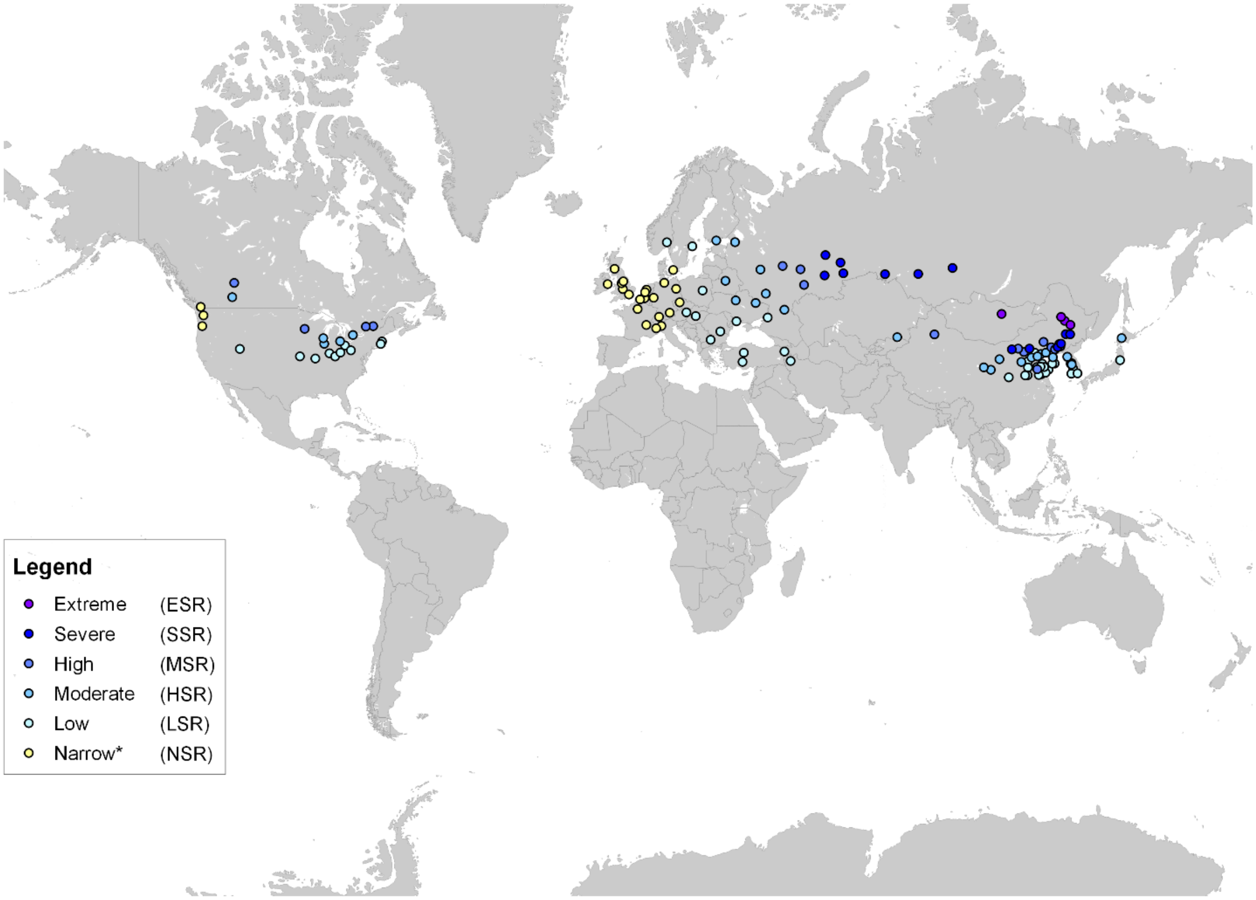


Figure 5.10 Global Distribution of Wide Seasonal Range (WiSR) Metropolitan Cities.

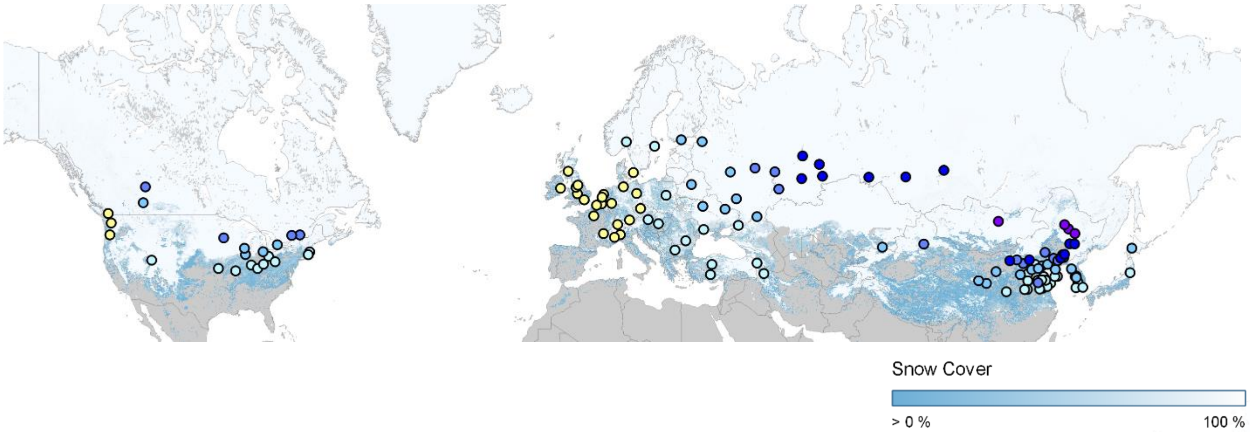


Figure 5.11 Enlarged view of WiSR metropolitan cities with average monthly snow cover for January. Percentage of snow cover represents the length of time where each 500-metre pixel of land is completely covered by snow. 100% snow cover indicates that land surface is covered for the entire month of January. (Adapted from Snow Cover Imagery provided by NASA Earth Observations Team; National Snow & Ice Data Center; Hall and Riggs 2015)

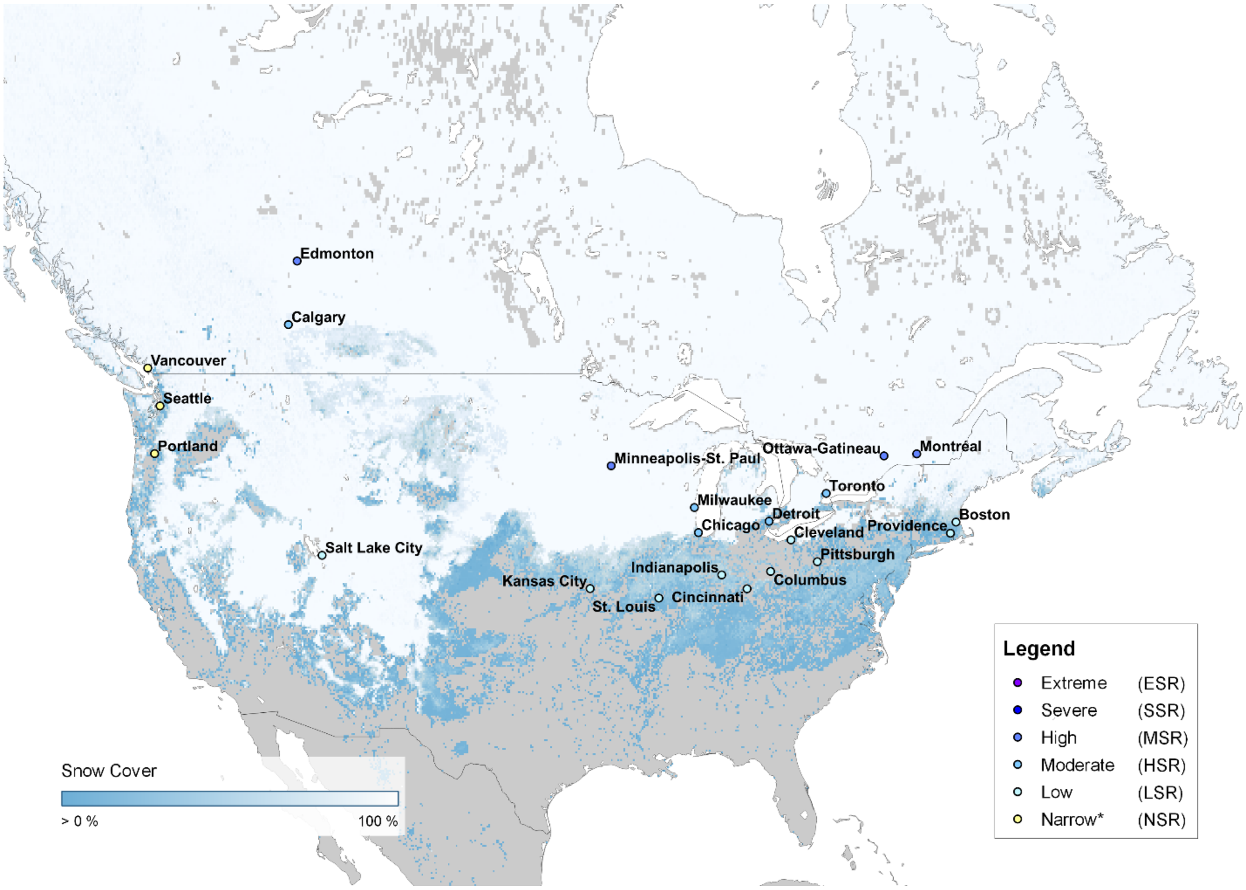


Figure 5.12 WiSR Cities of North America with Average Monthly Snow Cover for January. (Ibid.)

