THERMALLY COMFORTABLE PLAYGROUNDS:

A review of literature and survey of experts

National Program for Playground Safety
NPPS

PREPARED FOR

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Prepared for

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EXECUTIVE SUMMARY

Children are drawn to playgrounds. Playgrounds are a central hub for child play, fun for families, enjoyment with friends, and places for communities to come together. Thus, any concerns that may impact children's play, such as unsafe temperatures or conditions, may hinder children's health and well-being.

Children are particularly vulnerable to hot ambient environments and heat stress compared to adults due to various age-related factors (Berry et al., 2014). They are also more susceptible to sunburns and burn injuries on playgrounds because their skin is more sensitive (Volkmer & Greinert, 2011). Planning, designing, and managing thermally comfortable outdoor spaces is increasingly important as the numbers of very hot days in many parts of Canada is expected to increase, with significant impacts on human health (Berry, McBean & Seguin, 2008). Making playground equipment and spaces thermally comfortable and safe during all seasons of play helps to ensure that children can go outdoors, play, and be active for a longer time period.

This report is intended to provide readers with contextual knowledge of thermal comfort as it relates to playgrounds. It also provides actionable design considerations to improve thermal comfort on playgrounds and further summarizes common design features to support safe and comfortable playgrounds for all seasons of play. Guidance in this report draws heavily on the insight of both academic and grey literature about playgrounds and thermal comfort, as well as insights from a diverse representation of Canadians and international topical experts to provide knowledge and perspectives in this topic area. This guidance can both be implemented today by designers and integrated into future design and equipment standards.

In support of developing evidence-based recommendations, the project team at the National Program for Playground Safety produced the following components, which are included within this report:

1. **Literature review**. A literature review was developed that focuses on thermal comfort and playground microclimates, climate change and extreme heat in a Canadian context, and children's health and safety connected to considerations for heat adaptation in urban areas and children's playgrounds.
2. **Needs assessment**. A comprehensive needs assessment was completed – with input from a broad range of researchers, scientists, and practitioner experts – to gather perspectives about thermal comfort and children's playgrounds. The needs assessment helped support the development of recommendations for a thermal comfort annex for the forthcoming update to the CSA Children's playgrounds and equipment standard (CAN/CSA Z614).
3. **Design and management recommendations**. Practical design and management suggestions are provided for creating thermally comfortable outdoor spaces to support opportunities for children to go outdoors, play, and be active. Recommendations are drawn from the literature and feedback provided by experts. The need for continued data collection as well as quantification of the effects of thermal comfort and child play are summarized at the end of this document.
4. **Recommendations for further work**. The evidence gathered from both the literature review and the needs assessment survey have highlighted that thermal comfort is an important topic for creating outdoor spaces conducive for supporting children's play. While the focus of this project was on recommendations for developing a thermal comfort annex for inclusion in CAN/CSA Z614, the needs assessment and literature review also provided lessons learned that informed recommendations for future areas of work to enhance thermal comfort at playgrounds in Canada. The project team has therefore identified recommended actions beyond the current project.
5. **A draft thermal comfort informational annex**. An informational annex was drafted and submitted to the Canadian Standards Association to consider including in the next revision of the CSA Children's playgrounds and equipment standard (CAN/CSA Z614). The informational thermal comfort annex provided a concise summary of practices and useful design suggestions that influence thermal comfort in playground areas. The guidelines are intended for use during the planning stages of playground development.

This report finds overwhelming agreement in the literature and among the topical experts surveyed that thermal comfort is an important element in children's playgrounds, yet there is a strong consensus that management of such environmental factors have not been prioritized compared to other safety factors presented in relevant equipment and design standards (e.g., materials, structural integrity, surfacing, inspection, maintenance, etc.). Surveyed experts from both the academic and practitioner profession (e.g. landscape architects, playground designers, engineers, child health researchers, and educators) agree that thermal comfort should be and could be included in future playground safety standards. Future research efforts that encompass the interrelationship between equipment and design standards as well as thermal and environmental design elements on playgrounds is critically needed to help communities across Canada examine these issues, better informing a thermally safe and comfortable playground framework.

1 Introduction & Context

In 2014, the CSA Group published the fifth edition of CAN/CSA Z614, *Children's playspaces and equipment* which "addresses safety measures that help minimize exposure to serious injuries" (CSA 2014). While the existing version of the standard includes several references to heat, considerations for designing play equipment and spaces for extreme heat were not systematically integrated into the document. In October 2018, following a presentation by Dr. Jennifer Vanos (Arizona State University) and Gregory R.A. Richardson (Health Canada), the Children's Playspaces and Equipment Technical Committee (TC-S704) agreed by consensus to consider inserting a short informational annex for practitioners on how to design playspaces and equipment for thermal comfort in summer in the context of broader climate-sensitive design.

In March 2019, the Standards Council of Canada commissioned the National Program for Playground Safety to review the relevant literature, engage with topical experts to assess stakeholder needs, and to develop recommendations on how to integrate thermal comfort in the context of climate change into standards for children's playspaces and equipment. A key criterion in developing the recommended annex text was that it be based on the best available evidence and extensive stakeholder engagement. The recommended annex collated the results of such evidence-based research and was provided to CSA Group in May 2019 for consideration by the Technical Committee in drafting a new edition of the CAN/CSA-Z614-14 *Children's playspaces and equipment* standard.

The overall project is part of the Standards Council of Canada's Standards to Support Resilience in Infrastructure Program, which supports the development of a broad range of standardization solutions to adapt infrastructure to climate change impacts. This initiative includes: standardization guidance on weather data, climate information and climate change projections; new and revised standards and guidance to ensure infrastructure across Canada is climate-ready; and investments in new standards and guidance that support northern infrastructure.

1.1 Child's Play and Playgrounds

Play, which involves engagement in an activity for enjoyment, is the fundamental means through which children develop physically, socially, emotionally, and intellectually. In fact, play is considered so vital to a child's development, including their physical and mental health, that it is included in Article 31 of the U.N. Convention on the Rights of the Child (Cohen 1989).

Playgrounds are highly valued spaces in towns and cities to support child well-being and opportunities for physical and social development. Playgrounds are a central hub for child play, fun for families, enjoyment with friends, and places for communities to come together. Unfortunately, approximately 200,000 children per year visit emergency departments for playground-related injuries in the United States (Adelson et al., 2018). Additional studies have reported that playgrounds are the leading cause of recreational injury for children ages one to seven and are the second leading cause of injuries (next to bicycles) for children aged eight to nine (Schwebel et al., 2014). Fractures account for greater than 90% of admitted playground injuries and are mostly caused by falls which account for greater than 75% of all injuries (Laforest et al., 2001; Mowat, 1998).

Although numerous playground surface and equipment standards (CSA Group, ASTM International, ISO) have been devised, injury rates have plateaued (Macarthur et al., 2000; Keays & Skinner, 2012). Issues that may negatively impact children's play, such as unsafe materials and/or equipment, are vital to consider in the initial design or in retrofitting a playground. Of equal importance are environmental dangers. Unsafe exposure to adverse environmental conditions that cause thermal discomfort due to dangerous temperatures or heightened radiation levels, for example, may also hinder children's health and well-being. Additionally, these exposures present the potential for near-term issues such as heat stress and heat illness (Berry et al., 2014; Vanos 2015) as well as for long-term chronic health problems that may not present themselves until later in life, such as adult skin cancer due to overexposure to solar radiation (Dennis et al., 2008, American Cancer Society, 2013).

Environmental Safety at Playgrounds Warrants Increased Attention

- UV exposure and sunburns as a child are linked to many adult skin cancers and melanoma (*Dennis et al. 2008; American Cancer Society 2013*).
- Playgrounds often present some of the highest surface temperatures within an urban area, amplifying heat extremes – and most playgrounds lack adequate shade (*Olsen*, *Kennedy, & Vanos, 2019; Bloch 2019*).
- Research has shown contemporary playground materials, along with peak sun and temperature periods (10 am – 2pm), can expose children to unsafe equipment and surface temperatures (*Vanos et al., 2016*).

