



Perceived impact of meteorological conditions on the use of public space in winter settlements

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Abstract

This study aimed to assess the impact of meteorological conditions on the use of public space in Scandinavia and Canada. Between September 21 and December 18, 2017, a cross-sectional online survey ‘EAMQ-Climate: space’ was distributed via web-based platforms. Survey responses were received from 361 residents (258 people from Scandinavia and 103 from Canada). The relative impact of the meteorological determinants on the use of public space was calculated, and a factor analysis was performed. Disparities between Canada and Scandinavia as well as between the climate zones represented were analysed using ANOVA. Overall results showed that the most significant meteorological enablers for the use of outdoor public spaces in winter were solar gain, snowfall and snow-covered surfaces. The main barriers were slush-covered and icy surfaces, rainfall and darkness. Wind and cold were conditions with less influence. The impact of rain and ice, however, differed between climatic zones. It was also established that, when addressing the meteorological impact on avoiding the use of public spaces in winter, it is vital to discriminate between conditions related to a) the ground surface and b) ambient conditions, as well as the particular significance of c) snow and sun, and d) darkness. For the design of public space in winter cities, we conclude that designers need to focus on a wider range of weather conditions than sun, wind and cold, and include snow, rainfall, slushy and icy ground and poor visibility. The study suggests that winter public space has a higher climatic design requirement to be successful than streets and pathways that are mainly used for soft mobility.

Keywords Public space · Urban microclimate · Winter cities · Outdoor activity

Introduction

Winter communities have, over generations, evolved lifestyles adapted to local climatic conditions and seasonal variations. However, evolving and less predictable winter meteorological conditions, such as rapid temperature fluctuations, may present new risks and unexpected outcomes with respect to residents’ use of public spaces, which people will need to adapt to. In this context, a key urban design challenge in winter cities is to create built environments that encourage safe, year-round outdoor activity. A closely related challenge is to understand how local meteorological conditions influence people’s decisions about visiting outdoor public spaces. The

rationale for this research is that designers and planners of winter settlements need a better understanding of the relationship between the built environment, meteorological conditions and the obstacles that discourage people from visiting public spaces. For example, whether people participate in activities that involve gathering in public spaces.

A key factor in advancing urban planning is to understand how individuals and populations perceive and respond to outdoor conditions that impact on their public space usage. This study aimed to help fill this knowledge gap about how different meteorological conditions effect people visiting/ the use of public space in winter cities. This is important because little research is available on how the various meteorological conditions found in a winter city effect public space usage. Most is either focused on soft-mobility or generalized to the main conditions of winter. This study also aimed to assess if there is differences in the perceived impact of meteorological conditions on the use of public space in winter in Canada and Scandinavia. This is important as much of the winter city design guidance used in Scandinavia emanates from Canada.

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As local meteorological conditions have been shown to be a major determinant of people's decision-making about soft-mobility (Amiri and Sadeghpour 2015; Chapman et al. 2017; Ebrahimabadi et al. 2015; Eliasson et al. 2007), a key premise of this work is that interactions between the built environment and meteorological conditions play central roles in determining how people perceive and decide to visit public spaces. A variety of social and physical factors also influence people's perceptions and use of urban space (Chen and Ng 2012; Knez et al. 2009; Leng et al. 2019; Lenzholzer 2010).

It has been established that for soft-mobility in winter communities, a wider palette of meteorological conditions than traditionally discussed, i.e. sun, wind and cold need to be considered in future urban design and planning. Rainfall, icy surfaces and darkness have been identified as significant barriers to soft-mobility in winter, while wind and cold were less (Chapman et al. 2017). This study builds upon this earlier research. Such meteorological conditions are commonly applied in transport and health sciences research on daily mobility and physical activity (Böcker et al. 2019; Ogawa et al. 2019), which emphasizes the need for including this knowledge in the planning and design of the built environment (Chapman and Larsson 2019).

Here, good urban design has a focus on the quality of the public space and its year-round usability (Carmona et al. 2010). Promoting high quality public spaces along with communities where walking is possible within our settlements is considered to help deliver outcomes including economic improvement, social cohesion, resource efficiency, sustainability and better land economy (Carmona et al. 2002; Cowan et al. 2010). Importantly, such places can also help support human activity without reliance on motorized vehicles, thus helping to reduce emissions and pollution (Jenks et al. 1996), which is vital for efforts to slow down climate change.

Urban climatology has long been applied in city planning (Hebbert 2014). However, research has predominantly focused on 'hot' climatic zone and examined how microclimatic factors affect perceived thermal comfort and hence influence the use of urban outdoor spaces. Air temperature, solar radiation and wind speed have been shown to be significant elements in research and design strategies in hot climatic zones (Chen and Ng 2012; DeKay and Brown 2013; Givoni 1998). This research helps grow the knowledge base of urban climatology for cold climate settlements.

For winter cities, research into their design was prevalent during the mid to later twentieth century, but has tailed off during the first part of the twenty-first century (Chapman et al. 2018). This has left practitioners following classical urban design principles for winter cities that focus on preserving solar access, providing shelter from the wind and designing for snow management (Pressman 2004; Pressman and Zepic 1986). Much of this research and guidance for the design of winter cities also emanates from Canada (Chapman et al. 2018).

In Scandinavia, municipalities have expressed that there is a lack of and a need for winter conditions to be considered more in urban planning strategies (Costamagna et al. 2019; Nilsson and Kostenius 2016). To address this, new winter, "blue-green-white" strategies have been piloted in settlements such as Luleå and Gällivare, Sweden. These plans "address the structure, function and design of green, blue and public areas, spaces, streets and paths when they become white due to snow and ice" (Chapman et al. 2017). However, while these plans are a step forward for winter settlements, they lack of up to date research about how the winter climate affects people's use of public space.