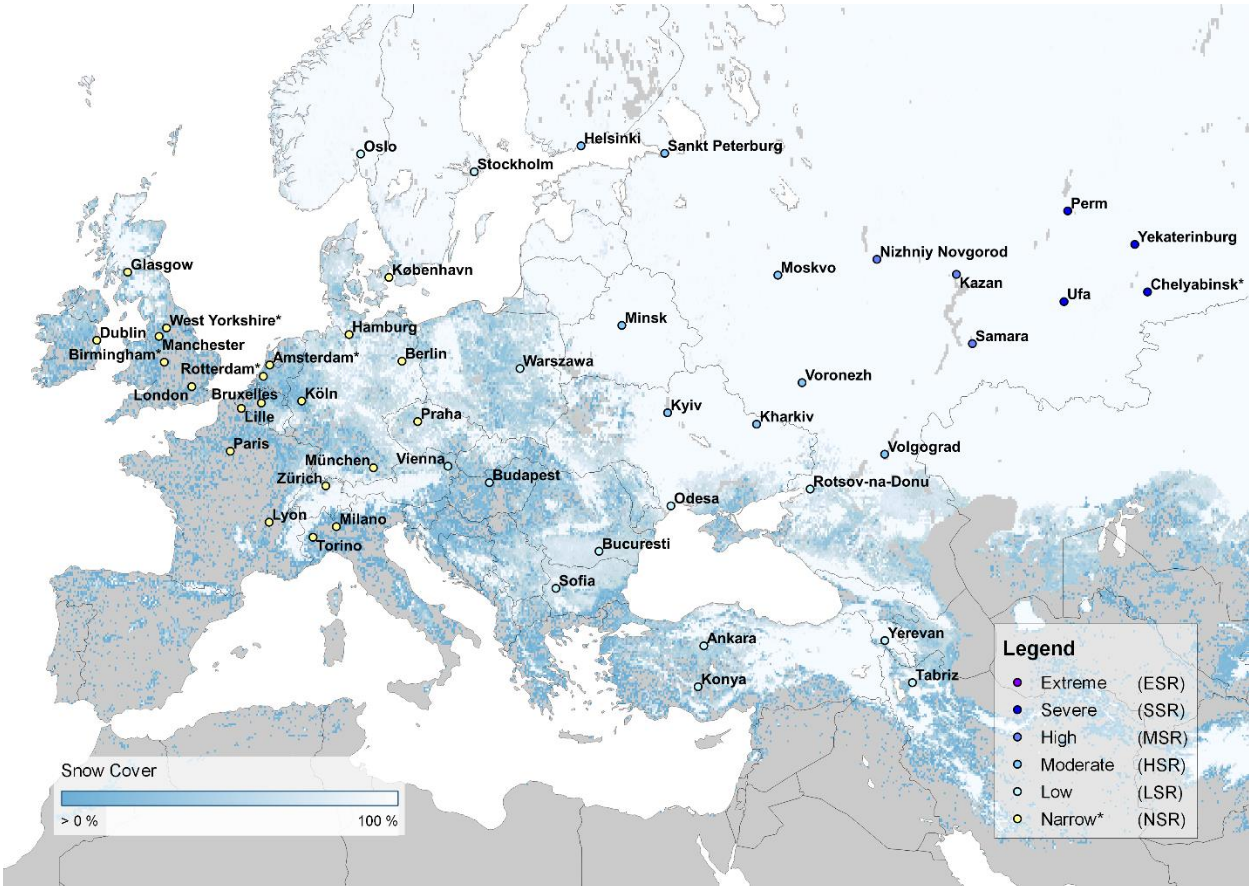


Figure 5.13 WiSR Cities of Europe with Average Monthly Snow Cover for January. (Ibid.)

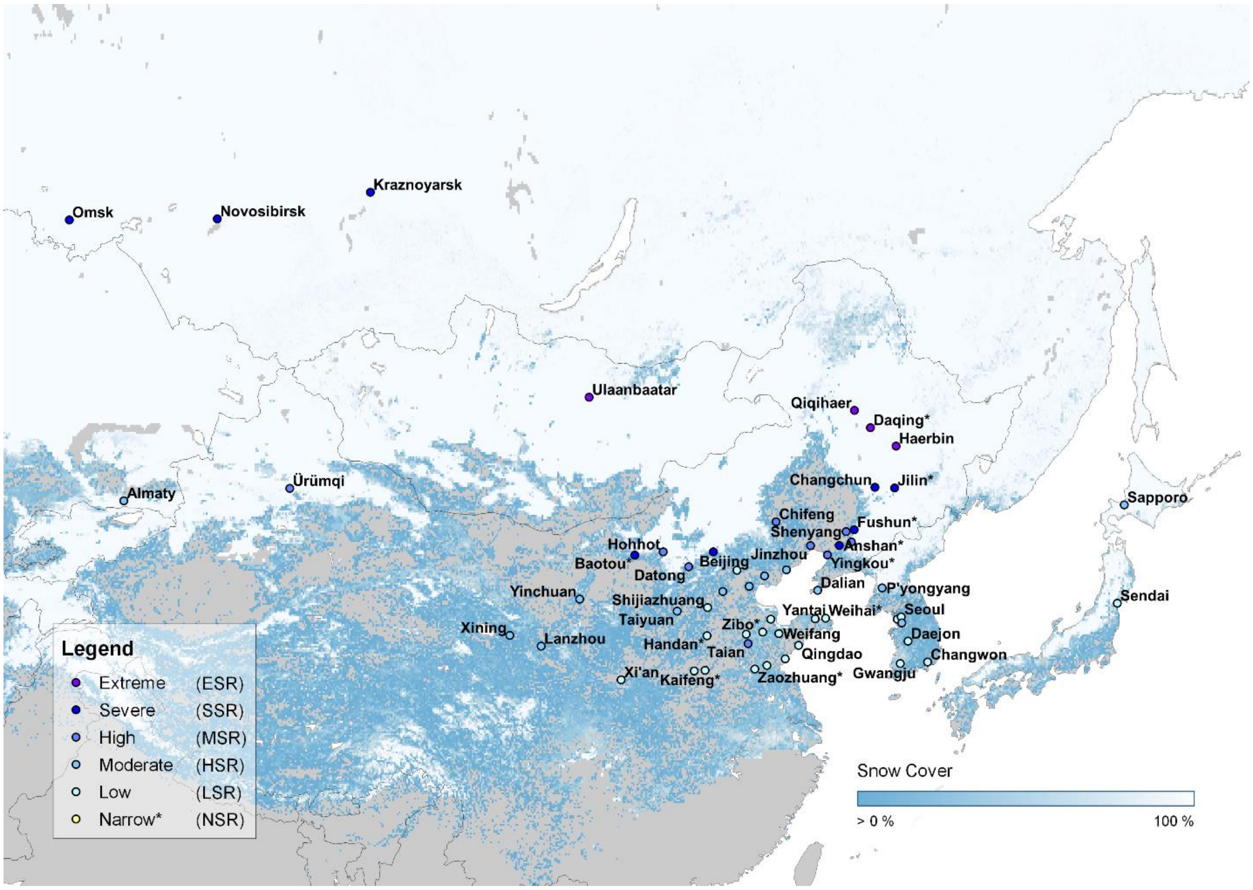


Figure 5.14 WiSR Cities of Northeast Asia with Average Monthly Snow Cover for January. (Ibid.)

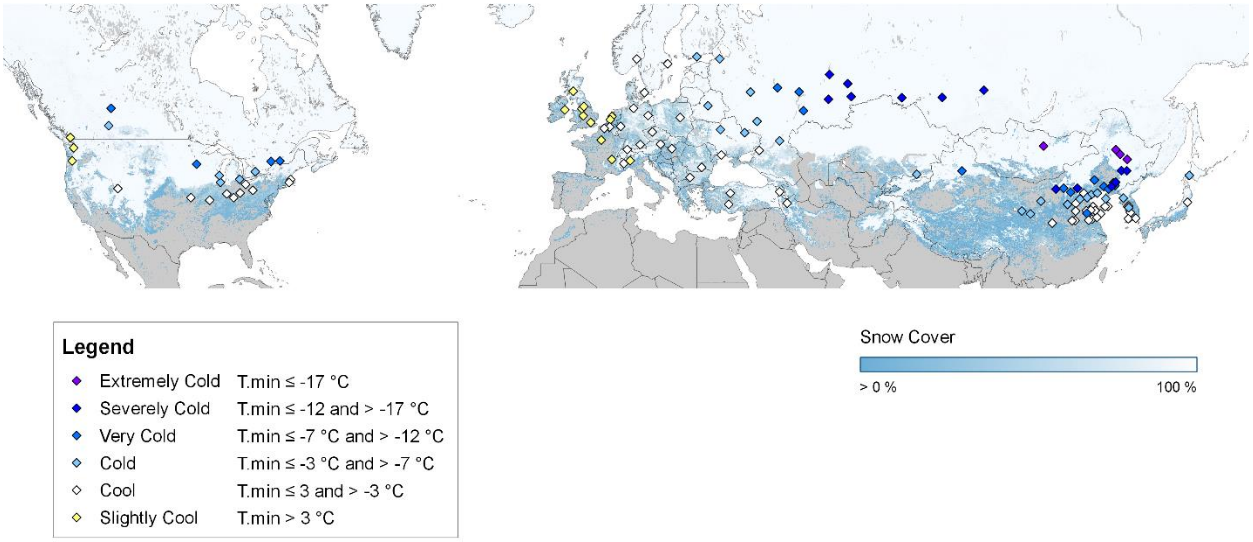


Figure 5.15 Distribution of average temperature of the coldest month (T_{min}) and average monthly snow cover for January 2016. (Ibid.)

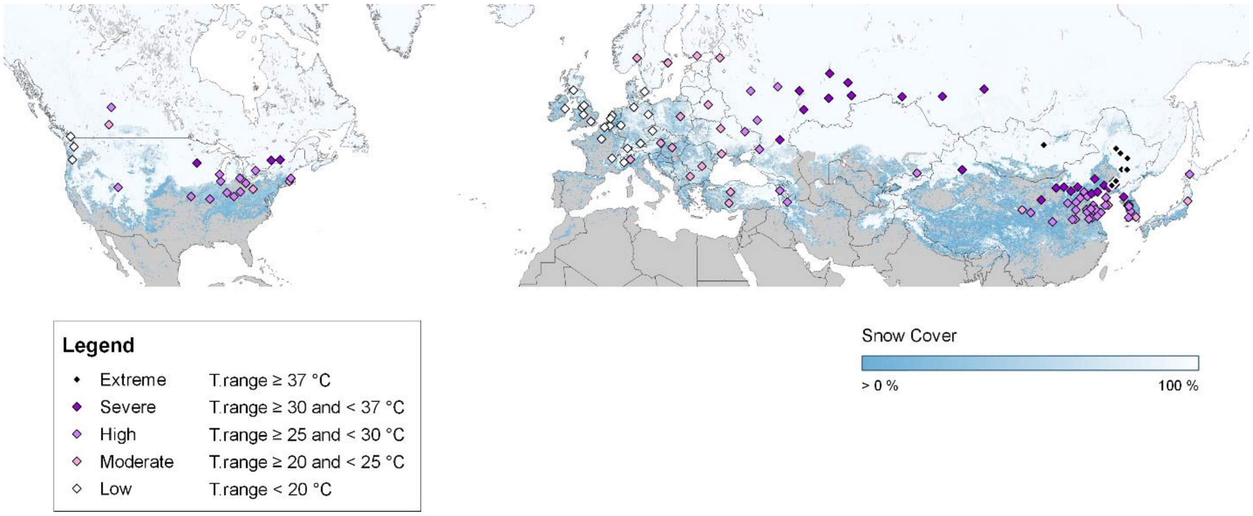


Figure 5.16 Distribution of average annual temperature range (T_{range}). (Ibid.)