Past playground injury prevention work has focused on the integrity and compliance of equipment and materials in order to minimize playground injuries (e.g. fatalities, fractures, traumatic brain injury-TBI). However, no study has comprehensively examined how exposures to extreme heat and radiation at playgrounds impact children's health or how changes in playground designs and materials can prevent heat-related illnesses or skin injuries. Due to the number of playground-related injuries and the heightened risk of environmental exposures to children, it is critical that researchers and practitioners better understand the combined impacts of playground design on child risk factors (e.g. UV exposure, environmental hazards, impact attenuation, fall injuries, and other common injuries). This new understanding, in turn, will help improve playground design and consequently support increases in child's play, deepen our knowledge of children's thermal comfort, and most importantly promote short- and long-term health.

Finally, a well-designed playground can help increase the enjoyment of play outdoors. Playgrounds should be developmentally appropriate, inclusive, safe, and be thermally comfortable so children and families can play freely (Figure 1). Thermal comfort within a playground setting dictates both the activity levels during play and duration of time spent there. If the playground or park is perceived as uncomfortable, the play experience is often shortened, or the children may simply be more sedentary during their visit (Vanos et al. 2017a), and thus gain less physical activity.

Figure 1.
Active play and comfortable playground.

1.2 What is Thermal Comfort?

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment. It is dependent upon the environmental factors of sun exposure, air movement, humidity, and air temperature, as well as behavioural factors of clothing and physical activity. Thermal comfort is also affected by psychological factors of experiences, expectations, and length of exposures, among others (Nikolopoulou & Steemers 2003).

Each play area has its own distinct microclimate (a local set of atmospheric conditions that differ from those in the surrounding areas and region) based on various man-made and natural factors surrounding the area. The unique patterns of temperature, wind, radiation, and humidity are based on various local attributes, such as shade, vegetation, surface cover, and structures. The microclimate of playgrounds can have a significant influence an individuals' use of parks and play spaces and thus levels of physical activity (Semenzato et al., 2011; Vanos et al., 2017a; Huang et al., 2016; Nasir et al., 2013). **Thermal safety and comfort are essential factors in optimizing children's physical, social, and emotional play experiences**.

Children are particularly vulnerable to hot ambient environments and heat stress compared to adults due to various age-related factors (Berry et al., 2014).They are also more susceptible to sunburns and burn injuries on playgrounds because their skin is more sensitive (Volkmer & Greinert, 2011). Making playground equipment and spaces thermally comfortable during all seasons of play helps to ensure that children can go outdoors, play, and be active for a longer period of time.

Planning, designing, and managing thermally comfortable outdoor spaces is increasingly important as the numbers of very hot days in many parts of Canada is expected to increase, with significant impacts on human health (Berry, McBean & Seguin, 2008). For example, in the City of Windsor, Canada's southernmost city, the number of very hot days is expected to double from 24 days annually to over 40 days by 2050 from the 1976-2005 reference period (Climate Atlas of Canada, 2018).

Although thermal comfort is often discussed in the context of the summer season, the influence of cold weather conditions can also negatively affect a child's play experience. Research shows that weather variations and different seasons affect behaviour and levels of physical activity (Tucker & Gilliland, 2007). While focused on improvements to thermal comfort in the summer season, the information in this report touches on how to design for thermal comfort in all seasons given that many parts of the country experience four distinct seasons, including long and cold winters. Canada is a vast country characterized by large variations in regional climate. The recommendations included herein are therefore not limited to one region, but instead provide high-level applications across various geographic and climatic zones. The need for continued data collection and particularly quantification of the effects of thermal comfort and child play are summarized in the Future Research and Dissemination Efforts of Section 5.

1.3 Thermal Comfort and Playgrounds

The concept of thermal comfort dates back to the 1970s (Fanger, 1970), but to-date has been minimally addressed in relation to children's play and within playgrounds. While the overall decline of play in children is troublesome, one especially concerning trend is the decline of outdoor play activity (Burdette & Whitake, 2005). This decline in outdoor play is potentially related to poorly designed outdoor spaces that may not be thermally comfortable throughout the year; however, further research is needed to address this hypothesis.

With the internationally recognized increase of childhood obesity (World Health Organization, 2019) there is a renewed movement to advocate for outdoor play (Murray et al., 2013; RWJF, 2007), since research shows unstructured play increases children's activity and creativity (Brussoni et al. 2012; Ramstetter et al. 2010; Pellegrini 2009). Furthermore, there has recently been a growing interest in the potential benefits of designing natural playgrounds, with some evidence they help improve cognitive function (Wells, 2000), increase physical activity levels (Dyment & Bell 2007), improve behaviour (Amoly et al. 2014; Acar & Torquati 2015), and better accommodate children of various ages and abilities (Dyment & Bell 2007).

Safety standards, such as CAN/CSA Z614, *Children's playspaces and equipment* (CSA 2014), have helped prevent injuries and improve safety design of playground equipment and materials. However, there are many important factors neglected in traditional playground safety standards, which can cause injury and negative health consequences to children. For example, extreme temperatures and harmful UV radiation exposure can cause injury to children (Moogk-Soulis, 2010; Vanos, 2015). Additionally, heat extremes are amplified by the combination of the urban heat island and climate change, and playgrounds often present some of the highest surface temperatures within an urban area, and many lack shade (Olsen et al., 2019; Bloch, 2019; Vanos et al., 2016).

Given the potential negative health consequences to children (e.g. rise in childhood obesity; increase UV exposure), environmental conditions at playgrounds warrant further attention. **A more holistic view of playground design and safety** is vital for children's health to reduce hyperthermia, thermal burns, sunburns, and respiratory illness (Hayes, et. al, 2012; Winquist, et. al, 2016; Xu, Huang, et.al., 2013) while simultaneously promoting higher levels of physical activity by designing spaces that are more conducive to safe and active play (Cosco et. al., 2014).

Methodology

This report is intended to provide readers with contextual knowledge of thermal comfort as it relates to playgrounds. It also provides actionable design considerations to improve thermal comfort on playgrounds and summarizes common design features to support safe and comfortable playgrounds for all seasons of play. Furthermore, this report focuses on collecting and analysing evidence in support of preparing recommended text that could be included in equipment and design standards, such as the CAN/CSA Z614, *Children's playspaces and equipment* standard.

2.1 Literature Review

The project involved an investigation of both academic (e.g. scientific, peer review, and books) and grey (e.g. magazines, books, websites, policy guides, technical reports) literature. The investigation of the literature involved documenting and reporting the scientific understanding of the factors that influence thermal comfort, as well as best practices for management of related environmental factors.

Sources for the literature review were pulled from a variety of locations. Literature was collected that dealt with the topic of thermal comfort, children's health, design strategies for thermal comfort, and field-work that investigated playgrounds related to extreme temperatures, heat, safety, and other environmental factors. Additionally, literature summarized the susceptibility of children to heat-related illness, epidemiology related to UV exposure, and the importance of play. Complimentary to the academic literature, grey literature such as government, industry, or organizational reports that discussed similar topics were utilized.

2.2 Thermal Comfort/ Playgrounds Survey

In an effort to understand the interrelationship between thermal comfort and other playground safety and hazards, the National Program for Playground Safety (NPPS), in partnership with the thermal comfort task force of the CSA Group's *Children's playspaces and equipment* Technical Committee (TC-S704), invited a diverse list of experts to collect professional opinions, judgement, and experiences on the matter of child health and well-being during play, playground environmental conditions, thermal comfort, playground design, and user experience. These experts were respondents in the *Thermal Comfort and Children's Playground Survey*. All survey methods were reviewed and approved by Bucknell University's Institutional Review Board (IRB# 1819-076) on behalf of the University of Northern Iowa / National Program for Playground Safety and Arizona State University.

A total of 80 experts were invited to complete the survey. Each survey respondent was recruited based on expertise and experience. Additionally, given the geospatial importance of collecting information relative to the Canadian environment, respondents were identified and recruited based on both topical expertise, as well as those with background and experience within the context of Canada and Canadian geographical regions. Overall, the survey respondents consisted of a diverse group of individuals from a variety of Canadian geographical regions, along with experts with an international background. In total, fifty-five individuals (response rate of 69%) provided input and provided expertise on the topic.

The survey was developed to collect opinions and background on four main topic areas:

- **Playground priorities –** identifying relative priorities that environmental factors receive vs. other design (particularly safety) factors
- **Thermal comfort factors –** identifying the perceptions of the relative importance or contributions of different factors to the idea of thermal comfort
- **Mitigation strategies –** identification of the priority levels for different design factors that are most commonly associated with thermal comfort management
- **Standard development –** collection of the perceptions of individuals on how standards can and should address the topic of thermal comfort – which may also be useful in highlighting areas of the most consensus and most persuasive (but not commonly known) suggestions, etc.