For this study, winter settlements are defined as places that experience temperatures below 0 °C for several months of the year, normally receive precipitation in the form of snow and experience limited hours of daylight (Pressman 2004). In these places, the winter season has a significant influence on people's daily outdoor activity.

Materials and methods

Study design

The design of the study is cross-sectional, taking place at one specific point in time and involving two cohorts of residents in different geographical areas, Scandinavia and Canada. It also piloted a survey aiming to identify and explore the impact of a wide range of meteorological conditions on decisions to use public spaces in winter.

Study setting (meteorological context)

Climatically, Scandinavia and Canada share some common ground. Both straddle a number of climate classifications, including Arctic territories, and both contain communities that identify with living in winter settlements (Pressman 1985; Pressman 2004). The Köppen - Geiger climate classification characterizes the climate of winter settlements in Canada and Scandinavia as mainly Subarctic climate (Dfc) but also Humid continental climate (Dfb) and Temperate oceanic climate (Cfb).

However, significant differences also exist due to the higher latitude communities found in Scandinavia. These high latitude communities experience what are commonly called 'polar nights'. That is, in winter, the sun can be below the horizon for significant periods, and in summer, there can be extended periods of 24-h sunlight as the sun stays above the horizon.

Survey design: Meteorological analysis of the use of public space

To investigate how people perceive the impact of meteorological conditions commonly found in winter settlements with respect to visiting public space, a tailored questionnaire was

developed. In step one of its development, the original Environmental Analysis of Mobility Questionnaire (EAMQ) (Patla and Shumway-Cook 1999) was amended to create a climate-sensitive version for urban design research ‘EAMQ-Climate: mobility’ (Chapman et al. 2017).

The original EAMQ provided a method for assessing environmental determinants (eight dimensions: distance, time, ambient conditions, terrain, physical load, body posture, attention, and density) for people’s walking-related activities in the community. Here the dimensions of distance, ambient conditions (dark, snow, rain) and terrain were selected and expanded to address both summer and winter walking distance, and a wider range of weather conditions commonly found in winter, that is, temperature and wind, and ground surface properties of ice and snow (Chapman et al. 2017).

For this study, in step two, the questionnaire was further developed to include sun and slush-covered ground, and the reference to walking-related activities was substituted with ‘visiting public spaces’ to form the ‘EAMQ-Climate: space’. The questionnaire consists of 22 items measured using a 5-step Likert scale (never, rarely, sometimes, often, always). The questions address 11 different meteorological conditions; each question comprises two parts, proposing either encountering or avoidance of the condition (Table 2). In addition, three questions to obtain basic background factors, gender, age and city of residence were asked.

Data collection

The views of residents in the study locations were collected via ‘the EAMQ-Climate: space’ questionnaire distributed online via web-based media platforms. The online survey automation software EvaSys© was used, allowing a virtual link to the survey to be distributed and re-distributed via digital platforms. For example, in Linked-in the survey was distributed via the group *Smart Urbanism*, in Facebook via the group *Winter Cities Institute*. The survey was also distributed via the City Planning Administration and Luleå University of Technology.

The survey was open for responses between September 21 and December 18, 2017. In total 409 people responded. Of these, 361 respondents met the criterion of living in Canada or Scandinavia and had completed all of the survey questions, and, thus, were included in the data analysis.

Data analysis

Firstly, the study group characteristics and the relative impact of the meteorological determinants on the use of public space results were summarized using frequencies, percentages, means and standard deviations. Secondly, a sub-analysis was performed considering the participants from Canada and Scandinavia as separate groups, and here between-group

differences were analysed using ANOVA and the Pearson Chi-Square test. To explore possible disparities between the three Climatic zones ANOVA and post hoc analyses (Tukey HSD, significance level 0.05) was used.

Thirdly, to identify the relative impact of each meteorological condition, results were visually presented in graphs with error bars (95% CI). A ‘range of common elements effect’ was applied for normalization of the ratings. Here, we used the avoidance and encounter questions relating to the frequency of visiting public spaces in summer and winter respectively to define a range of common elements (marked as a blue band in the graphs). The principle behind the selection of these two questions is that we consider them to embody a variety of elements that either facilitate or hinder public space use. Environmental factors include microclimate, design and maintenance of public areas, and elements related to individuals include attitudes and capacities in relation to physical and attentional demands.

They also include shared values, norms and behaviours within social groups or populations. Hence, using this range of collective elements for normalization made it possible to compare the impact of specific meteorological conditions among populations in different geographical regions. In the analysis, conditions outside the normalized range are interpreted as having either a significantly enabling or inhibiting impact on the use of public space.

Internal consistency of the survey items was analysed with Chronbach’s alpha. The scales (the encounter scale scored 0.88 and the avoidance scale 0.87) showed Cronbach’s alpha levels above 0.7, indicating overall satisfactory reliability.

In addition, to explore the internal structure of the scale items, explorative factor analysis was performed. The extraction method involved principal components and Varimax with Kaiser normalization was used for factor rotation. An item had to have a loading over .50 (Hair et al. 1998) to be considered a meaningful item for the factor. A factor consists of multiple variables with similar patterns of responses, which is interpreted as being associated with a latent (i.e. not directly measured) element.

All statistical analyses were performed using IBM SPSS version 23.0.

Results: Meteorologically determined use of public space

Study group

In total, 361 respondents from Scandinavia and Canada were included in the analysis. Climate types Dfc and Dfb, according to the Köppen Geiger classification, had the highest representation, but Cfb was also represented. Of the total sample, a higher number of respondents were located in Scandinavian

countries (72%) than in Canada. The majority of the respondents in Scandinavia and Canada were in the age range 21–40 years and female. However, in comparison there was a slightly higher proportion of male and younger aged respondents in Scandinavia. There was a significantly higher proportion of respondents from Dfc climate areas in Scandinavia. Canada had a higher proportion of respondents from Dfb areas (Table 1).