Regarding average temperature of the hottest month (T_{max}), distribution is remarkably linear compared to the distribution observed for T_{min}. Figure 5.20 shows that, while there is no strong correlation between latitude and winter climate severity, there is a strong tendency for cities at lower latitudes to experience hotter summer conditions. Figure 5.21 also shows that, as with the latitudinal distribution of T_{min}, there is no significant correlation between T_{range} and latitude.

Thresholds for T_{max} were not necessary for defining seasonal range since T_{min} and T_{range} combined already addresses the coldest and hottest extremes. However, some thresholds were set for comparison and graphic representation. As with T_{min} and T_{range}, thresholds were set at regular increments, although this time these were spaced at every 2 °C and no additional adjustments were made (see Figure 5.18). These thresholds remain arbitrary as well, but they allow for quantitative comparison of the maximum average monthly temperature of different cities on a category by category basis. It also seems appropriate that Beijing does not fall within the same category as Milan, and that Helsinki's cool summers are not confounded with that of Berlin or Vienna. Another notable conclusion is that cities in Western Canada experience cold to very cold T_{min} and relatively cool T_{max}, while cities in eastern Canada experience cold to very cold T_{min} and warm summer (see Figure 5.17).

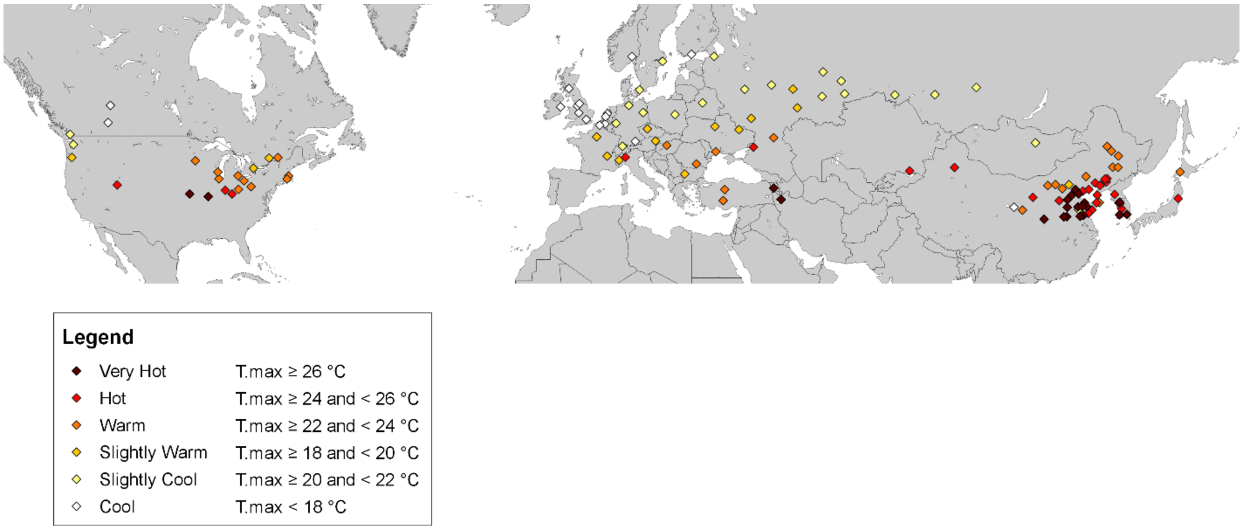


Figure 5.17 Distribution of average temperature of the hottest month (T_{max}).

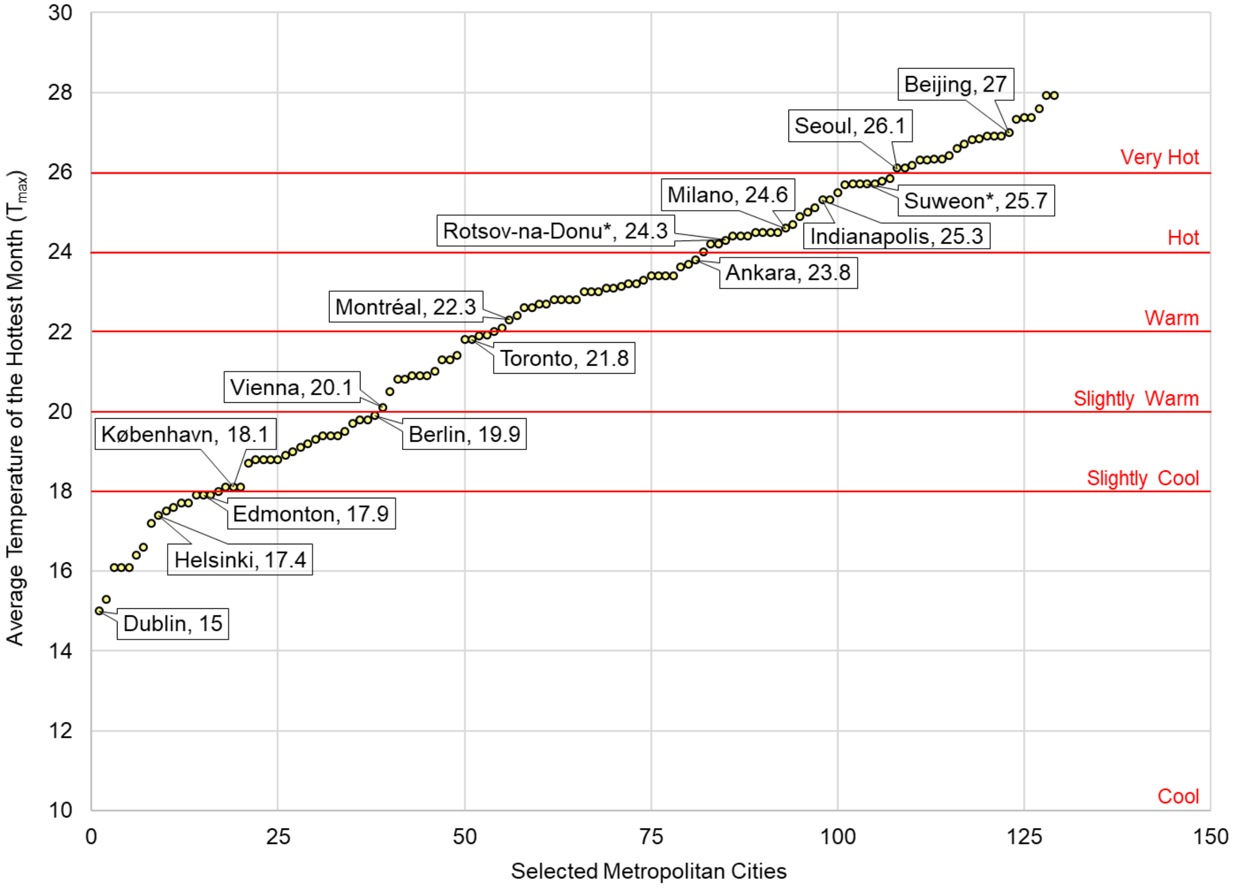


Figure 5.18 Average temperature of the hottest month (T_{max}) for selected cities and assigned thresholds.

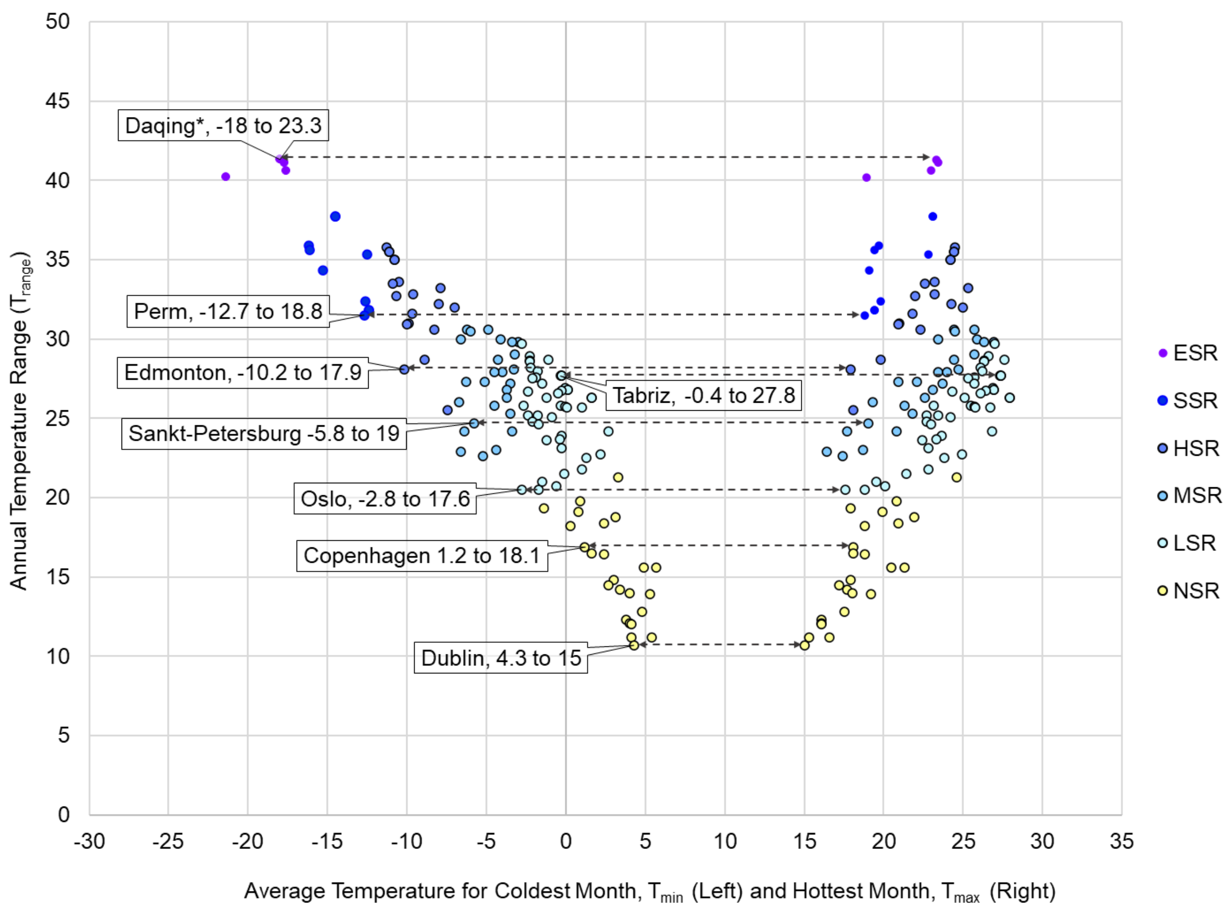


Figure 5.19 Average annual temperature range, T_{range} for selected cities according to their average temperature for coldest and hottest month.