The questions of the survey were informed by concepts related to thermal comfort from both academic (e.g. scientific, peer review, and books) and grey (e.g. magazines, books, websites, policy guides, technical reports) literature review. For example, respondents were asked to rate the priority of design features that improve a child's thermal comfort and thermal safety within the playspace environment such as shade, utilization of materials with low solar reflectance, colour selection for surfaces and equipment, choice of material(s) for equipment, and other factors most commonly discussed in the literature with respect to affecting thermal comfort and design. Questions were presented as a likert-scale ranking of factors or a solicitation for open-ended responses. The overall analyses and recommendations are detailed in Sections 4 and 5 and were used in proposing text about designing playgrounds for thermal comfort within the upcoming edition of the CSA CAN/CSA Z614, *Children's playspaces and equipment* standard (Appendix A).

Respondents who participated in the survey were from one of the following five backgrounds:

1. **Climate/ Environmental Scientist**: Scientific Directors, Professors, Researchers, Ecosystem Engineers
2. **Landscape Architect, Urban Planning, Independent Designer**: Experience operating as Urban Planners, Management and Operations of Municipal Parks, Manager of Parks Design, Play Designer, Landscape Architects
3. **Manufacturer, Installation, Supplier**: Playground Installers (Commercial, Wood, Steel, Surfacing), Equipment Manufacturers
4. **Child Health & Wellbeing**: Senior Research Fellow Skin Cancer Prevention, Professors, Injury Research and Prevention, Pediatric Emergency Medicine, Researchers
5. **Educator, Consultant, Risk Management**: Consultants, Safety Experts, Design Research Assistant, Playground Inspector

2.3 Thermal Comfort Informational Annex

The survey results, in combination with the literature review, were used to interpret trends and develop recommendations regarding the principle environmental management factors related to thermal comfort, as well as various site and design practices and playground features/elements that influence thermal comfort.

The project team used the information collected through the literature review and survey to generate content to draft a recommended informational annex to CSA Children's playgrounds and equipment standard (CAN/CSA Z614) for considerations for the next revision of the standard. The informational thermal comfort annex provided a concise summary of practices and useful design suggestions that influence thermal comfort in playground areas. The guidelines are intended for use during the planning stages of playground design and development.

The proposed informational annex that was delivered to CSA Children's playgrounds and equipment standard (CAN/CSA Z614) for considerations for the next revision of the standard can be found in Appendix A.

3

Literature Review

In 2014, CSA Group published the fifth edition of CAN/CSA Z614, *Children's playspaces and equipment*, which *"addresses safety measures that help minimize exposure to serious injuries"* (CSA 2014). While the existing version of the standard includes several references to weather, considerations for designing play equipment and spaces for extreme heat and thermal comfort has not been systematically integrated into the standard or informational attachments. A literature review is presented below that addresses thermal comfort and playground microclimates, climate change and heat in a Canadian context, children's health and safety connected to thermal comfort, heat, and UV radiation and elucidates emerging trends in new techniques and considerations for heat adaptation in urban areas and children's playgrounds.

3.1 Climate

CLIMATE CHANGE & VARIABILITY OVERVIEW

Climate change, as defined by the Intergovernmental Panel on Climate Change (IPCC 2014), is the "state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". Climate changes can be attributed to two different factors. The first factor is natural variability in the climate system, which are influenced by both internal (e.g. ocean-atmosphere influences, such as the El Nino-Southern Oscillation) and external (e.g. sunspot or Milankovitch earth orbit cycles) factors. The second factor is the anthropogenic (human) influence, most notably, the increases in atmospheric concentrations of greenhouse gases (GHGs), such as carbon dioxide and methane, which result from the burning of fossil fuels. These gases hold heat (energy) within the Earth system; therefore, as we increase the concentrations of GHGs, more heat can be held within the earth's system. Over the long term (three or more decades) natural processes typically balance out GHG emissions. However, human sources of GHG emissions have dramatically increased over the past century, considerably raising the heat energy available for atmospheric processes (IPCC 2014). As a result, record warming and changes in precipitation are now commonplace: 2018 was found to be the fourth-warmest year in the modern record with global average temperatures 0.83°C warmer than the 1951–1980 mean according to data from NASA and NOAA (NASA 2019). According to (ECCC 2015), over the period 1948 to 2013, the average annual temperature in Canada has warmed by 1.6°C (relative to the 1961–1990 average), with the strongest warming in the north.

THE CANADIAN CLIMATE: PAST, PRESENT, AND FUTURE

The Canadian climate is characterized by diverse climate zones and climate variability, with more moderated marine climates along the coasts, to hotter and more humid environments surrounding the Great Lakes, and dry continental climates in the interior presenting wide temperature extremes. Each climate zone has its own distinct climate—that is, a distinct pattern of precipitation, temperature, wind, and humidity—thus resulting in important considerations when designing for outdoor and indoor thermal comfort. For example, cities in the Prairies and near the Great Lakes (e.g., Saskatoon, Winnipeg, Ottawa, Toronto) are most prone to heat wave events and have longer lasting heat waves when they do occur (Bellisario et al. 2001; Smoyer-Tomic et al. 2003).

An increasing body of literature details the historical increase in temperatures across the country and how they impact heat-related illness and death (e.g., Cheng et al. 2008; Seguin and Berry 2008; Martin et al. 2012). A recent study by Health Canada (Vanos and Cakmak, 2014) found increasing trends in moist tropical (i.e. warm and wet/humid) air mass types across most of the country (excluding the far western portions) at the expense of colder, drier "polar-type" air masses during the summertime. These findings are consistent with long-term trends in the United States (Knight et al. 2008; Vanos and Cakmak 2013) and with past studies in Canada, such as that by Vincent et al. (2007) who showed country-wide increases in air temperature with accompanying dewpoint, and specific humidity increases (increasing moisture). These findings also translate into more oppressive (hot and humid) heat waves.

Projected (future) changes in mean summertime temperatures across Canada are shown in Figure 2. These simulated climates are based on the RCP8.5 emissions pathway scenario. The RCP8.5 scenario represents an 8.5 Wm^{-2} increase in radiative forcing (or amount of energy absorbed per square meter of earth) by the year 2100 due to continued greenhouse gas release into the atmosphere, currently referred to as the "business as usual" pathway. Mean summertime temperatures are projected to increase across the entirety of Canada. July and August temperatures across the southern half of Canada, where over two-thirds of the Canadian population lives, are expected to be 5ºC warmer than they were at the turn of the 21st century. As average temperatures increase across the country, the frequency of extreme heat events is also expected to increase (Romero-Lankao et al. 2014).

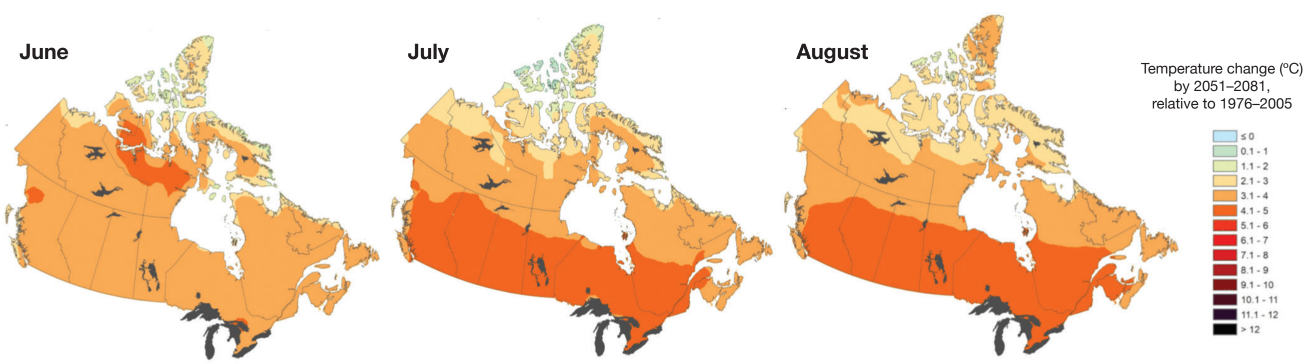


Figure 2.

Projected average summertime changes for the years 2051–2081 relative to 1976–2005 baseline. Maps show increasing mean summertime temperatures across the entirety of Canada based on the RCP8.5 emissions scenario. Downscaled data are from the Prairie Climate Centre (2017).