1 p values for the comparison of scores between the Canadian and Scandinavian groups using the Pearson Chi-Square test.

Meteorological conditions significantly affecting decisions about using public spaces

The results from the encounter/avoidance questions show that the common meteorological conditions found in winter had varying impacts on people's use of public space (Table 1, Fig. 1 and Fig. 2). A greater resistance to using outdoor public space in winter compared to summer was noted and used in the analysis to define the range of collective effects. The results reveal that not only sunshine, but also snow-covered surfaces, were not avoided, and were perceived as positive conditions to encounter. Similarly, snowfall tended not to be seen as a barrier: the data indicated that its influence on the use of outdoor space in winter was marginal. Cold and windy conditions came next in the order of relative importance for both using and avoiding public spaces.

The main barriers to the use of public space were slushy and icy ground and rainfall. In addition, darkness had a negative influence on people's use of public space.

Commonalities and differences between the respondents in the two geographical regions

Table 2 shows how the respondents in the two geographical regions perceived the impact of meteorological conditions on their use of public space. The results show that the likely public space use is higher among respondents in Canada than in Scandinavia. In general, the Canadian respondents

allocated higher scores than the Scandinavian respondents, both in terms of avoidance and use, in all cases except '... visiting public spaces when the ground is icy?' In this case, the Scandinavian respondents were more likely to allocate a higher score.

However, after normalization using the range of collective effects, although the relative importance of the meteorological conditions varied slightly between geographical locations, in the main they followed the same pattern (figs. 3 and 4). The exception was ice-covered surfaces. Canadian residents perceived ice-covered surface to represent the worst condition, while Scandinavian residents perceived slushy surfaces as the greatest limitation.

To further explore the influence of the climate zones, an ANOVA analysis was applied, indicating significant inter-zone differences in terms of visiting public spaces when it is raining and when the ground is icy. Also snowfall tended to be a significant element.

Significant inter-climate zone differences in avoidance of using public spaces in winter was noted for rainfall and icy ground surfaces. A tendency of differences due to cold temperatures was noted (Table 3).

Post hoc analyses showed that residents in climate zone Cfb (Temperate oceanic climate) stood out as more likely to use public space during rainfall, while the usage was less among residents in the Dfc (Subarctic climate). Correspondingly, climate zone Cfb was least likely to avoid public space due to rainfall, while here, it was the residents in the Dfb (Humid continental climate) that had the highest avoidance.

Also avoidance of ice was highest in the Dfb climatic zone, while avoidance of visiting places with ice covered surfaces was lower in Dfc.

In summary, residents in the Dfb zone were more affected by rain and ice than those in the cooler and warmer zones.

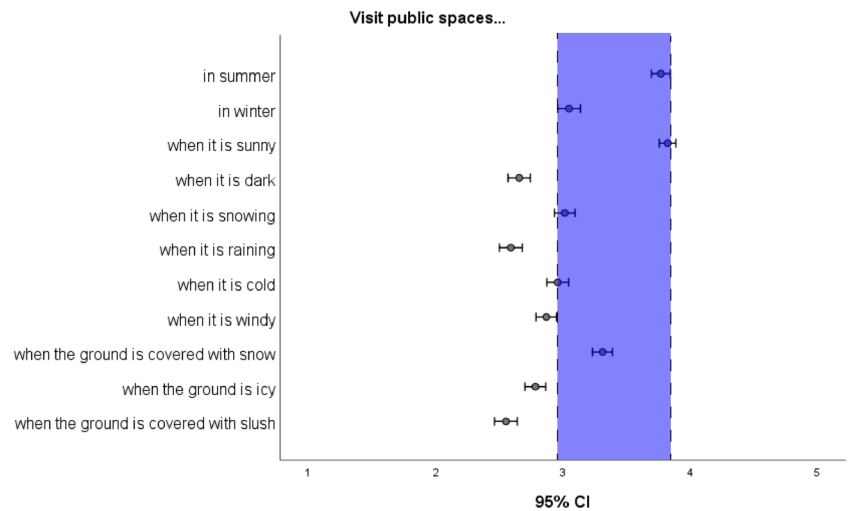
Analysis of the internal structure of the EAMQ-climate scale items

The links between different meteorological conditions were supported by a supplementary factor analysis (Table 4). The

Table 1 Basic background factors for the respondents

	All (n = 361)	Scandinavia (n = 258, 72%)	Canada (n = 103, 28%)	p ¹
Gender, n (%)				
(female/male/other)	236(65)/116(32)/6(2)	158(61)/92(36)/8(3)	78(76)/24(23)/1(1)	0.027
Age groups, n (%) (<20/21–40/41–60/ 61–80/>81 years)	16(4)/257(71)/69(19)/18(5)/1(3)	16(6)/180(70)/50(19)/12(5)/0(0)	0(0)/77(75)/19(18)/6(6)/1(1)	0.052
Köppen climate type, n (%) Dfc/Dfb /Cfb	180(50)/148(41) /33(9)	164(64)/71(27)/23(9)	16(15)/77(75)/10(10)	< 0.001

Fig. 1 Meteorologically determined use of public space as perceived by the study group ($n = 361$), analysed by using the range (blue band) of common element effects for summer and winter. Scale: never =1, rarely =2, sometimes = 3, often = 4, always = 5



first factor comprised all the questions relating to use (i.e. ‘Do you visit...?’) and meteorological conditions with the exception of darkness; this factor is referred to as ‘*general meteorological impact on use*’.

Further, the factor analysis showed that questions about encounters did not discriminate between conditions to the same extent as questions about avoidance. The *second* factor ‘*ambient impact on avoidance*’ reflected the impact of cold, wind, rain and snowfall on people avoiding using public spaces. The *third* factor ‘*terrain impact on avoidance*’ signifies the impact of snow, ice and slush on whether people avoid using public spaces. Here, ice had a negative impact: people are less likely to use public spaces when it is icy.