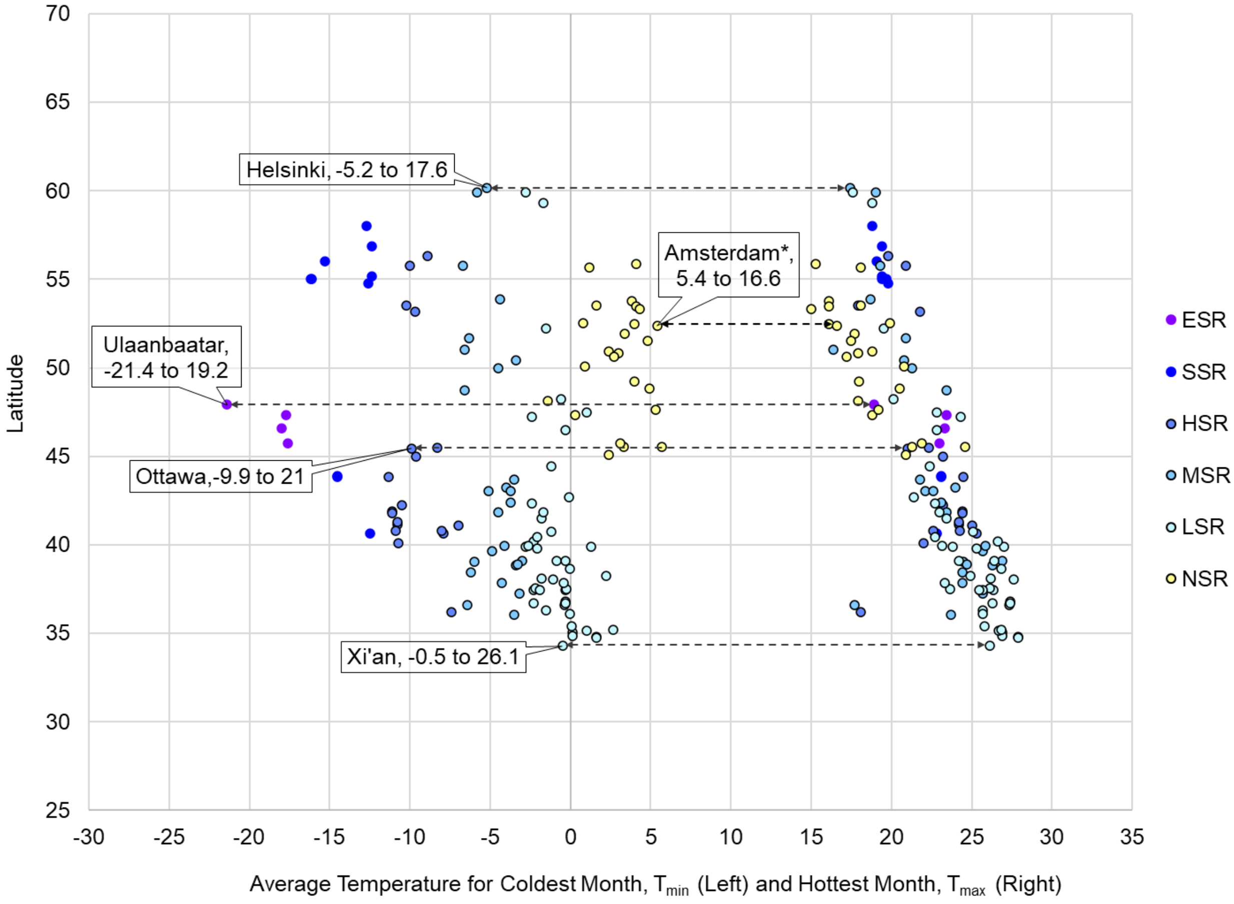


Figure 5.20 Latitude for selected cities according to their average temperature for coldest and hottest month.

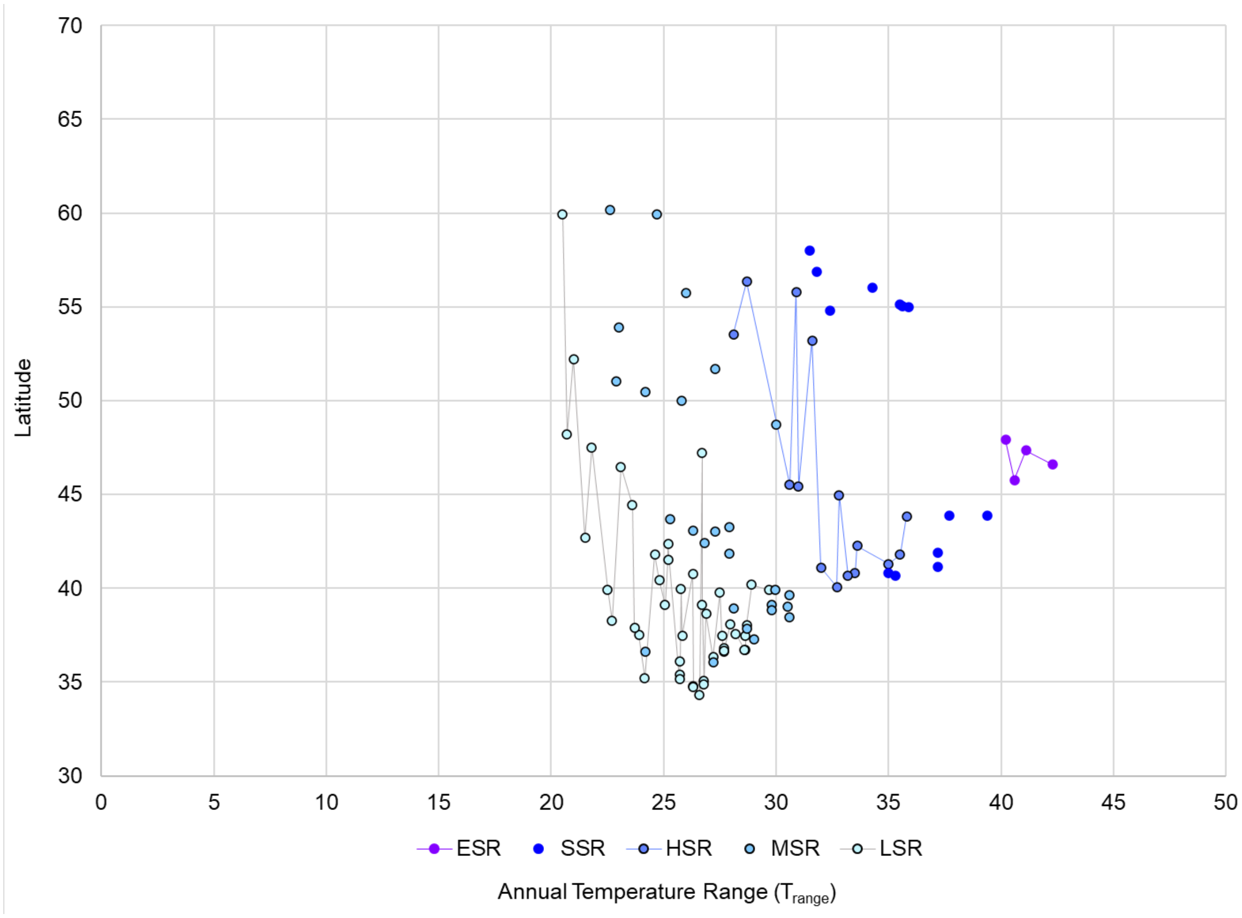


Figure 5.21 Latitude for selected cities according to their average annual temperature range, T_{range}. Lines are added at ESR, HSR, and LSR classes for greater legibility.

5.4 Significance to Early-Stage Public Space Design Decisions

Urban planners and designers in WiSR cities are currently limited by a lack of clear guidance on which climate elements should be factored into public space design. The findings from the Copenhagen model or the Placemaking movement are useful for public space design in general, but the specific climate needs of different WiSR cities remain to be sufficiently understood for a full appreciation of these models' applications toward the challenge of WiSR public space design. Nevertheless, it is expected that with clearer identification of the specific local climate challenges of different cities, other design components—i.e., activity distribution, spatial configuration, user control, and non-thermal aspects of ambient stimuli—can be better informed toward increasing the all-year use and enjoyment of public spaces.

Some mid- to high latitude cities experience extreme and prolonged winter seasons, while others may experience only moderate winter conditions and may rely on a summer-based approach to satisfy all-year public space needs. Many mid- to high latitude cities experience both severe cold winters and warm to hot summers, yet this particular challenge is rarely acknowledged in the literature despite important implications on human activities.

Based on the assessment of cities above and below 45 °N, it is clear that latitude is not a reliable parameter for determining local climate severity. From a global perspective, cities at lower latitudes do experience warmer summer temperatures, but high-latitude cities do not necessarily experience colder winters. Among the selected cities, there is a strong relationship between T_{min} and T_{range}. Knowledge of these two parameters can guide design professional on the public space design needs from an all-year perspective, which is critical to effective outcomes in WiSR cities. Although it focuses exclusively on T_{min} and T_{range}, the WiSR classification finds similar rankings as the Winter Climate Severity Index (WCSI) (see Figure 4.12) for the same cities. One major difference with WCSI is that the WiSR classification is mainly concerned with thermal challenges related to seasonal range and does not factor other parameters such as precipitation and sunshine hours. Naturally, this leads to a lower Seasonal Range (SR) ranking for Northern European cities because these cities are generally more challenged by sunshine hours, winter precipitation, and the length of winter than minimum temperature and high annual temperature range.

5.4.1 Comparison of Köppen-Geiger and WiSR Climate Classification Systems

To show the benefits of the proposed WiSR Classification System, the analysed cities were laid over maps of Köppen-Geiger climate zones of Southern Canada and Northern US (See Figure 5.22 to Figure **5.24**). Consistent with the findings of chapter 4, this shows that many cities with identical Köppen-Geiger climate zones have significantly different seasonal climates. This subsection describes differences and similarities of selected WiSR cities in the Western Hemisphere.