CLIMATE CHANGE, URBAN HEAT EXPOSURE, AND HUMAN HEALTH

As climate change is expected to exacerbate hot summertime conditions in the future, urban areas will experience exacerbated heat impacts due to the urban heat island (UHI) effect (Habeeb et al., 2015; Li & Bou-Zeid, 2013; Tan et al., 2010). As of 2017, 81% of Canadians lived in urban areas (with ~90% of the Ontario population urban), a trend which has increased dramatically over the last century (Statistics Canada 2017). Urbanization alters the landscape and hence the localized weather. This urbanization magnifies the UHI, which when combined with large-scale climate warming presents important impacts on social, economic, and health systems in cities both now and in the future (Grimmond et al. 2010). A depiction of the urban heat islands, with pockets of mini-heat islands and mini cool islands, is presented in Figure 3. As previously mentioned, recent studies have pinpointed *higher surface temperatures* within playgrounds (Moogk-Soulis 2010; Vanos et al. 2016)

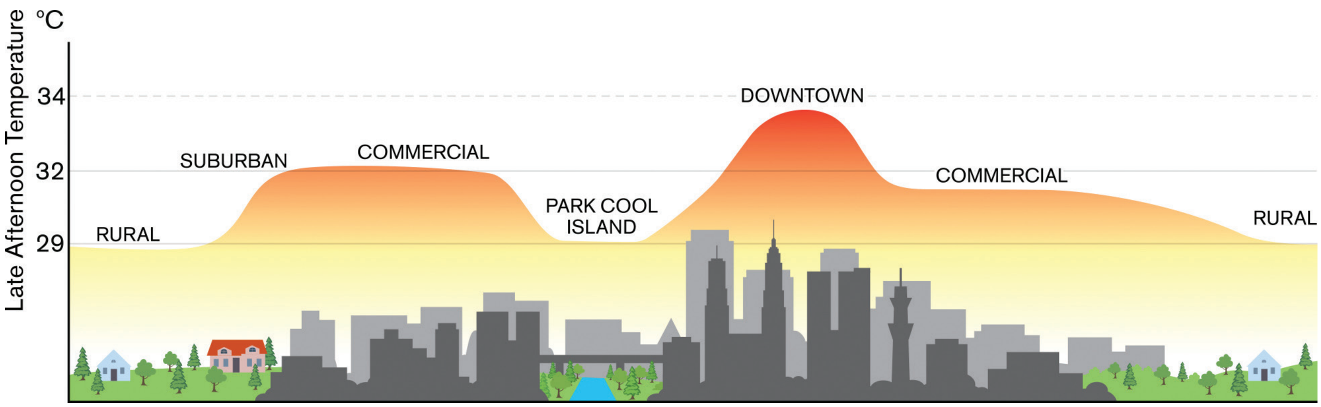


Figure 3.

Depiction of variability in air temperatures within an urban area due to design. Lowest temperatures are found within rural areas and in park cool islands within the city contain blue and green spaces; hottest areas exist in the more highlighted buildings in downtown, commercial, and suburban areas. Image created by Graphic Artist at the Julie Ann Wrigley Global Institute of Sustainability, Arizona State University.

A recent sweltering heat wave in early July 2018 in Québec was estimated to have killed 86 people (Lebel et al. 2019, Weather Network 2018), and extreme heat events combined with air pollution are estimated to have caused an average of 462 deaths per year in the City of Toronto and 1,082 in Montreal between 1954 and 2000 (Cheng et al. 2008). The epidemiological literature lacks adequate statistics on child heat-related mortality and morbidity in Canada, yet this topic has been investigated in other regions of the world. In a five-year period from 2006–2010, 261 children aged 14 or younger died in the United States due to various heat illnesses (Berko et al. 2014). Further, a systematic review by Xu et al. (2014) found inconsistent narratives concerning the significance of heat waves on child heat-related mortality (i.e., some narratives indicated increased risk, while others did not see such an increase) across different countries, but that heatwaves did exacerbate heat-related morbidity associated with renal and respiratory diseases in children.

In general, studies addressing child vulnerability point to a higher risk of morbidity rather than heat mortality (as in the elderly) in children due to their heat vulnerability (e.g., Kovats and Hajat 2008; Knowlton et al. 2009; Rhea et al. 2012). Further, the narrow age window for children (~0–14 years) as compared to the adult age group (18–65) makes it difficult to generate robust risk estimates for mortality, and thus is often combined with a <65 age group. A shifted focus and emphasis on heat health monitoring along the continuum from heat stress to heat strain and heat exhaustion (see Section 3) is needed to better understand those issues that may be affecting children that are currently being missed by traditional health surveillance records. Such data can address significant child heat concerns for public health agencies, emergency responders, and hospitals (Knowlton et al. 2009; Klinenberg 2015; Winquist et al. 2016), particularly with a rise in population.

As the fastest growing G7 country, the number of Canadian children (aged 0 to 14 years) continues to grow. After a slight decrease in growth pre-2008, the number reached 5.66 million in 2012. These numbers are expected to rise to between 5.9 and 11.1 million by 2061 depending on the growth scenario (Statistics Canada 2012), with much of this growth in urban and suburban areas. Thus, additional efforts to protect children in urban playgrounds can be highly valuable. Heat-Alert Response Systems (HARS) in Canada focus on increasing awareness of heat-related health impacts through health promotion and outreach and building the science/evidence base to support the HARS program (Davidge et al., 2018). There is a large focus on vulnerable populations, including children. New findings in the current report can advise on new HARS outreach initiatives to children and parents.

THE URBAN HEAT ISLAND

Characteristics of the built urban environment include low-albedo, impervious surfaces such as concrete and brick surfaces and buildings, asphalt, rubber or rubber-based surfaces, artificial turf, etc., which absorb high amounts of shortwave radiation that is emitted (or released) as longwave radiation from the surface (which will increase the heat felt by a human on the given surface). This process results in urban areas having on average higher air and surface temperatures than their rural counterparts, with up to +8°C possible overnight on calm and clear nights (Oke 1982). The summertime UHI effect exacerbates already strong heat waves (Habeeb et al., 2015; Li and Bou-Zeid, 2013; Tan et al., 2010) with many studies showing increasing long-term urban temperatures trends worldwide in large cities (Golden 2004; O'Neill and Ebi 2009), particularly overnight due to the processes outlined above (Mishra et al. 2015). Recent studies have pinpointed higher surface temperatures within playgrounds (Moogk-Soulis 2010; Vanos et al. 2016), which can also cause higher air temperatures and can be detrimental to play.

Most weather observations within cities are taken at airports that can be tens of kilometres outside of the city center and outside of areas characterised by UHIs, which is important to monitor global-scale climate change and to not bias data with urban influences. However, direct measurements within the urban areas (on buildings, within parks, etc.) can be taken through the use of micronets, a collection of weather stations within the urban center (Muller et al. 2013). These urban data collection centers can capture city- or neighborhood-scale heterogeneity in atmospheric variables at fine resolution. Hardin et al. (2017) used micronets in four northeastern U.S. cities to calculate the intensity of the UHI in different parts of each city. ECCC used a similar system (referred to as a mesonet rather than micronet) around the city of Toronto to collect data on meteorological and air quality-related variables to aid in forecasting and decision support during the 2015 Pan-American Games (Joe et al. 2018). Utilizing weather stations and meteorological sensors within parks and playgrounds is a novel way to understand finer-scale exposures during play for health protection, and there is future potential to incorporate "smart city" initiatives to improve our ability to link environmental indicators to health risks in parks and playgrounds (e.g., Morabito et al. 2015; Ramaswami et al. 2016).

HEAT ADAPTATION IN URBAN AREAS

The combination of climate change and the summertime UHI may inhibit child outdoor play due to 1) the threat of heat illness and/or 2) a lack of thermal comfort experienced by children. Past studies show a correlation between weather variables, specifically radiation exposures, and children's reported thermal comfort in playground settings (Vanos et al. 2017a). For children to maintain healthy lifestyles that include outdoor play in a warming world, adaptation measures must be taken. The main types of climate change adaptation related to heat include physiological adaptation (or acclimatization), behavioural, infrastructure, and technological adaptation (Table 1).

Table 1.

Climate adaptation types from the Intergovernmental Panel on Climate Change (IPCC 2014).