Factor *four* ‘*sun and snow impact on avoidance*’ indicated that sunshine, snow-covered surfaces and snowfall are conditions that people rarely avoided when deciding to visit public spaces.

‘*Darkness*’, factor five, was the sole condition covered by the survey that could not be grouped with any other conditions.

In conclusion, the factor analysis indicated that meteorological conditions related to terrain, ambient conditions, snow and sun, and darkness reflect different elements.

In summary, the significant meteorological conditions to be considered can be split into four broad groups. These are

1. – Conditions that enable the use of public space are a) solar gain, b) snow-covered surfaces, and c) snow precipitation.
2. – The main barriers to using public space are a) slush or icy surfaces (terrain), and b) rain (ambient).
3. – Darkness, i.e., low visibility, is a hinderance to use and needs to be considered as a separate element.
4. – Elements with less relative impact are wind and cold.

Meteorological conditions affecting people’s *avoidance* of using public spaces discriminate between conditions related to a) the ground surface, and b) ambient conditions, as well as the particular significance of c) snow and sun, and d) darkness.

Fig. 2 Meteorologically determined *avoidance* of the use of public space as perceived by the study group ($n = 361$). Analysed by using the range (blue band) of common element effects for summer and winter. Scale: never =1, rarely =2, sometimes = 3, often = 4, always = 5

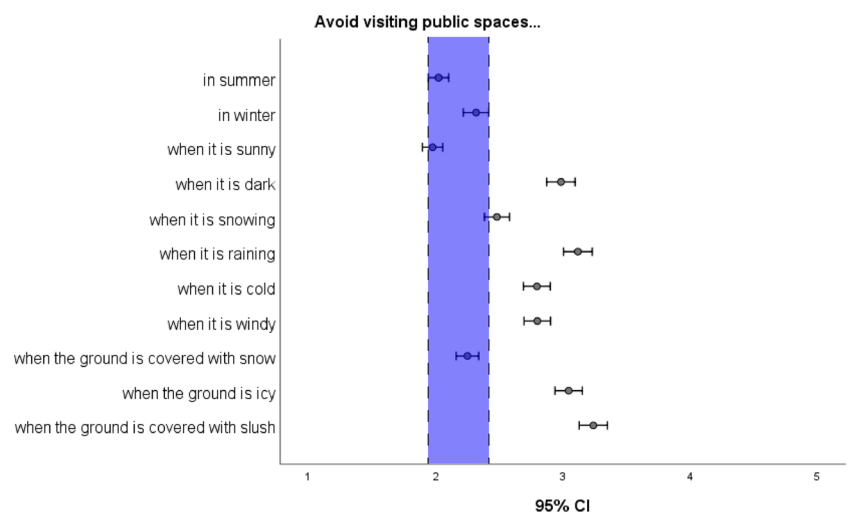


Table 2 The phrasing of questions 1 to 22 of ‘the EAMQ-Climate: space’ survey and results pertaining to the impact of meteorological conditions on use of public space reported as encounter and avoidance scores

When you go into the community, how often do you...	All (n = 361) Mean (SD)	Scandinavia (n = 258, 72%) Mean (SD)	Canada (n = 103, 28%) Mean (SD)	p ¹
Encounter score by item				
Use dimension				
1. ...visit public spaces in summer?	3.8 (0.72)	3.7 (0.75)	4.0 (0.55)	0.001
3. ...visit public spaces in winter?	3.0 (0.86)	3.0 (0.88)	3.2 (0.80)	0.041
Ambient dimension				
5. ...visit public spaces when it is sunny?	3.8 (0.63)	3.7 (0.67)	4.0 (0.44)	<0.001
7. ...visit public spaces when it is dark?	2.7 (0.84)	2.6 (0.87)	2.7 (0.76)	0.537
9. ...visit public spaces when it is snowing?	3.0 (0.78)	2.9 (0.78)	3.2 (0.75)	0.008
11. ...visit public spaces when it is raining?	2.6 (0.86)	2.6 (0.90)	2.6 (0.78)	0.976
13. ...visit public spaces when it is cold?	3.0 (0.83)	2.9 (0.83)	3.0 (0.83)	0.646
15. ...visit public spaces when it is windy?	2.9 (0.78)	2.8 (0.78)	2.9 (0.78)	0.513
Terrain dimension				
17. ...visit public spaces when the ground is covered with snow?	3.3 (0.76)	3.2 (0.77)	3.5 (0.70)	0.014
19. ...visit public spaces when the ground is icy?	2.8 (0.78)	2.9 (0.78)	2.6 (0.75)	0.002
21. ...visit public spaces when the ground is covered with slush?	2.6 (0.86)	2.5 (0.86)	2.8 (0.85)	0.006
Avoidance score by item				
Use dimension				
2. ...avoid visiting public spaces in summer?	2.0 (0.77)	2.0 (0.79)	2.1 (0.70)	0.142
4. ...avoid visiting public spaces in winter?	2.3 (0.97)	2.2 (0.98)	2.5 (0.91)	0.014
Ambient dimension				
6. ...avoid visiting public spaces when it is sunny?	2.0 (0.77)	1.9 (0.78)	2.1 (0.74)	0.109
8. ...avoid visiting public spaces when it is dark?	3.0 (1.08)	2.9 (1.13)	3.2 (0.93)	0.026
10. ...avoid visiting public spaces when it is snowing?	2.5 (0.95)	2.4 (0.96)	2.7 (0.88)	0.008
12. ...avoid visiting public spaces when it is raining?	3.1 (1.09)	3.0 (1.14)	3.5 (0.83)	<0.001
14. ...avoid visiting public spaces when it is cold?	2.8 (1.02)	2.7 (1.05)	3.1 (0.87)	<0.001
16. ...avoid visiting public spaces when it is windy?	2.8 (1.00)	2.7 (1.02)	3.0 (0.92)	0.004
Terrain dimension				
18. ...avoid visiting public spaces when the ground is covered with snow?	2.2 (0.86)	2.2 (0.89)	2.4 (0.76)	0.027
20. ...avoid visiting public spaces when the ground is icy?	3.0 (1.00)	2.8 (1.05)	3.5 (0.82)	<0.001
22. ...avoid visit public spaces when the ground is covered with slush?	3.2 (1.07)	3.2 (1.12)	3.4 (0.91)	0.114

Scale: 1 = never 2 = rarely 3 = sometimes 4 = often 5 = always.