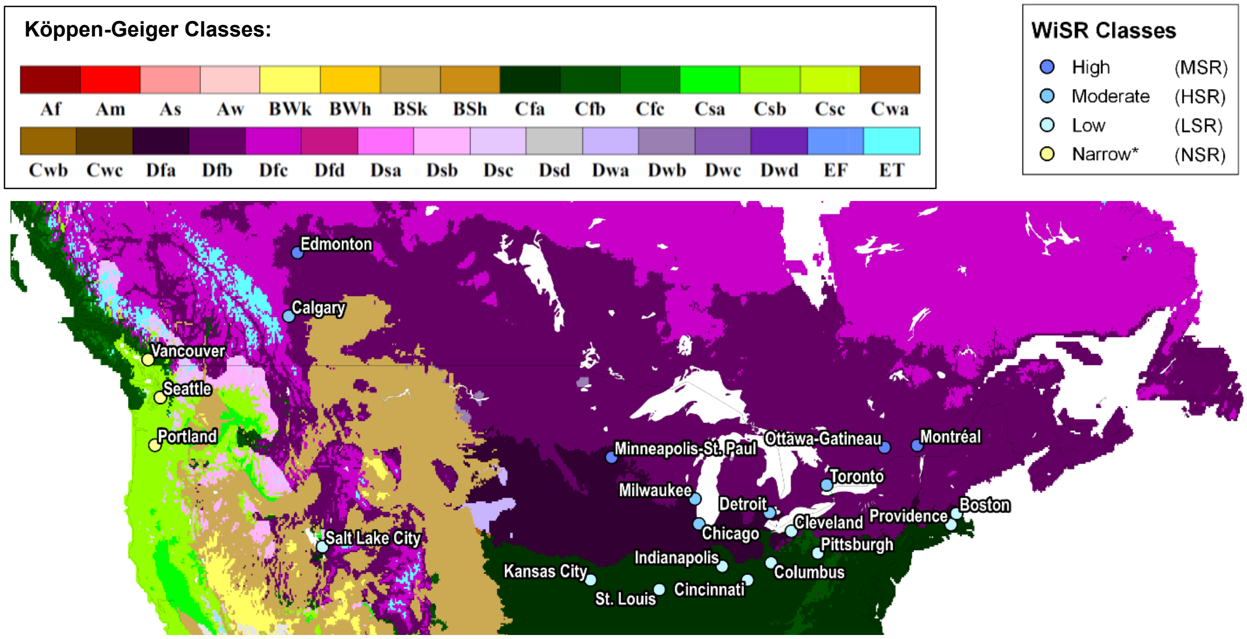


Figure 5.22 Map of Southern Canada and Northern US overlaying Köppen-Geiger climate zones and WiSR cities. (Menne et al. 2018; Kottek et al. 2006; Rubel et al. 2017; koeppen-geiger.vu-wien.ac.at, retrieved August 9 2020)

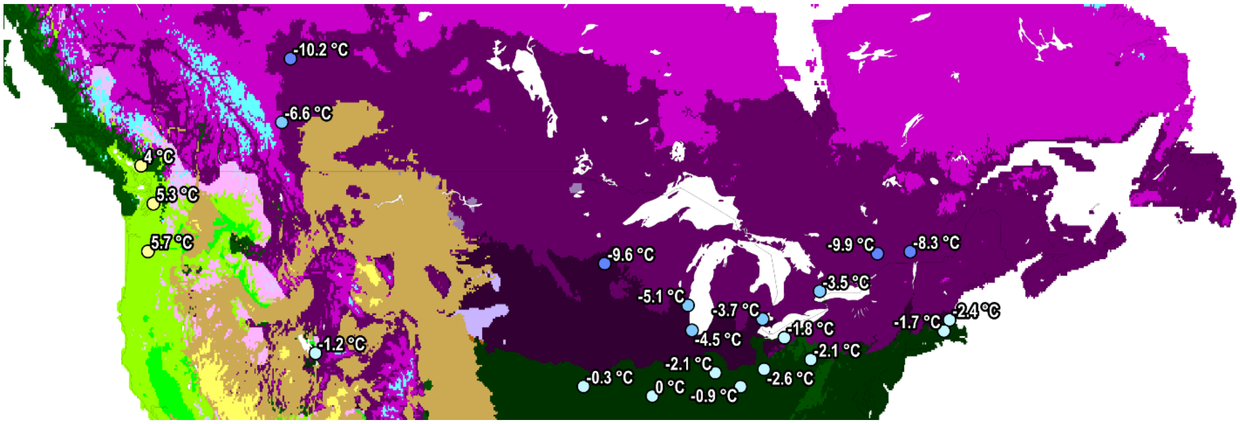


Figure 5.23 Same as above showing average temperature of the coldest month (T_{min}) for each city. (Ibid.)

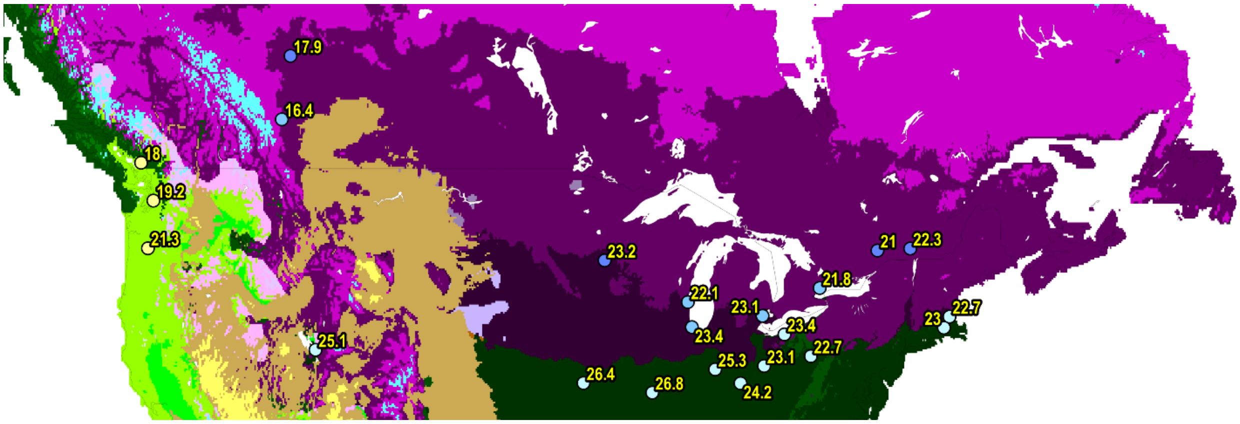


Figure 5.24 Same as above showing average temperature of the hottest month (T_{max}) for each city. (Ibid.)

Calgary (Dfb) and Montréal (Dfa/Dfb)

Calgary has moderately warm summers (T_{max} = 16.4°C) and dry winters (total winter precipitation for December, January, and February < 40 mm). It would be inappropriate to place this climate in the same classification as Montréal, which has hot, humid summers (T_{max} = 22.3 °C) and wet winters (total winter precipitation > 200 mm). The current version of the classification map (See Figure 5.22) suggests that these are both within the "warm summer humid continental" (Dfb) climate zone. However, the Köppen-Geiger criteria shown in Chapter 4 states that Montréal should be categorized as "hot summer humid continental" (Dfa), since its T_{max} is above 22 °C. It can be assumed that from a macro perspective these differences are minimal, but from a local scale perspective, this places Montréal in a separate category than Ottawa, which experiences similar hot and humid summer conditions (T_{max} = 21 °C).

Minneapolis (Dfa) and Ottawa (Dfb)

These two cities have very similar summer and winter temperature extremes. The key difference between these cities lies in the quantity of winter precipitation. Ottawa typically experiences heavy winter snowfall and freezing rain (total winter precipitation > 130 mm), while Minneapolis has comparatively dry winters (total winter precipitation < 60 mm). From a humidity standpoint it would make sense for these cities to be in separate categories. But as with Calgary and Montréal, the only distinction between these climates is that some have $T_{max} \geq 22$ °C and others have $T_{max} < 22$ °C. The Köppen-Geiger system does reveal that Ottawa and Minneapolis have a similar temperature range, which means that both are challenged by extensive seasonal variation. This fact is more informative to public space design than simply knowing that Minneapolis has slightly hotter July temperatures.

Milwaukee (Dfa) and Toronto (Dfb)

Despite having very similar climates, Milwaukee and Toronto are classed differently. This is striking because Milwaukee's T_{max} of 22.1 °C is only 0.3 °C warmer than Toronto's. Meanwhile, Milwaukee's T_{min} is -5.1 °C and Toronto's is slightly warmer at -3.5 °C. So even though these cities have similar summer and winter temperature extremes, they are labelled differently because of "a: Hot summer" threshold of $T_{max} \geq$ 22 °C (shown in Table 4-5 of Chapter 4). The same can be stated for Dfa cities such as Montréal as mentioned above, or Minneapolis and Chicago, which have a T_{min} of -9.6 °C and -4.5 °C, respectively.

Limitations of the WiSR Climate Classification System

This thesis is not arguing that temperature is the single most important parameter for public space design in mid- to high latitude cities. Rather, it highlights that all cities experiencing common winter problems are related by T_{min} and T_{range}, and it argues that locations with wide seasonal range require climate metrics that provide tangible information on critical needs in all seasons. By identifying seasonal challenges related to temperature, the needs regarding other types of winter-related challenges—e.g., low solar radiation, frequent and heavy snowfall, freezing rain, or frequent freeze/thaw events—may also be more clearly identified. Future research should expand the WiSR classification's scope of application by providing information on other key climate variables of relevance to public space designers.

6. Conclusions

This thesis sought to assist urban designers of cold climate public spaces in mid- to high-latitude cities during the early stages of design. To do so, literature was reviewed in climatology, urban planning and design, and human thermal ergonomics; public space design precedents and their associated approaches were analysed; climate metrics were reviewed to identify key constraints and opportunities for public space design; and a climate classification (WiSR) was proposed to assist in identifying specific local climate challenges for public space design in mid- to high latitude cities. The WiSR Climate Classification System provides a direct and measurable basis for identifying the minimum, maximum, and all-year temperature range for cities with comparable seasonal challenges. This allows design professionals to easily and quickly identify public space design precedents.

The success of public spaces depends on their levels of use and enjoyment by people. This in turn depends on the compatibility between environmental design components (activity distribution, spatial configuration, and ambient stimuli) and human components (user needs, preferences, and control). A critical but often neglected aspect of these components is their effect on human perception over multiple time scales. For instance, greater attention should be paid to projecting the possible activities within public spaces at different frequencies, durations, times of day, and seasons. In addition, this thesis showed that a core function of the physical components of public spaces is to ensure adequate levels of thermal sensation, comfort, and adaptation among users throughout the year. In climates with cold weather, this function constitutes a major part of ambient stimuli. This is shown by the fact that thermal perception and adaptation are greatly influenced by microclimate severity, exposure time (time of day, time of year, duration, and frequency), and user control over thermal stress via behavioural adaptation. For example, public spaces can offer shelter and warmth by modifying variables such as wind flow and exposure to solar radiation and precipitation. The facilities and activities provided by public spaces may be configured to also offer thermal comfort by providing restorative environments and offering opportunities for users to increase or decrease their metabolic rate. Desirable microclimate conditions can extend the use and enjoyment of public spaces, which are typically followed by greater social and economic activity. Still, however, an effective distribution of necessary and optional activities remains the primary requirement for high levels of use, after which ambient stimuli (thermal and other aspects of human ergonomics) and spatial configuration will either support or impede on social activities within public spaces.