Adaptation Type	Relevant Examples
Physiological	Children acclimatization to warmer weather at the start of the heat season. This process can take up to 2–4 weeks.
Behavioural	Children learning to make appropriate clothing choices, learning about the feelings of heat stress, wearing a hat, taking water breaks.
Infrastructure	Incorporating increased shade (both natural and built) in playgrounds; focus on creating park cool islands to increase playability; using less heat retaining and heat conductive playground equipment
Technological	Air conditioning to cool off indoors; mister systems; heat-health warning systems; monitoring weather conditions within a playground (i.e., local microclimate conditions) for decision making by owners/ operators and users.

Advantageous landscape design for heat mitigation within the urban fabric has the ability to counteract the UHI at the neighborhood-scale, an urban form that includes the presence of urban parks (Brown 2011). The addition of green spaces to the urban landscape can significantly lower the temperature of the area it is situated in through shading and evaporative cooling (Bowler et al. 2010; Brown et al. 2015), though the impacts of different vegetation types and patterns on cooling can vary (Cao et al. 2010; Chen et al. 2014). Place-specific implementation of green and blue infrastructure can result in pockets of cool space within the urban environment, better known as park cool islands (PCI), as shown by Vanos et al. (2012) in Toronto, Canada. Conditions that favor PCI development by day (tree shade, evapotranspiration, soil wetness) may lower the strength of a PCI at night (Spronken-Smith and Oke 1999), yet given that playgrounds and parks are used by children in the day, this factor should not be a deterrent, and is also a benefit in the cold season. Overall, efforts to create PCIs also help to decrease the UHI effect, help moderate diurnal variability, and provide spaces more conducive to play throughout the year.

Critical modeling advancements have been made in the preceding decades regarding the development, sensitivity, and accuracy of urban climate models. At the same time, numerous research articles work to apply said models to predict the potential heat stress of various locations worldwide. Although complex, these models come with large uncertainties. The question then arises: How should climate uncertainties in air temperature be translated into thermal safety factors in playgrounds? One can address historical long-term trends to show that increasing temperature is directly related to a decrease in allowable play hours in some cities (based on heat thresholds set by school districts, for example). For instance, increasing temperatures have resulted in a loss of 10% of available daytime summer play hours in El Cajon, California, since 1999, based on the county's 92ºF limit for outdoor activity (San Diego Unified School District 2017). In Phoenix, a 6% loss in playtime is present since 1973 based on the 105ºF heat index threshold for play (MCPHD 2018). However, urban design can change air temperature by many degrees, and surface temperatures to an even greater extent. The magnitudes of such changes are dependent on the climate type, season, and designs. Such design is something that humans can directly control in cities, and thus should play a larger focus in urban parks and playgrounds to reduce temperatures for heat adaptation and climate change mitigation.

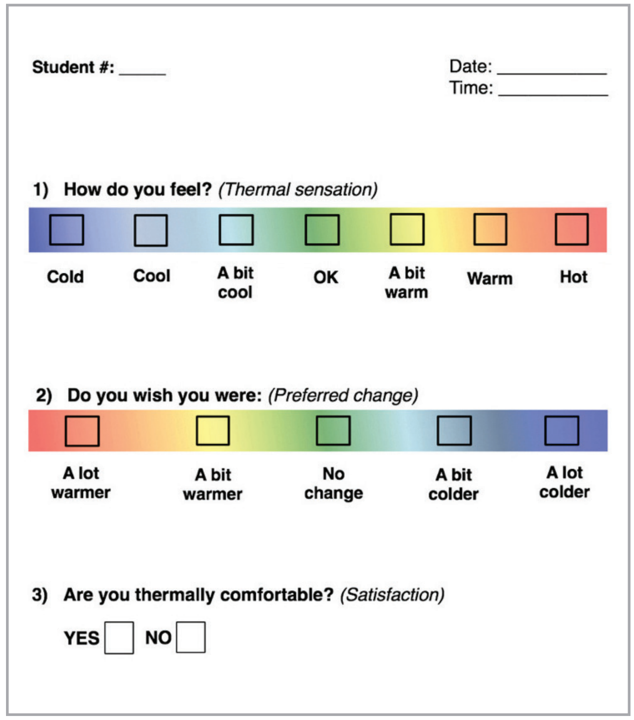
3.2 Human Thermal Comfort in Outdoor Environments & Play Spaces

The Canadian climate has historically been characterized by heat extreme that has lead to heat-health issues. However, with projected climate change, the issue of heat exposure is being exacerbated. The intensification and lengthening of heat events are compounded by fine-scale urban and anthropogenic heat which negatively affects summertime thermal comfort, and thus the usability of recreational spaces, in large Canadian cities.

DEFINING OUTDOOR THERMAL COMFORT

Thermal comfort, thermal sensation, and preferred change are important factors to consider when designing an outdoor space. Thermal comfort is merely the absence of discomfort, defined as "the condition of the mind that expresses satisfaction with the thermal environment" (Fanger 1970), and is separate from equations for heat and mass transfer and energy balances that are used in energy balance models (see below). The level of thermal comfort is often characterized using the ASHRAE thermal sensation scale.

The main environmental components influencing thermal comfort are atmospheric temperature, radiation, wind speed (ventilation) and humidity. Air temperature is important because it reflects the level of heat in the air resulting from sensible heat transfer (i.e. transfer of energy as heat without a phase change) mainly from the earth's surface into the lower layers of the atmosphere, although in urban environments sensible heat transfer from vertical surfaces is also important. The main behavioural components affecting thermal comfort are clothing and physical activity (metabolism). An example of an outdoor survey provided to children to assess their perception of each is shown in Figure 4 (Vanos et al. 2017a). Such a method can be used to properly provide subjective surveys of children's thermal perception in outdoor spaces to advance knowledge of child responses and satisfaction in space designed for their health and activity.


Student #: _____

Date: ___________
Time: ___________

1) How do you feel? *(Thermal sensation)*

Cold | Cool | A bit cool | OK | A bit warm | Warm | Hot

2) Do you wish you were: *(Preferred change)*

A lot warmer | A bit warmer | No change | A bit colder | A lot colder

3) Are you thermally comfortable? *(Satisfaction)*

YES ☐ NO ☐

Figure 4.

Example of a simple thermal comfort survey that can be administered to children. Questions are written to reflect actual thermal sensation (1), preferred change (2), and satisfaction with the environment (3). *Credit: Vanos et al. (2017a), adapted from Teli et al. (2012).*

QUANTIFYING THERMAL COMFORT & THERMAL SENSATION

Thermal sensation can be assessed in two ways: 1) through direct surveying of an individual in a given environment along a 7-point scale (e.g., 'hot' (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2), cold (-3)), and 2) through energy balance modeling of an individual to predict their thermal sensation. The energy balance model approach is displayed in Figure 5, whereby an energy budget of the energy 'fluxes' (often assessed as a Watt per meter squared of the body area, or W m^{-2}), can be created to assess the difference between heat gains to the body (e.g., metabolism, radiation) and normal losses (e.g., convection, evaporation) that draw energy away from the body. When at or near balance (i.e., budget ~0 W m^{-2}), an individual is expected to report a neutral thermal comfort. However, this is not always the case due to psychological factors (Nikolopoulou and Steemers 2003). A high gain of energy as compared to losses (e.g., budget > 100 W m-2) will result in thermal discomfort on the warm-hot end of the scale and may slowly lead to a rise in core body temperature if either the environment and/or the activity is not changed.