¹ p values for the comparison of scores between the Canadian and Scandinavian groups using the ANOVA test

Discussion

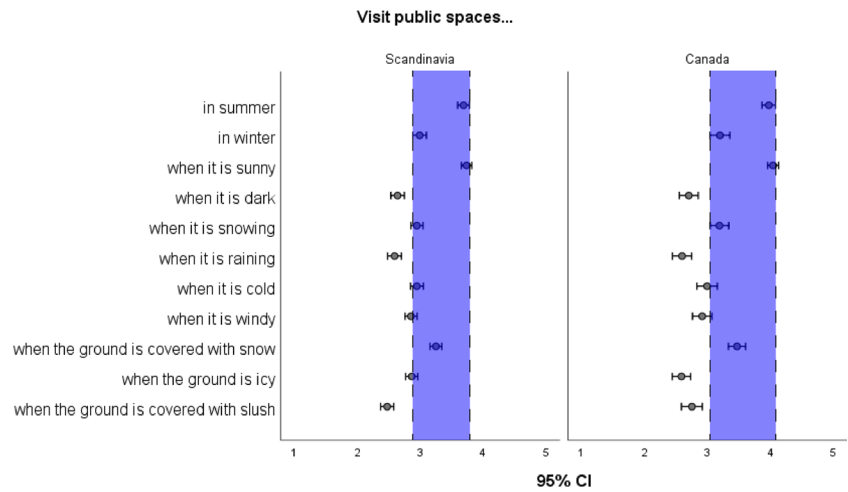
This research assessed how residents in winter cities perceived the impact of meteorological conditions on their use of public spaces during winter. While the main proportion of respondents were located in Scandinavian settlements and mainly in the Dfc climate area, Canada and Dfb areas also had a relatively high representation.

The overall results show that residents in these winter cities perceived solar gain, snowfall and snow-covered surfaces to be the most significant meteorological enablers for the use of outdoor public spaces. The main barriers to using outdoor public spaces were slush-covered and icy surfaces, rainfall and darkness. Wind and cold were conditions with less impact.

The sub-analysis by location indicated that, for meteorologically determined use of public space, Scandinavia and Canada share much common ground. The order of conditions by relative importance were the same, except for ice and slush-covered surfaces: slush was considered the most influential barrier in Scandinavia, while ice had the highest impact in Canada. A second sub analysis exploring the influence of climatic zones on residents appraisals of meteorological conditions showed that mainly *rain* and *ice* was perceived differently between zones, residents in the Dfb (Humid continental climate) zone were more inhibited by rain and ice than those in the cooler Dfc, and warmer Cfb, climatic zones.

These impacts of meteorological conditions on resident's use of public space are broadly aligned to conditions of

Fig. 3 Perceived meteorologically determined use of public space, analysed separately for residents in Scandinavia ($n = 258$) and Canada ($n = 103$). The blue band denotes the range of common element effects for summer and winter. Scale: never = 1, rarely = 2, sometimes = 3, often = 4, always = 5



significance for people’s soft mobility choice, as reported previously (Chapman et al. 2017): rainfall, icy surfaces and darkness were significant barriers to soft-mobility in the Dfc Climatic area of Northern Sweden. Cold, wind and snow, however, were conditions that exerted less influence. In this comparison of the data, it is notable that the impacts of these meteorological conditions had a higher impact on people’s choice to visit public space than on soft-mobility. This may be explained by the fact that there is a greater need for daily movement to work or to school through these spaces and, indeed, travel may be essential, unlike using or visiting public spaces for leisure activities. These findings confirm Gehls (Gehl 1971) notion of three types of activities: 1) necessary activities (everyday functional tasks) that would occur in any weather, and activities that are 2) optional (resting places) or 3) social (people gathering together). Here both optional and social activities are, to a great extent, shaped by the physical design of a place and the weather. Places also have different functions. Previous research has shown that thermal conditions have less influence on the use of a town square where people pass through or make a short stop, in comparison to a

park used as a resting place (Thorsson et al. 2007). Thermal sensation, however, is subjective and is affected by various factors, such as clothing, activity pattern, attitudes, previous experiences, expectations and perceived control (Bosselmann et al. 1995; Chen and Ng 2012; Knez et al. 2009; Leng et al. 2019; Lenzholzer 2010; Nikolopoulou and Steemers 2003).