The literature review showed that air streams in the macroclimate influence smaller scales of climate, down to the microclimate level at the earth's land and water surface. Hence, without an understanding local and macroclimate processes in an all-year perspective, one cannot effectively design microclimates. Without an understanding of local climate challenges in a cross-seasonal perspective, the problems related to low use and enjoyment of public spaces in WiSR cities are likely to remain unsolved.

Of course, effective planning and design outcomes require that multiple aspects still be addressed holistically. To do so ultimately requires that many factors be thoroughly understood and considered in the context of the public space design goals.

An analysis of public space design precedents revealed that many semi-public spaces exist in WiSR cities that respond to all-year needs with permanent, winter-based solutions. But as these spaces are not entirely public, these examples offer little guidance for public space design. On the other hand, there are examples of successful semi-outdoor public spaces in other climates, e.g., covered arcades, that could inform public space design in WiSR cities if one could clearly identify the design precedent's relative suitability for a WiSR climate. Similarly, there could be existing prototypes of successful public space design strategies in WiSR cities that remain undocumented in urban design studies, which is partly the result of an overemphasized connection between local climate severity and latitude in urban design literature.

It was also demonstrated that ephemeral activities such as programmed events, festivals, markets, and seasonal installations are very successful in WiSR cities. The ephemeral approach is made possible by permanent summer-based, permanent all-season, or convertible all-season approaches as these support temporary modification for a wide range of activities and spatial configurations. However, there does not appear to be a consensus on how much these isolated, temporary events contribute to the all-year use and enjoyment of public spaces throughout the city, or how to improve the all-season, everyday condition of WiSR public spaces in various neighbourhoods. Hence, although the Copenhagen model is effective in general and provides clear guidance on activity distribution and spatial configuration, there is still more to be understood about the key climate challenges and associated design strategies for public space design in WiSR cities. Since the Copenhagen model has not been substantially applied or documented in WiSR cities, it is also difficult to provide a confident appraisal of its potential benefits. However, it is evident that a summer-based approach remains a better starting point than a permanent winter-based approach for public space design in WiSR cities. Figures 6.1 and 6.2 locate selected public space precedents of the world. These maps reflect the fact that many documented public spaces using a permanent and convertible design approaches can be found in Europe and Asia. By contrast, examples of the ephemeral approach are widespread in the Northern Hemisphere. However, as stated in Chapter 3, more research is needed to determine the effectiveness of these approaches for different locations and users.

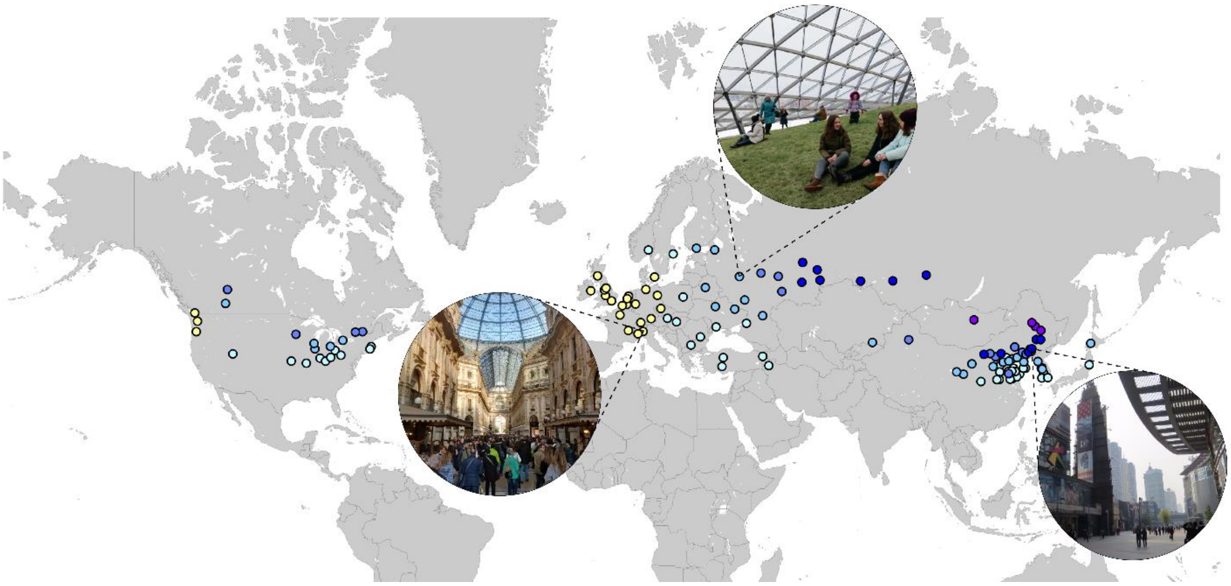


Figure 6.1 Location of selected projects using permanent summer-based, permanent all-season, and convertible all-season public space design approaches in NSR, MSR, and HSR cities. Projects shown are Galleria Vittorio Emanuele II in Milan, Zaryadye Park in Moscow, and Joy City Shopping Mall in Shenyang, respectively. (Sources, from left to right: Dr. John Straube, n.d.; Matthew Monteith, n.d.; Alex M., November 2015)

Figure 6.2 Location of selected projects using an ephemeral public space design approach. Projects shown from left to right: a public skating rink at MacEwan University in Edmonton, heated bus shelters in Minnesota, Christkindl Market in Kitchener-Waterloo, Winterlude Festival on the Rideau Canal in Ottawa, "Montréal en Lumière", Christmas markets in Vienna and Stockholm, and the Sapporo Snow Festival. (Sources, in respective order: www.macewan.ca, n.d.; Stafford Photography, n.d.; www.ctvnews.ca, n.d.; www.susanandmoe.com, n.d.; "Braseros RBC", n.d.; Alisa Anton, published November 2016; Diana Tonner, December 2016; Takashi Noguchi, December 2020)

Chapter 4 documented an analysis of local 30-year climate normals for 13 cities spread across the Northern Hemisphere. This revealed that local winter climates conforming to the Winter City criteria vary significantly in type and intensity, and that an earlier version of the definition excluded many cities below the 45th parallel due to the misconception that latitude can be used to indicate winter climate severity. Thus, it was concluded that commonly used terms such as ‘Winter City”, “cold climate”, “snow climate”, and “northern city” are too inaccurate, imprecise, and narrow for urban planning and design in cities that have a wide seasonal range. They do not capture the nuance of design challenges related to seasonal variation. The continued use of these terms propagates a narrow perspective on key challenges for planning and design in these climates. If a city was to experience severe winter climate conditions throughout the entire year, then the climate would be predictably severe, and the same strategies used for winter would apply for fall, summer, and spring. However, the challenge for most mid- to high latitude cities lies in responding to conflicting seasonal needs in cities where climate is severe and variable for a major part of the year. Both approaches must respond to the needs of winter, but the former generally leads to solutions that conflict with summer and all-year needs. The Köppen-Geiger Climate Classification System refers to “continental climate” and “cold steppe climate” to describe climate zones that experiences wide seasonal variation, but these are rarely used, do not encompass all cities that experience wide seasonal range, and do not directly convey the challenge of seasonal range in a manner that is intuitive for urban planning and design. In response to the need for a term that describes cities that experience a cold winter and a hot summer within the same year, the concept of Wide Seasonal Range (WiSR) is proposed.

The analysis and mapping also showed that current climate metrics for assessing local winter severity do not provide tangible guidance for key challenges facing urban planning and design in WiSR cities. Specifically, the Winter Climate Severity Index (WCSI) offers a method for measuring overall severity in a relative manner, but by themselves the output index values tend to obscure rather than clarify the precise climate challenges for different cities. At the same time, macroscale climate metrics also show significant limitations for urban planning and design. For example, the widely used Köppen-Geiger Climate Classification System may offer useful guidance to climatologists by categorizing zones for the growth of five major plant groups, but these zones have little relevance for understanding human needs and activities, which concern meso to micro scales. Nonetheless, a global classification map is useful to understand differences and similarities of local challenges from a macro perspective. But global maps have limited use to planners and designers if they do not provide tangible data on local climate challenges at seasonal extremes.

Early Winter City studies suggest that latitude can be used to define climate-related design challenges. While existing knowledge on climate would differ from this statement, some studies continue to support the view that high latitude is associated with severe winter climate. To identify the parameters which provide a more tangible understanding of winter climate severity, an analysis of monthly temperature data was conducted for all metropolitan cities with cold winter conditions by using 30-year baseline climate normals provided by the Global Historical Climate Network – Monthly (GHCN-M) in combination with approximate population data (UN 2018). The selection was narrowed to all cities with an urban agglomeration population over 1 million people and either a latitude equal to or above 45 °N, or average temperature of the coldest day (mean of daily high and low) is equal to or below 0 °C. Of the 128 cities analysed, 100 met the temperature criteria. Among these 100 cities, only 44 were above 45 °N, while 66 were below 45 °N. This reveals that a majority of metropolitan cities that correspond to the most recent "Winter City" definition are located below the 45 °N latitude—rather than above 45 °N as stated in existing Winter City literature. It was also found that cities with the widest seasonal range—i.e., lowest average temperature of the coldest month (T_{min}) and highest annual temperature range (T_{range})—are located between latitudes 45 °N and 48 °N.

Noting the strong relationship between T_{min} and T_{range}, these parameters were used as the defining elements of the WiSR classification criteria. Plotting the data on these parameters also showed that there is a weaker relationship between T_{range} and average temperature of the hottest month (T_{max}). As expected, the examination of latitude according to T_{min} and T_{range} revealed no significant relationship. It is interesting to note that there is a considerable relationship between lower latitudes and high $T_{max.}$ Overall, it can be concluded that T_{min} and T_{range} are more reliable indicators of local winter climate severity than latitude for urban design in mid- to high-latitude cities.

Mapping these factors reveals a very gradual transition of seasonal range from western to eastern parts of Europe. By contrast, there are considerably sharper transitions among closely distributed cities in North America, and even sharper transitions between closely located cities in Northeast Asia. Further, by overlaying data on average snow cover for the month of January, it becomes evident that from a macroscale perspective, there is little relation between snow cover and T_{min}, T_{max}, T_{range}, or Seasonal Range (SR). These findings add further weight to the argument that urban planning and design in WiSR cities remain too influenced by approaches from warm temperate climates, which are substantially less challenged from a thermal standpoint in both winter and summer.