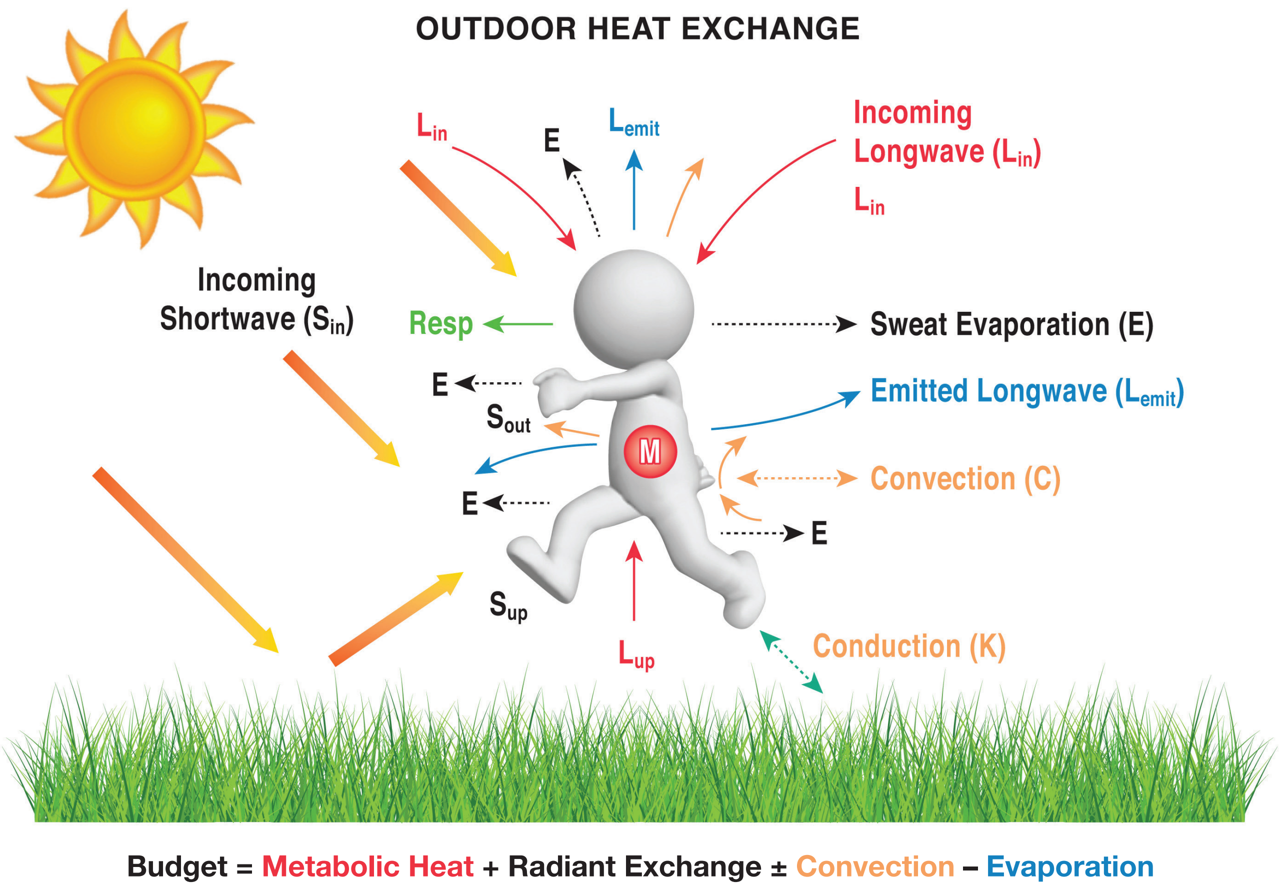


Figure 5.

Outdoor heat exchange between the environment and the human body. The gains of heat to the body that influence thermal comfort are: metabolic heat generation (M), shortwave radiation (S) from the sky and ground, and longwave radiation (L) from the sky and ground. The main losses of heat that influence thermal comfort are: convection (C), and evaporation (E). Clothing insulation will affect evaporation and convection.
Credit: McGregor and Vanos (2018).

Original thermal comfort models to predict an individual's perceived thermal comfort were created and calibrated for a standard male in indoor environments, which drastically simplifies the approach and decreases applicability. Hence, there is little certainty that the models can confidently be applied to children (Teli et al. 2012). The assessment of thermal comfort in classrooms has been studied since the 1930s (e.g. Partridge and MacLean 1935; Humphreys 1972; Auliciems 1973; Nicol et al. 2012). Only recently have studies been completed assessing children's outdoor thermal comfort during activity (Yun et al. 2014; Vanos et al. 2017a).

Moreover, during exercise, metabolism and sweating (for evaporative heat loss) increase. These large differences by person (activity, age, gender) and microclimate are not present in indoor environments, and therefore it is not appropriate to apply sedentary based indoor thermal comfort models to the outdoor environment during physical activity. Research also shows that children perceive thermal environments differently than adults (Mors et al. 2011).

CHILDREN'S THERMAL COMFORT IN OUTDOOR ENVIRONMENTS

Young children (less than ~5 years of age) are widely regarded as having inferior thermoregulation to that of adults during activity in warm environments (Bar-Or 1980). They have a higher body surface area to mass ratio, higher heat production per unit body mass (Fabbri 2013), and have been shown to have a quicker rise in core temperature (Falk and Dotan 2011). They are also less efficient at cooling through evaporation due to less sweat production (Gomes et al. 2013). However, very few studies exist and there is much to be learned about how heat affects the health of children across various age groups, genders, and fitness levels. There is also a paucity of health outcome and epidemiological data that associates these ambient risk factors with injury rates in children (Falk and Dotan 2008), with the most widely used predictive models currently being calibrated for **physiological** and **psychological** attributes of adults.

In general, attempting to accurately predict the perceived thermal comfort and sun safety of a child in a playground differs from adults due to the following physiological and psychological factors:

- Higher metabolic rate (Fabbri 2013)
- Higher surface-area-to-body-mass ratio (Falk and Dotan 2008)
- Lower sweat production (Gomes et al. 2013).
- Core of body is closer to hot surfaces (as shown by red colours in Figure A.4)
- Less experience coping with or knowing the signs of heat stress
- Lower reaction time to remove hand or foot from a hot surface
- Lack of knowledge for sunscreen use
- May not have access to water

Moreover, outdoor spaces microenvironments and metabolic heat load results in high complexity in modeling or measuring thermal comfort. For example, Figure 6 depicts two distinct environments within one playground. In location A, artificial turf is directly exposed to the sun and reaches temperatures of 67°C, while in the shade of a large Chinese Elm tree, the surface temperatures on the concrete and sand are near or at air temperature (~24°C). In the given playspace, the average solar radiation experienced by the children at point A was ~825 W m^{-2} in the sun, yet in the shade at point B, the solar intensity deceased to ~165 W m^{-2} given a 20% solar transmissivity. The amount of longwave radiation emitted from the hotter surface (sun) was ~740 W m^{-2} versus only 420 W m^{-2} in the shade, representing a significant difference to the energy balance of a child. **When combining these differences in air temperature with solar and longwave radiation to determine thermal comfort, it is easy to see why children will gravitate towards shaded areas on hot and clear days.**

Figure 6.

Example of a playground with two distinct environments affecting thermal comfort shown in visible (left) and infrared (right) spectrums. A) Sun-exposed artificial turf, which increases the overall long and shortwave radiation felt by a child; B) Shaded sandbox under large tree, which decreases the short and longwave radiation and lowers average air temperature.

3.3 Children's Safety Considerations in Playgrounds

Safety within the playground is paramount for children's health. Playground injury research has led to the development of equipment-related standards, such as by the CSA and ASTM (e.g. material type, structural integrity, performance requirements). These standards focus largely on the prevention of injuries, including single incidence events such as falls, entrapments, contusions and abrasions, and traumatic brain injuries (CPSC 2010; ASTM 2017). Many of these standards for improving playground safety (e.g. impact attenuation) have resulted in new contemporary designs of playgrounds (Lewis et al. 1993). These designs have increasing utilized artificial surfacing (e.g., rubber) to provide cushioning for falls and to provide accessibility. However, the environmental quality specifically focused on thermal comfort, air quality, or radiation exposure have a lower priority, or are not present in these standards, yet such concerns are closely associated and can lead to dangerous and unsafe situations.

THERMAL BURNS

Recent research has shown contemporary playground materials, along with peak sun and temperature periods (e.g. 10 am–2 pm), can expose children to unsafe surface temperatures (slides, surfacing) (Figure 7). These surface temperatures can also result in higher air temperatures, as shown by Hyndman (2017) in Australia. Playground surfaces that are not protected from solar gain and retain large amounts of heat in the warm season can reach dangerously high temperatures that can burn a child's skin in three seconds (Vanos et al. 2016).