Mainly sunshine, but also snowfall and snow-covered ground were perceived to act as enablers to peoples use of public spaces in winter. Access to sunlight is one of the key design principles (Pressman 2004) together with other weather conditions such as comfortable air temperature and wind that have been shown to enhance place-related emotions and presence in urban spaces (Chen and Ng 2012). The fact that snow is considered to be a positive element is important on two levels. First, winter weather has positive effects on visiting public spaces. This is significant as mainstream urban design thinking generally bundles meteorological or climate conditions together as a group of considerations, rather than viewing them as each having different qualities for people. The second is that snow cover and snowfall in settlements can bring positive benefits for outdoor activity and should

Fig. 4 Perceived meteorologically determined avoidance of the use of public space, analysed separately for residents in Scandinavia ($n = 258$) and Canada ($n = 103$). The blue band denotes the range of common element effects for summer and winter. Scale: never = 1, rarely = 2, sometimes = 3, often = 4, always = 5

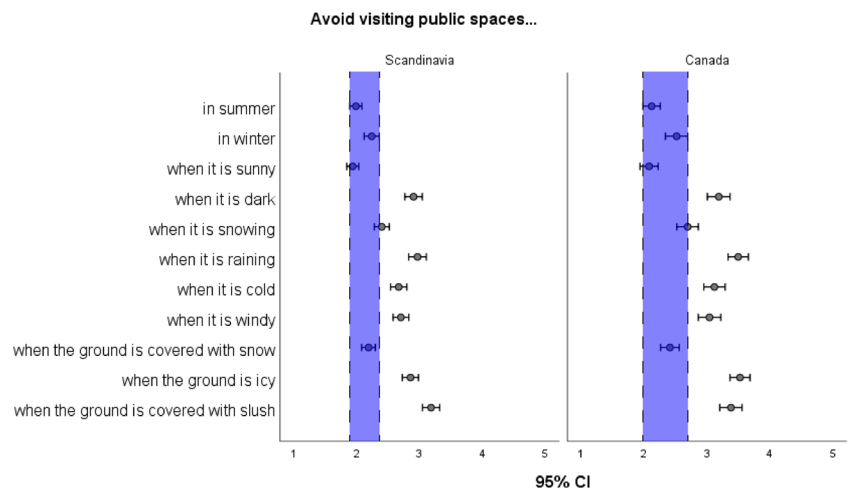


Table 3 Results pertaining to the impact of meteorological conditions on use of public space reported as encounter and avoidance scores, in different Climatic zones

	Dfc (n = 180) Mean (SD)	Dfb (n = 148) Mean (SD)	Cfb (n = 33) Mean (SD)	p1
Encounter score by item				
Use dimension				
1. in summer	3.7 (0.76)	3.8 (0.66)	3.8 (0.68)	0.161
3. in winter	3.0 (0.88)	3.1 (0.83)	3.2 (0.93)	0.325
Ambient dimension				
5. when it is sunny	3.8 (0.72)	3.9 (0.53)	3.8 (0.51)	0.084
7. when it is dark	2.6 (0.84)	2.7 (0.85)	2.8 (0.83)	0.351
9. when it is snowing	2.9 (0.81)	3.1 (0.75)	3.1 (0.68)	0.061
11. when it is raining	2.5 (0.91)	2.6 (0.79)	3.0 (0.83)	0.011
13. when it is cold	2.9 (0.82)	3.0 (0.85)	3.1 (0.78)	0.340
15. when it is windy	2.8 (0.79)	3.0 (0.75)	2.9 (0.82)	0.273
Terrain dimension				
17. when the ground is covered with snow	3.3 (0.75)	3.4 (0.75)	3.2 (0.83)	0.432
19. when the ground is icy	2.9 (0.77)	2.6 (0.78)	2.7 (0.74)	0.003
21. when the ground is covered with slush	2.5 (0.91)	2.6 (0.80)	2.4 (0.87)	0.699
Avoidance score by item				
Use dimension				
2. in summer	2.0 (0.79)	2.0 (0.71)	2.3 (0.88)	0.144
4. in winter	2.3 (0.97)	2.4 (0.98)	2.3 (0.95)	0.727
Ambient dimension				
6. when it is sunny	2.0 (0.79)	2.0 (0.74)	2.0 (0.79)	0.970
8. when it is dark	2.9 (1.15)	3.1 (1.00)	3.1 (1.09)	0.298
10. when it is snowing	2.4 (0.95)	2.6 (0.93)	2.4 (0.96)	0.157
12. when it is raining	3.0 (1.12)	3.3 (1.00)	2.7 (1.18)	0.009
14. when it is cold	2.7 (1.04)	2.9 (0.96)	2.6 (1.08)	0.074
16. when it is windy	2.8 (1.04)	2.8 (0.93)	2.7 (1.10)	0.791
Terrain dimension				
18. when the ground is covered with snow	2.1 (0.87)	2.4 (0.80)	2.2 (0.96)	0.039
20. when the ground is icy	2.8 (1.07)	3.3 (0.92)	3.2 (1.06)	<0.001
22. when the ground is covered with slush	3.1 (1.13)	3.3 (0.95)	3.4 (1.20)	0.116

Scale: 1 = never 2 = rarely 3 = sometimes 4 = often 5 = always.

¹ p values for the comparison of scores between the groups using the ANOVA test

be viewed as a positive attribute for design and not just a public area maintenance issue.

In earlier research, a negative impact of snowfall on outdoor activity has been reported (Chan and Ryan 2009; Edwards et al. 2015; Ogawa et al. 2019). As a consequence, the need to find ways that outdoor activities can be promoted in cold climates has been stressed (Chan and Ryan 2009). There are good examples of how snow and ice can create attractive urban environments, for example, opportunities for ice sculptures, activity areas and winter festivals in town squares, and winter cycling, ice skating or cross-country skiing (Chapman et al. 2019; City of Edmonton 2016). The creation and maintenance of ice roads on rivers and lakes creates new networks between neighbourhoods. Shelters with seats and fire spots along ice roads create resting places and social

meeting areas. However, snowdrifts on roads and walkways create serious barriers for mobility, plus as snowfall reduces visibility (Chapman et al. 2019) which could explain the inconsistency in perceived impact of snow.

In this study, coldness and wind were perceived as elements with less relative impact on residents' choices to use public spaces in winter. These findings are inconsistent with earlier research (Chen and Ng 2012; Knez et al. 2009) which may be explained by the palettes of meteorological elements asked about in different studies, or by the geographical locations and seasons when data was collected. Notable in this study was the indication that ice and rain was perceived as significantly more inhibiting during winter in Climatic zone Dfb, which implies a need of assessing and addressing the local climate context in planning. In parallel to the social context.