In sum, this preliminary analysis of mid- to high latitude cities provides three key findings:

- Existing climate metrics are not suited to early-stage decision making for public space design in WiSR cities;
- Latitude is not a reliable indicator of local winter climate severity;
- There are many different types of winter climates, and current metrics and terminology do not convey key information on local climate factors.

The proposed WiSR Classification System allows design professionals to discern the overall seasonal range of different cities for specific parameters of T_{min}, T_{range}, and the proposed Seasonal Range (SR) criteria. While the classification could be reinforced by providing explicit information on other winter-related parameters, its strength lies in the fact that it provides information on the specific parameters T_{min} and T_{range}, which act as minimum requirements for the occurrence of most common winter phenomena. As a result, it becomes more apparent whether parameters such as average winter snow cover, total winter snowfall, and total winter sunshine hours are more or less important in relation to the challenge of seasonal range. For any given city, then, the classification allows one to directly identify: the range of minimum monthly temperatures from slightly cool to extremely cold; the range of maximum monthly temperatures from cool to very hot; and the seasonal range from narrow to extreme. As a result, one can identify whether there is a substantial need for microclimate and thermal adaptation during winter, summer, or both seasons.

The WiSR classification system can also be used to:

- assess compatibility between built precedents and local context;
- identify differences and similarities between comparable climates in relation to all-year public space design needs, and;
- communicate local climate challenges between public space designers, decision makers, and researchers by connecting them to cities with similar local climate challenges.

Figure 6.3 proposes a workflow for applying the WiSR Classification toward public space design, implementation, and analysis.

Figure 6.3 Proposed workflow for selecting and analysing reference microclimate design strategies prior to their implemention within a comparable climate.

Recommendations and Future Research

The proposed WiSR Climate Classification System has some limitations compared to the Köppen-Geiger Classification System and the Winter Climate Severity Index (WCSI). It does not explicitly include relevant variables such as precipitation or sunshine hours. However, future research should investigate the importance of these limitations.

It is recommended that future concept definitions, climate metrics, and prediction tools for early-stage planning and design purposes provide tangible output values for specific climate challenge. Metrics may provide output indices or criteria addressing multiple challenges at once, but these should allow users to directly identify the weight of specific factors if they are to be widely used by planners and designers.

Future research should seek to develop prediction tools to allow planners and designers to identify local climate needs more directly. In turn, other design components—i.e., activity distribution, spatial configuration, user control, and non-thermal aspects of ambient stimuli—may be better understood in relation to the goal of increasing use and enjoyment within public spaces during all seasons.

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Appendix

Climate Data for WiSR Cities with Population Greater than or Equal to 1 million

Country	City	Latitude	Longitude	T_{min}	T_{max}	T_{range}	**SR Class**	Data Source	Baseline	Station Code	Alternate Station*
China	Daqing*	46.58	125.00	-18.0	23.3	41.3	ESR	GHCN-M	1981-2010	CHM00050854	Anda
China	Qiqihaer	47.34	123.97	-17.7	23.4	41.1	ESR	GHCN-M	1981-2010	CHM00050745	
China	Haerbin	45.76	126.65	-17.6	23.0	40.6	ESR	GHCN-M	1981-2010	CHM00050953	
Mongolia	Ulaanbaatar	47.91	106.88	-21.4	18.9	40.2	ESR	GHCN-M	1981-2010	MGXLT954291	
China	Jilin*	43.85	126.56	-14.5	23.1	37.7	SSR	GHCN-M	1981-2010	CHM00054161	Changchun
China	Changchun	43.88	125.29	-14.5	23.1	37.7	SSR	GHCN-M	1981-2010	CHM00054161	
Russian Federation	Omsk	55.00	73.40	-16.2	19.7	35.9	SSR	GHCN-M	1981-2010	RSM00028698	
Russian Federation	Novosibirsk	55.04	82.93	-16.1	19.4	35.6	SSR	GHCN-M	1981-2010	RSM00029634	
China	Baotou*	40.65	109.82	-12.5	22.8	35.3	SSR	GHCN-M	1981-2010	CHM00053336	Haliut
Russian Federation	Kraznoyarsk	56.01	92.79	-15.3	19.1	34.3	SSR	GHCN-M	1981-2010	RSM00029570	
Russian Federation	Ufa	54.79	56.05	-12.6	19.8	32.4	SSR	GHCN-M	1981-2010	RSM00028722	
Russian Federation	Chelyabinsk*	55.15	61.43	-12.4	19.4	31.8	SSR	GHCN-M	1981-2010	RSM00028440	Ekaterinburg
Russian Federation	Yekaterinburg	56.86	60.61	-12.4	19.4	31.8	SSR	GHCN-M	1981-2010	RSM00028440	
Russian Federation	Perm	58.02	56.29	-12.7	18.8	31.5	SSR	GHCN-M	1981-2010	RSM00028224	
China	Ürümqi	43.83	87.60	-11.3	24.5	35.8	HSR	GHCN-M	1981-2010	CHM00051463	
China	Fushun*	41.88	123.95	-11.1	24.4	35.5	HSR	GHCN-M	1981-2010	CHM00054342	Shenyang
China	Shenyang	41.79	123.43	-11.1	24.4	35.5	HSR	GHCN-M	1981-2010	CHM00054342	
China	Anshan*	41.12	122.99	-10.8	24.2	35.0	HSR	GHCN-M	1981-2010	CHM00054346	Benxi
China	Benxi	41.29	123.77	-10.8	24.2	35.0	HSR	GHCN-M	1981-2010	CHM00054346	
China	Chifeng	42.26	118.92	-10.5	23.2	33.6	HSR	GHCN-M	1981-2010	CHM00054218	
China	Hohhot	40.81	111.65	-10.9	22.6	33.5	HSR	GHCN-M	1981-2010	CHM00053463	
China	Yingkou*	40.66	122.23	-7.9	25.3	33.2	HSR	GHCN-M	1981-2010	CHM00054471	
United-States of America	Minneapolis-St. Paul	44.97	-93.27	-9.6	23.2	32.8	HSR	GHCN-M	1981-2010	USC00215433	
China	Datong	40.08	113.29	-10.7	22.0	32.7	HSR	GHCN-M	1981-2010	CHM00053487	
China	Zhangjiakou*	40.81	114.88	-8.0	24.2	32.2	HSR	GHCN-M	1981-2010	CHM00053487	Datong
China	Jinzhou	41.11	121.14	-7.0	25.0	32.0	HSR	GHCN-M	1981-2010	CHM00054337	
Russian Federation	Samara	53.20	50.15	-9.7	21.8	31.6	HSR	GHCN-M	1981-2010	RSM00028900	
Canada	Ottawa-Gatineau	45.42	-75.70	-9.9	21.0	31.0	HSR	GHCN-M	1981-2010	CA006105887	
Russian Federation	Kazan	55.79	49.12	-10.0	20.9	30.9	HSR	GHCN-M	1981-2010	RSM00027595	
Canada	Montréal	45.51	-73.59	-8.3	22.3	30.6	HSR	GHCN-M	1981-2010	CA007025280	
Russian Federation	Nizhniy Novgorod	56.33	44.00	-8.9	19.8	28.7	HSR	GHCN-M	1981-2010	RSM00027459	
Canada	Edmonton	53.54	-113.50	-10.2	17.9	28.1	HSR	GHCN-M	1981-2010	CA003012208	
China	Taian	36.19	117.12	-7.4	18.1	25.5	HSR	GHCN-M	1981-2010	CHXLT021571	

Country	City	Latitude	Longitude	T_{min}	T_{max}	T_{range}	**SR Class**	Data Source	Baseline	Station Code	Alternate Station*
China	Tangshan	39.63	118.18	-4.9	25.7	30.6	MSR	GHCN-M	1981-2010	CHXLT460398	
China	Yinchuan	38.47	106.27	-6.2	24.4	30.6	MSR	GHCN-M	1981-2010	CHM00053614	
North Korea	P'yongyang	39.03	125.75	-6.0	24.5	30.5	MSR	GHCN-M	1981-2010	KNM00047058	
Russian Federation	Volgograd	48.72	44.50	-6.6	23.4	30.0	MSR	GHCN-M	1981-2010	RSM00034560	
China	Qinghuangdao*	39.93	119.59	-4.1	25.9	30.0	MSR	GHCN-M	1981-2010	CHM00054539	Leting
China	Baoding	38.85	115.49	-3.4	26.3	29.8	MSR	GHCN-M	1981-2010	CHXLT847092	
China	Tianjin	39.11	117.19	-3.0	26.9	29.8	MSR	GHCN-M	1981-2010	CHM00054527	
South Korea	Suweon*	37.26	127.02	-3.2	25.7	29.0	MSR	GHCN-M	1981-2010	KSW00043242	Osan
China	Taiyuan	37.86	112.55	-4.3	24.4	28.7	MSR	GHCN-M	1981-2010	CHM00053772	
China	Dalian	38.91	121.60	-3.3	24.7	28.1	MSR	GHCN-M	1981-2010	CHM00054662	
Kazakhstan	Almaty	43.25	76.91	-4.0	24.0	27.9	MSR	GHCN-M	1981-2010	KZ000036870	
United-States of America	Chicago	41.85	-87.65	-4.5	23.4	27.9	MSR	GHCN-M	1981-2010	USC00111584	
United-States of America	Milwaukee	43.04	-87.91	-5.1	22.1	27.3	MSR	GHCN-M	1981-2010	USC00477964	
Russian Federation	Voronezh	51.67	39.18	-6.3	20.9	27.3	MSR	GHCN-M	1981-2010	RSM00034123	
China	Lanzhou	36.06	103.79	-3.5	23.7	27.2	MSR	GHCN-M	1981-2010	CHM00052889	
United-States of America	Detroit	42.39	-83.10	-3.7	23.1	26.8	MSR	GHCN-M	1981-2010	USW00014822	
Japan	Sapporo	43.06	141.35	-3.7	22.6	26.3	MSR	GHCN-M	1981-2010	JA000047412	
Russian Federation	Moskvo	55.76	37.62	-6.7	19.3	26.0	MSR	GHCN-M	1981-2010	RSM00027612	
Ukraine	Kharkiv	49.98	36.25	-4.5	21.3	25.8	MSR	GHCN-M	1981-2010	UPM00034300	
Canada	Toronto	43.70	-79.42	-3.5	21.8	25.3	MSR	GHCN-M	1981-2010	CA006158355	
Russian Federation	Sankt Peterburg	59.93	30.33	-5.8	19.0	24.7	MSR	GHCN-M	1981-2010	RSM00026063	
Ukraine	Kyiv	50.45	30.52	-3.4	20.8	24.2	MSR	GHCN-M	1981-2010	UPM00033345	
China	Xining	36.62	101.77	-6.4	17.7	24.2	MSR	GHCN-M	1981-2010	CHM00052866	
Belarus	Minsk	53.90	27.57	-4.4	18.7	23.0	MSR	GHCN-M	1981-2010	BOM00026850	
Canada	Calgary	51.04	-114.06	-6.6	16.4	22.9	MSR	GHCN-M	1981-2010	CA003036652	
Finland	Helsinki	60.17	24.94	-5.2	17.4	22.6	MSR	GHCN-M	1981-2010	FIE00142251	