The US CPSC tracked and reported thermal burns in several projects with data reported from 2001-2008 (O'Brien 2009), and the US CPSC maintains a thermal burn fact sheet for playgrounds on its website (CPSC 2012). Additional studies and data suggest that the introduction of new materials and artificial surfaces may contribute to the likelihood of thermal injury (Ford 2011; Vanos et al. 2016). Thermal burn statistics in Canada are unavailable. In the warm season, when these surfaces are exposed to sun for a long period of time (>30min), they will heat up and can reach dangerously high temperatures that burn a child's skin in as little as three seconds on solid metal surfaces; for plastics or non-metallic coatings that are more insulating, higher threshold temperatures are set (e.g., ≥ 77 °C for plastic see Table 2) (ISO 13732 2010). Exposed playground slides, rubber, and artificial turf are the leading culprits of burns (Sinha et al. 2006; Mitchell et al. 2009; Ford et al. 2011; Asquith et al. 2015; Hanway 2016), with underreporting likely (Ramirez et al. 2004). Further research and field data collection are needed to ascertain the direct benefit of these surfaces on playground injuries, to understand if these surfaces are used correctly in practice (e.g., orientation to sun, proper cushioning in the long-term), their lifetime and maintenance needs, as well as testing of their performance in outdoor conditions under a range of environments. Playground owners, operators, and managers should stay aware of these interactive concerns to promote safe and effective play and consider signage if necessary.

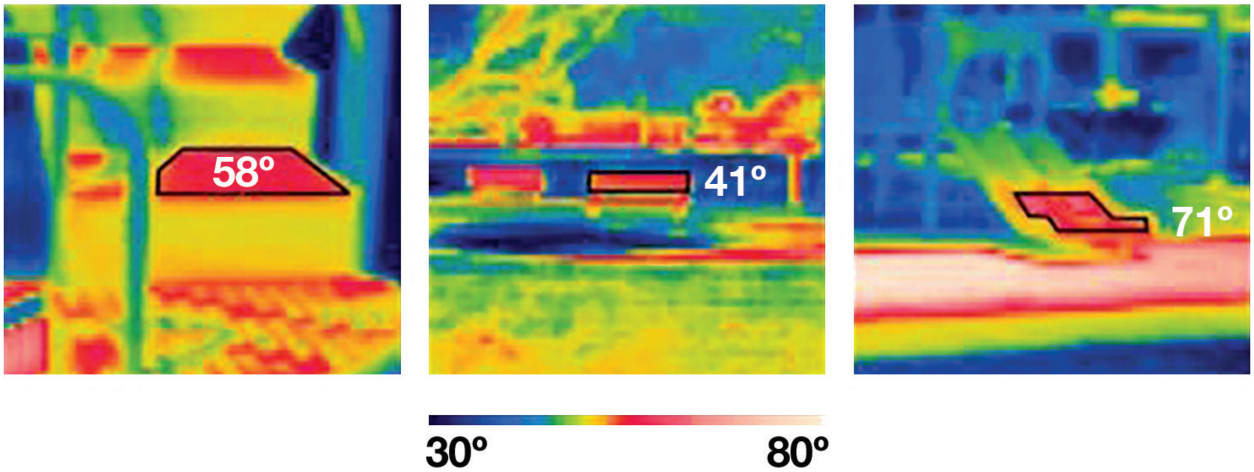


Figure 7.

Thermal infrared images of playgrounds in Phoenix, AZ collected by Vanos et al. (2016), reproduced with permission. Refer to table below for ranges of thermal burn to the skin from there temperatures.
Credit: Vanos et al. 2016.

Table 2.

Burn thresholds when skin is in contact for short periods of time (3 sec, 5 sec, 60 sec) with hot surfaces made of materials commonly found within playgrounds. Thresholds of materials with similar heat conductivity are combined to represent one value (Source: ISO 13732, 2010).

		Burn Threshold (°C) & Skin Contact Time		
Material	**Material Characteristics**	**3 sec**	**5 sec**	**60 sec**
Metal	Uncoated	60°C	57°C	51°C
Coated Metal[1]	Lacquer Coat: 100µm thick	68°C	61°C	51°C
	Powder: 90µm thick	65°C	60°C	51°C
	Enamel: 160µm	63°C	59°C	51°C
	Polyamid 11 or 12: 400µm	77°C	70°C	51°C
Stone Material	Concrete, granite, asphalt	73°C	60°C	56°C
Plastic[2]	Polyamide, acrylglass, polytetrafluorethylene, duroplastic	77°C	74°C	60°C
Wood	Bare, low moisture	99°C	93°C	60°C

1 Polyurethane enamel-coated steel is used predominantly in the study playgrounds for hold/touch surfaces, and powder coated steel for walking surfaces.

2 UV stabilized high-density polyethylene (HDPE) used in playgrounds is similar in material properties to polyamide.

HEAT ILLNESS AND CHILDREN

Not only do these surfaces pose a risk for burns, but the hotter surfaces also emit high amounts of heat towards children (e.g. as demonstrated in Figures A.4 and A.5), thus increasing the potential for heat illness during warm and hot weather, with heightened vulnerabilities as compared to adults listed in Section 3.2 above. While most thermal energy resulting in heat stress transfers from the surrounding environment, excessive physical activity in warm-to-hot environments can produce what is known as exertional heat stress or illness (Armstrong et al. 2007) through the added heat produced by metabolic activity. Given that play spaces are designed for physical activity, considering metabolism in thermal comfort assessments is important. When the body core temperature begins to rise, a range of heat illnesses may arise, which, in increasing order of severity, are heat rash, heat oedema, heat syncope, heat cramps, heat exhaustion and life-threatening heatstroke (McGregor and Vanos 2018). A full list of symptoms is provided in Table 3.

Table 3.

Heat symptoms and symptom management for children.

Heat Illness Symptoms
Confusion Dark-coloured urine Dizziness Fainting Headache Muscle or abdominal cramps Nausea, vomiting, or diarrhea Rapid heart rate Pale skin Profuse sweating Dehydration
Impacts on Well-being
Missing class time or being sent home Missing recess Low performance in class Poor Behaviour Poor Mood
Related: Sun & Thermal
Sunburns to skin Thermal burns (1st, 2nd, 3rd) Heat Rash

Factors connected to heat illness are important to consider (e.g., asthma, obesity), as well as impacts to well-being and learning, and connected to sun (below) and thermal safety (above). Children have minimal experience of the signs of heat illness, which creates underdeveloped psychological and behavioural adaptations (Humphreys 1977; Mors et al. 2011; Teli et al. 2015), and thus rely heavily on parents and care takers to provide protection and notice signs of heat illness, sun burn, or overexertion. A recent survey completed in five cities (Regina, Fredericton, Winnipeg, Windsor, Sarnia) by Alberini et al. (2011) showed that respondents tended to be more proactive during heat waves when they had a child or elderly person they take care of than for themselves.

SUN SAFETY

One in every three cancers diagnosed in Canada and worldwide is a skin cancer, 80–90% of which are caused by ultraviolet (UV) radiation, and rates in Canada and the United States are on the rise (Canadian Cancer Society 2017). The incidence of melanoma in those < 20 years of age increased 2.9% annually between 1973 and 2001 in the U.S. (Strouse et al. 2005). Preventing over-exposure to UV radiation and extreme heat, while ensuring that there are safe outdoor spaces for adequate play, are vital to promoting children's long-term health and reducing risk (USDHHS 2014). Children are identified as a vulnerable population to sun exposure (Balk 2011), and adult skin cancers are often traced back to childhood sun exposures, particularly severe burns (Dennis et al. 2008; American Cancer Society 2013). For example, it is estimated that children who get five or more sunburns double their chances of melanoma later in life (Canadian Cancer Society 2017). Children have heightened sensitivity and vulnerability to sunburns arising from less adaptive behaviour (e.g., knowledge and sunscreen use), high intermittent exposures, and more sensitive skin (Oliveria et al., 2006).

It is well-known that exposures to UV radiation and temperature vary significantly by activity type and person (Glanz et al., 2007; Kuras et al., 2017; Weihs et al., 2013). A study from San Diego, California used UV dosimeters on children's wrists, as well as heart rate monitors and GPS devices, to show that on hot days (~27–33°C), children gain more physical activity in the sun (metabolic activity +30 Wm^{-2}), yet spend less than 10% of their time in the sun. Hence, minimal shade in hot cities may decrease children's overall physical activity, while more shade may increase physical activity as well as protect children from hot surfaces and UV radiation (Vanos et al., 2018) which align with the presence of shade increases children's activity levels (Boldemann et al., 2011; Colabianchi et al., 2011). Indeed, the 2014 U.S. Surgeon General's Call to Action to Prevent Skin Cancer (USDHHS 2014) recommends that communities provide shade in recreational areas to protect children from over-exposure to UV radiation. Yet there are no UV-based playground design guidelines (e.g., low-albedo surfaces, shade provision) to limit UV radiation, and few studies (e.g., Downs and Parisi 2009; Boldemann et al. 2011; Vanos et al. (2017b) have been completed to improve exposure estimates.