Table 4 The internal structure of the data according to the factor analysis. The factor analysis revealed five major factors, each capturing a certain amount of total variance in the observed variables. In total, the five-factor solution explained 69.9% of the total variance, and all 22 original items comprising the scale were represented

Factor	1	2	3	4	5
Explained % of total variance	19.8	17.1	13.4	10.2	9.0
Encounter:					
Ambient dimension					
5. when it is sunny	.52		.30	-.33	
7. when it is dark	.32				.86
9. when it is snowing	.78				
11. when it is raining	.62	-.45			
13. when it is cold	.69				
15. when it is windy	.65	-.37			
Terrain dimension					
17. when the ground is covered with snow	.76				
19. when the ground is icy	.51		-.66		
21. when the ground is covered with slush	.60		-.46		
Avoidance:					
Ambient dimension					
6. when it is sunny				.76	
8. when it is dark		.31			-.82
10. when it is snowing		.52		.60	
12. when it is raining		.82			
14. when it is cold		.66	.34	.35	
16. when it is windy		.75			
Terrain dimension					
18. when the ground is covered with snow			.62	.47	
20. when the ground is icy		.40	.76		
22. when the ground is covered with slush		.55	.57		

Principal component analysis, varimax rotation with Kaiser normalization.

One reason for cold and wind being perceived as having less impact could be that these winter settlements, through long experience, have been successful in planning and designing for shelter from the wind and managing snow. It could also be the attitudes, expectations and successful adaptive strategies of residents in these areas. There is evidence for psychological and physical adaptation taking place with the seasonal variation (Nikolopoulou and Lykoudis 2006).

Implications for winter settlement design

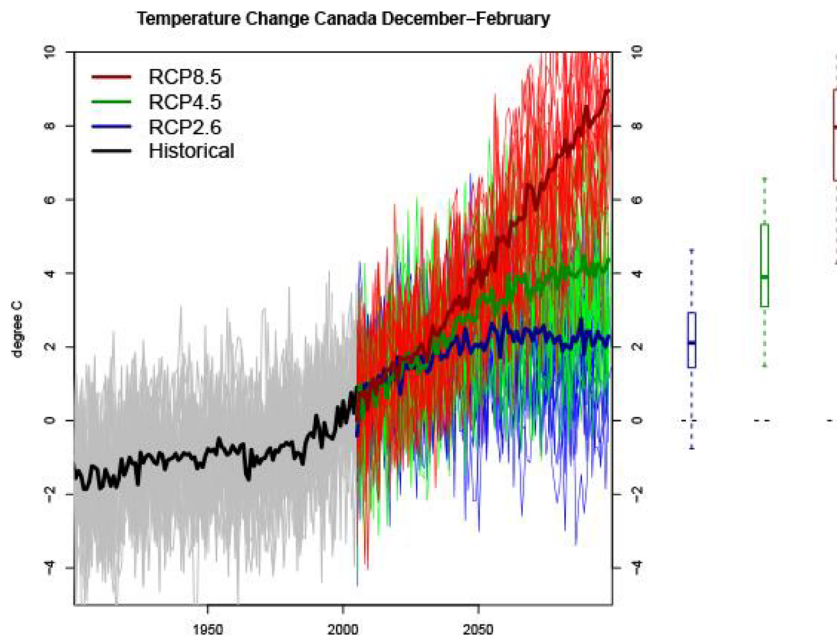
The identification of rainfall and ice as the current main inhibitors in the use of public space is of particular significance in this study. These conditions relate to the state in which water is encountered in the outdoor environment. Snow mainly forms when temperatures are below 0 °C, while rain, slush and ice are more likely when temperatures are above or fluctuating around 0 °C.

Here it can be argued that, with ongoing climate change and warmer winter conditions, problems of rain and ice are gaining prominence in winter and Arctic communities as they experience warmer winters with more

fluctuating winter temperatures. Hence, the current meteorological conditions linked to the use of public space could be changing with evolving climate. Arctic communities are also becoming likely to experience less snowfall and fewer benefits from snow and snow-covered surfaces, as this will reduce during the year (figs. 5 and 6). By default, this will mean that conditions associated with warmer winters with more fluctuating winter temperatures will become a more important consideration for public space design in winter settlements. There is also the risk that unfamiliar outdoor conditions will lead to increased activity avoidance and fall injuries in the population (Larsson et al. 2019; Lépy et al. 2016). Again, this needs to be considered in the design process.

While darkness, and consequent reduced visibility, in itself cannot be linked directly to the state that water is encountered in the outdoor environment, levels of ambient lighting in the built environment can be. This is because of the reflective qualities of snow in comparison to ice or water. Andbert (Andbert 1979) and Børve (Børve 1987) argue that snow reflects around 85% of directly incident solar radiation, whereas water and ice may reflect

Fig. 5 Wintertime temperature trajectories until 2100 (Canada)