Country	City	Latitude	Longitude	T_{min}	T_{max}	T_{range}	**SR Class**	Data Source	Baseline	Station Code	Alternate Station*
China	Beijing	39.91	116.40	-2.8	27.0	29.7	LSR	GHCN-M	1981-2010	CHM00054511	
Armenia	Yerevan	40.18	44.51	-2.3	26.6	28.9	LSR	GHCN-M	1981-2010	AM000037789	
China	Shijiazhuang	38.04	114.51	-1.1	27.6	28.7	LSR	GHCN-M	1981-2010	CHM00053698	
China	Dongying*	37.45	118.58	-2.3	26.3	28.6	LSR	GHCN-M	1981-2010	CHM00054843	Weifang
China	Weifang	36.71	119.10	-2.3	26.3	28.6	LSR	GHCN-M	1981-2010	CHM00054843	
South Korea	Seoul	37.57	126.98	-2.2	26.1	28.2	LSR	GHCN-M	1981-2010	KSM00047108	
Iran	Tabriz	38.08	46.29	-1.8	26.2	28.0	LSR	GHCN-M	1981-2010	IR000040706	
China	Handan*	36.60	114.47	-0.4	27.3	27.7	LSR	GHCN-M	1981-2010	CHM00053898	Anyang
China	Jinan	36.68	117.00	-0.3	27.4	27.7	LSR	GHCN-M	1981-2010	CHM00054823	
China	Zibo*	36.79	118.06	-0.3	27.4	27.7	LSR	GHCN-M	1981-2010	CHM00054823	Jinan
South Korea	Incheon	37.45	126.73	-1.9	25.7	27.6	LSR	GHCN-M	1981-2010	KS000047112	
United-States of America	Indianapolis	39.79	-86.15	-2.1	25.3	27.5	LSR	GHCN-M	1981-2010	USC00124264	
South Korea	Daejon	36.32	127.42	-1.5	25.7	27.2	LSR	GHCN-M	1981-2010	KSM00047133	
United States of America	St. Louis	38.63	-90.20	0.0	26.8	26.9	LSR	GHCN-M	1981-2010	USC00237465	
China	Linyi	35.05	118.33	0.1	26.9	26.8	LSR	GHCN-M	1981-2010	CHXLT424795	
China	Zaozhuang*	34.86	117.55	0.1	26.9	26.8	LSR	GHCN-M	1981-2010	CHXLT424795	Linyi
United States of America	Kansas City	39.11	-94.63	-0.3	26.4	26.7	LSR	GHCN-M	1981-2010	USC00234379	
Russian Federation	Rotsov-na-Donu	47.22	39.70	-2.4	24.3	26.7	LSR	GHCN-M	1981-2010	RSM00034720	Taganrog
China	Xi'an	34.29	108.94	-0.5	26.1	26.6	LSR	GHCN-M	1981-2010	CHM00057036	
China	Kaifeng*	34.79	114.35	1.6	27.9	26.3	LSR	GHCN-M	1981-2010	CHM00057083	Zhenzhou
China	Zhenzhou	34.76	113.65	1.6	27.9	26.3	LSR	GHCN-M	1981-2010	CHM00057083	
United-States of America	Salt Lake City	40.75	-111.89	-1.2	25.1	26.3	LSR	GHCN-M	1981-2010	USC00427608	
China	Yantai	37.47	121.44	-0.3	25.5	25.8	LSR	GHCN-M	1981-2010	CHXLT034952	
United States of America	Columbus	39.96	-83.00	-2.6	23.1	25.8	LSR	GHCN-M	1981-2010	USC00331781	
China	Qingdao	36.10	120.37	0.0	25.7	25.7	LSR	GHCN-M	1981-2010	CHM00054857	
China	Rizhao	35.40	119.51	0.1	25.8	25.7	LSR	GHCN-M	1981-2010	CHXLT111565	
South Korea	Gwangju	35.15	126.92	1.0	26.7	25.7	LSR	GHCN-M	1981-2010	KSM00047156	
United-States of America	Boston	42.35	-71.06	-2.4	22.7	25.2	LSR	GHCN-M	1981-2010	USW00094701	
United-States of America	Cleveland	41.50	-81.69	-1.8	23.4	25.2	LSR	GHCN-M	1981-2010	USW00014820	
United States of America	Cincinnati	39.10	-84.52	-0.9	24.2	25.1	LSR	GHCN-M	1981-2010	USW00003871	
United-States of America	Pittsburgh	40.44	-79.99	-2.1	22.7	24.8	LSR	GHCN-M	1981-2010	USW00014762	
United-States of America	Providence	41.82	-71.42	-1.7	23.0	24.6	LSR	GHCN-M	1981-2010	USW00014765	
Republic of Korea	Changwon	35.23	128.68	2.7	26.8	24.2	LSR	GHCN-M	1981-2010	KSM00047155	
China	Weihai*	37.50	122.11	-0.3	23.6	23.9	LSR	GHCN-M	1981-2010	CHM00054776	Chengshantou
Turkey	Konya	37.87	32.48	-0.4	23.3	23.7	LSR	GHCN-M	1981-2010	TUM00017244	

Country	City	Latitude	Longitude	T_{min}	T_{max}	T_{range}	**SR Class**	Data Source	Baseline	Station Code	Alternate Station*
Romania	Bucuresti	44.43	26.10	-1.2	22.4	23.6	LSR	GHCN-M	1981-2010	ROE00108889	
Ukraine	Odesa	46.48	30.73	-0.3	22.8	23.1	LSR	GHCN-M	1981-2010	UPM00033837	
Japan	Sendai	38.26	140.90	2.2	24.9	22.7	LSR	GHCN-M	1981-2010	JA000047590	
Turkey	Ankara	39.92	32.85	1.3	23.8	22.5	LSR	GHCN-M	1981-2010	TUM00017130	
Hungary	Budapest	47.50	19.04	1.0	22.8	21.8	LSR	GHCN-M	1981-2010	HUE00000064	
Bulgaria	Sofia	42.70	23.32	-0.1	21.4	21.5	LSR	GHCN-M	1981-2010	BUM00015614	
Poland	Warszawa	52.23	21.01	-1.5	19.5	21.0	LSR	GHCN-M	1981-2010	PLM00012375	
Austria	Vienna	48.21	16.37	-0.6	20.1	20.7	LSR	WMO	1961-1990	11035	
Norway	Oslo	59.91	10.75	-2.8	17.6	20.5	LSR	GHCN-M	1981-2010	NOM00001492	
Sweden	Stockholm	59.33	18.06	-1.7	18.8	20.5	LSR	GHCN-M	1981-2010	SWM00002485	
Italy	Milano	45.55	9.18	3.3	24.6	21.3	NSR	GHCN-M	1981-2010	ITE00100554	
Czech Republic	Praha	50.09	14.42	0.9	20.8	19.8	NSR	GHCN-M	1981-2010	EZE00100082	
Germany	München	48.14	11.57	-1.4	17.9	19.3	NSR	GHCN-M	1981-2010	GMM00010870	
Germany	Berlin	52.52	13.41	0.8	19.9	19.1	NSR	GHCN-M	1981-2010	GME00111445	
France	Lyon	45.75	4.85	3.1	21.9	18.8	NSR	GHCN-M	1981-2010	FRXLT914472	
Italy	Torino	45.07	7.68	2.4	20.9	18.4	NSR	GHCN-M	1981-2010	ITM00016061	
Switzerland	Zürich	47.36	8.50	0.3	18.8	18.2	NSR	GHCN-M	1981-2010	SZ000003700	
Denmark	København	55.68	12.57	1.2	18.1	16.9	NSR	GHCN-M	1981-2010	DA000030380	
Germany	Hamburg	53.55	10.00	1.6	18.1	16.5	NSR	GHCN-M	1981-2010	GME00004182	
Germany	Köln	50.93	6.95	2.4	18.8	16.4	NSR	GHCN-M	1981-2010	GME00121042	
France	Paris	48.85	2.35	4.9	20.5	15.6	NSR	GHCN-M	1981-2010	FR000007150	
United-States of America	Portland	45.52	-122.68	5.7	21.3	15.6	NSR	GHCN-M	1981-2010	USW00024274	
Belgium	Bruxelles	50.85	4.35	3.0	17.9	14.8	NSR	GHCN-M	1981-2010	BEM00006451	
France	Lille	50.63	3.06	2.7	17.2	14.5	NSR	DWD	1961-1990	-	
Netherlands	Rotterdam	51.92	4.48	3.4	17.7	14.2	NSR	GHCN-M	1981-2010	NLE00102427	
Canada	Vancouver	49.25	-123.12	4.0	18.0	14.0	NSR	GHCN-M	1981-2010	CA001108487	
United-States of America	Seattle	47.63	-122.33	5.3	19.2	13.9	NSR	GHCN-M	1981-2010	USW00024281	
United Kingdom	London	51.51	-0.13	4.8	17.5	12.8	NSR	GHCN-M	1981-2010	UKXLT878748	
United Kingdom	West Yorkshire*	53.80	-1.76	3.8	16.1	12.3	NSR	GHCN-M	1981-2010	UKM00003257	Leeming
United Kingdom	Birmingham*	52.48	-1.90	4.0	16.1	12.1	NSR	GHCN-M	1981-2010	UKM00003414	Shawbury
United Kingdom	Manchester	53.48	-2.24	4.1	16.1	12.0	NSR	GHCN-M	1981-2010	UKM00003334	
Netherlands	Amsterdam*	52.37	4.89	5.4	16.6	11.2	NSR	WMO	1961-1990	6235	De Kooy
United Kingdom	Glasgow	55.87	-4.26	4.1	15.3	11.2	NSR	GHCN-M	1981-2010	UKXLT360085	
Ireland	Dublin	53.33	-6.25	4.3	15.0	10.7	NSR	GHCN-M	1981-2010	EI000003969	