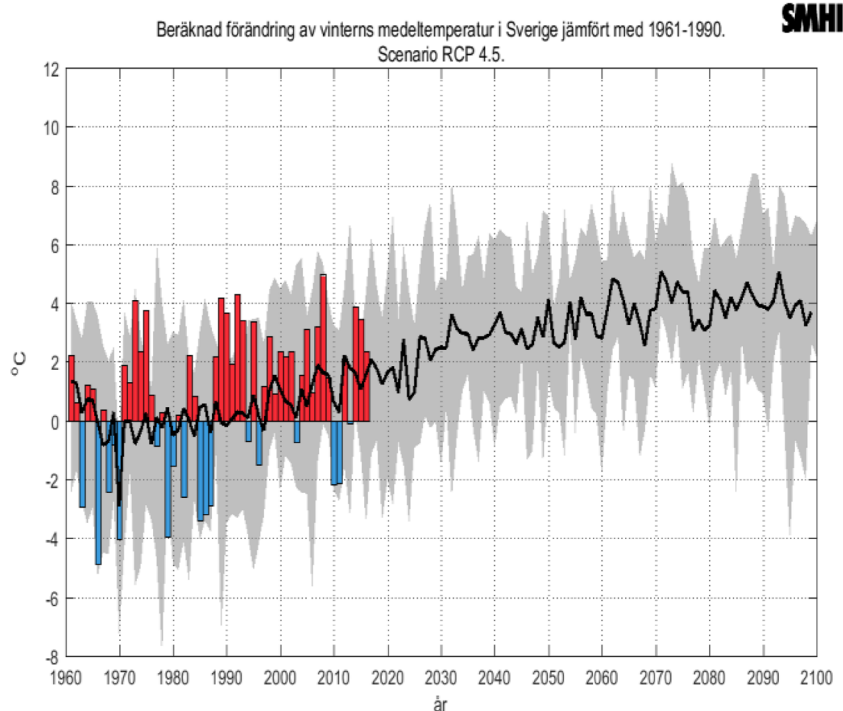


as little as 5%. For all winter communities that experience limited daily hours of daylight or sunlight, reduced levels of ambient lighting caused by reduced snow cover will have a detrimental effect on public space use in winter. This suggests that, for winter communities and especially those at high latitudes, the design of lighting for public spaces and in the public realm is likely to increase in importance as climate change brings warmer winters and reduced snow cover.

Methodological considerations

The results reflect the perceptions of 361 residents in Scandinavia and Canada, and were reported at a single time only. The validity of subjective data may be influenced by recall bias, social expectations, values and behaviours. In the original EAMQ, self-reported encounters with or avoidance of specific environmental features were significantly correlated with observed mobility (Shumway-Cook et al. 2005).

Fig. 6 Wintertime temperature trajectories until 2100 (Sweden)



Amended into the climate sensitive version (EAMQ-Climate: mobility/space), several winter-specific meteorological conditions were added. It may be the case that subjective data relating to the senses, such as thermal environment, vision or noise, have a more instant impact (Raccuglia et al. 2018), than e.g. perceptions of mobility-related physical demands and movement such as in the original EAMQ. This indicates a need to validate the EAMQ-climate: space/mobility in terms of the direct microclimatic effects on people's soft-mobility choices for transport and their likely use of public space.

The results indicate that there is a wide range of elements involved in peoples' decision-making process when choosing to use public spaces in winter. The survey only covers a few. Nevertheless, one strength of this novel questionnaire is that it includes meteorological conditions not commonly measured, namely ground surface conditions. Terrain was found to be of high relative importance in relation to peoples' use of space.

There are several limitations with this study design. Due to the piloting of a new survey and exploring perceptions among only a limited study group from two regions, this result cannot be generalized to all winter cities.

The majority of respondents were from Scandinavian countries and from areas where a Dfc climate dominated. There were a relatively high proportion of female and middle aged responders. The distribution of the survey via digital platforms may mean that a large proportion of respondents may have been professionals with a focus on urban planning. Consequently, these respondents do not reflect the voices of whole community.

Nevertheless, when comparing the results pertaining to the relative impact of the various meteorological conditions in Scandinavia and Canada, it was interesting to note that they exhibited similar patterns. This suggests that the relative impacts of these conditions may be similar among residents in winter cities in different regions. Studies with an increased number of respondents and from a wider range of winter cities, such as, for example, regions in the Alps and Northern China are needed to verify these results. More information about elements relating to the respondents and their residential areas should be collected to support statistical models and future design solutions.

As the study was cross-sectional it does not follow trends in perceived impact of different meteorological conditions over time. However, in light of scientific evidence that global warming is resulting in warmer winters, it is plausible to expect that the meteorological conditions that influence people's use of public space will alter over time with climate change.

Conclusions

This study has shown that, in winter cities in both Canada and Scandinavia, sun, snowfall and snow-covered surfaces are all

enabling factors for visiting public space. It has highlighted that ambient conditions, such as rainfall, and terrain conditions, such as ice and slush, are major barriers to the use of public spaces. Equally, poor lighting and darkness also reduce likely public space use.

The study highlights that winter public space has a higher climatic design requirement to be successful than streets and pathways that are mainly used for soft-mobility. This is important because it highlights the increased design demands if we want to attract people to visit outdoor winter spaces for social activities rather than just transport activities. Here designers and urban planners need to focus even more carefully on how they can improve the microclimatic environments of these places. This suggests that in winter cities the design requirements for public spaces should be at a higher level than those prescribed for streets and pathways.

To create useable public spaces in winter settlements, focus needs to be placed on balancing design and management requirements created by seasonal climate variation. Here it is important to focus on what makes these spaces attractive for users all year round, when public spaces are both free of snow and ice and when they have the white cover of winter.

The local climate context needs to be assessed and addressed in planning. Urban planners should focus on taking the positive aspects of winter such as sun access, snowfall and snow cover into account to a higher extent in the design process, while minimizing the issues of water, slush, ice and wind. Here, urban design guidance for public spaces in winter settlements should include 'qualities'-based criteria for design across the seasons. Such guidance would benefit from focusing on how the winter season alters public spaces and their use. In particular, public space design should address how rainwater and snowmelt can be managed in the public realm. Designers should also seek suitable terrain and surface designs that remain attractive all year round. As darkness is a major barrier to public space use in winter, solutions that maximize natural lighting and integrate artificial illumination should be sought.

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Compliance with ethical standards

The study was performed in compliance with the ethical principles for good research practice. This includes that informed consent was obtained from each participant in the study.

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