Finally, it is well-known that solar UVR is the predominant source of Vitamin D formation in humans, which aids in bone health, it also causes genetic mutations in DNA which are precursors for various skin cancers mentioned above. Narbutt et al. (2018) studied the effects of prolonged child solar radiation exposure on each, finding that the amount of harmful DNA mutation far outpaced Vitamin D formation. However, other researchers note that benefits of reasonable amounts of sun exposure must not be ignored when considering a person's overall health profile (Geller et al. 2018). Future work is needed in this area to determine the optimal exposure level to sunlight across the lifespan.

AIR POLLUTION CONSIDERATIONS

There is a need to address the potential negative implications of playground surfaces on children's health (e.g., off-gassing or volatile organic chemicals (VOCs); temperature, and irradiance) to promote optimal utilization and safety. Briefly, many synthetic surfaces are made of crumb rubber from recycled tires (RMA 2006). Within playgrounds, poured-in-place rubber, loose-fill, tiles, bonded rubber, and synthetic turf surfaces contain recycled tire materials. These surfaces off-gas VOCs into a respirable form (Sanner 2006). Limited work has characterized VOC analytes off-gassing from rubber on synthetic turf fields (EPA 2009, 2016; Li et al. 2010; Peterson et al. 2018).

Levels of traffic-related pollutants are elevated within approximately 100–500 meters of major roadways (Health Effects Institute 2010), and thus ensuring that playgrounds and schools are not adjacent to busy roadways is important for children's health. Children have an increased breathing rate relative to body size and under-developed respiratory tract, and thus experience the negative impacts of air pollution at lower concentrations (e.g., onset of inflammation and immune stimulants), in combination with high temperature effects. While not directly related to thermal comfort, discomfort can arise from difficulty breathing, and pollution impacts may be heightened with higher air temperatures (Karl et al. 2009).

3.4 Best Practices in the Design of Thermally Comfortable Playgrounds

The prevailing climate of an area interacts with objects in the landscape to create microclimates (Brown and Gillespie, 1995). Landscape architects and designers determine the locations and types of objects within a landscape, which can then in turn strongly influence the microclimate. This section discusses the factors that are involved in understanding the biophysical environment of outdoor playgrounds as connected to site planning and design, bioclimatic design, and the influence of trees. Considerations of "bioclimatic design" (i.e., designing outdoor spaces and buildings based on the local climatology), specific to children's play, can help to provide safe, thermally comfortable, functional, accessible, and healthy spaces is of paramount importance in maintaining health and well-being (Fjørtoft 2004; Wolch et al. 2011; Ciucci et al. 2013).

PASSIVE INFRASTRUCTURE: BIOCLIMATIC DESIGN FOR THERMAL COMFORT IN PLAYGROUNDS

Passive cooling or passing heating are key elements to moderate the microclimate of a small area without using any mechanical or electrical energy, merely through natural design.

Warm Season

Passive cooling utilizes natural forces, such as cool breeze and added ventilation, shade and cool nighttime air, and vegetation to provide cooling through evapotranspiration, and alternative surface types that do no retain heat and warm the surrounding environment. Numerous passive cooling techniques have been designed and studied with respect to many urban outdoor spaces and thermal comfort (e.g., Shashua-Bar et al. 2011; Brown et al. 2015; Lenzholzer 2015). The most well-known and impactful technique is solar shading by structures and trees, and the second ensuring air flow, both of which correlate to air temperature through surface heating and air mixing, respectively. Thus, techniques used in playgrounds to reduce sun exposure and improve wind flow during days of high heat are the most important solutions to improve thermal comfort. Intense solar radiation without any air flow is often a recipe for extreme discomfort on already hot days.

Micro-design features that can create cooler microclimates include shade cover (treed and artificial), misters (evaporative cooling), natural surfaces, trees, shrubs, human-made shade, and other vegetation (Chow et al. 2011; Vanos et al. 2012). Improved air quality can also arise from such features, particularly with the use of vegetation or vertical facades that absorb and/or block air pollution (Nowak and Greenfield 2012; Abhijith et al. 2017; Abhijith and Kumar 2019).

Micro-scale air temperatures can also be reduced by using nature-based surfaces (e.g., woodchips), ‘cool’ coatings, and vegetation for cooling, yet thermal comfort is less sensitive to changes in air temperature as compared to wind flow and radiation. Factors to consider, include: the orientation of shade to reduce sun exposure, the placement of playgrounds on the north side of a building to take advantage of already-existing building and overhang shade, and appropriate orientation of shade sails or trees to reduce south sun.

All provided examples are individual approaches to improve and evaluate outdoor microclimates, with some having multiple co-benefits to health, energy, or precipitation events by season (see Appendix A). However, there has been little research evaluating multiple strategies simultaneously and the impact on the microclimate, playability, and children’s health using multiple passive cooling systems.

Although shade protection and reduction of radiant exposures are essential factors to truly maximize user thermal comfort and experience through passive design, they also have the co-benefits of reducing sunburn, thermal burn, and heat illness risks while improving playability. Common playground surfaces have varying solar and UVR albedos that impact overall cumulative sun exposures. For example, grass results in average respective albedos of 0.24 and 0.03 in the sun, while concrete presents albedos of ~0.34 and 0.15, respectively (Castro et al. 2001; Vanos et al. 2017b).

Dobbinson et al. (2014) demonstrated that in a sunny, warm climate, shade sails increased secondary school students’ use of the newly shaded areas and thus decreased sun exposure. Furthermore, introducing shade sails in passive recreational areas such as playgrounds is found to increase the use of these areas in Melbourne and Denver (Buller et al., 2017); however, this finding was based more on adult use of the shaded areas (which is also important to support children’s attendance at a playground).

A study by Parsons et al. (1998) demonstrated that effective UV protection is obtained mostly in shade that eliminates both direct exposures from the sky those reflected from vertical and horizontal surfaces, thus factoring lower sun angles into designs is important. Such findings underline the differences in sun protection provided by trees within playgrounds and that small leafed trees with compact canopies will do little to protect children from the sun as compared to thickly vegetated/wooded areas with low, wide overhang (Downs and Parisi 2008).

Cold Season

There are two important microclimate considerations in the cold season that can be partially controlled through design: radiation and wind. However, the goal is opposite from that of the summer. In winter, we hope to reduce winds and increase radiation to create a more comfortable outdoor space for play. Table A.4 provides examples of design strategies for such benefit (e.g., use of deciduous trees to allow shade in summer and sun in winter). Although play also occurs in winter, the vast majority of play occurs within the summertime across Canada, hence why there is an extra focus in the current literature review on ensuring summertime safety from heat and radiation for thermal comfort and health.

SITE PLANNING & DESIGN CONSIDERATIONS FOR NEW AND CURRENT PLAYGROUNDS

It is vital to make a distinction between playgrounds that already exist, and then may be retrofitted to attempt to improve thermal comfort, versus new playgrounds that may be built and thus can consider these additions from the beginning of design. When spaces are already designed (e.g., a certain surface is already in use), some modifications may be very difficult to employ. Thus, providing effective and realistic thermal comfort solutions depending on whether a space will be retrofitted or brand new is important.

As Brown and Gillespie (1995) note, it is near impossible to modify large-scale, ambient air temperature and humidity to any significant degree in microclimate design (yet wind and radiation modifications are much easier and make a large impact on thermal comfort). Thus, site design decisions can be made to affect airflow through and radiation retention, or lack thereof, within the space, which in turn can have an effect on the radiant temperature experienced by a body (which is helpful for thermal comfort in winter but causes discomfort in the warm summertime) and the amount of convection and evaporation experienced by the body (enhanced convection and evaporation in winter cause discomfort, but aid thermal comfort in the summer). Please refer to Table A.4 for further examples.

Below are some methods for playground design to improve the thermal comfort of users in the summertime:

- **Incorporation of green space (e.g., vegetation or green infrastructure) –** The addition of green space around the perimeter of the playground has a number of beneficial effects on the microclimate of the overall site. Grasses, shrubs, and trees generally have higher albedos than other ground types typically found in playgrounds such as sand, concrete, or asphalt, allowing more shortwave radiation to be reflected away from the area. In addition, the moisture within these plant systems can be evapotranspired, leading to additional cooling of the air.
- **Wide tree canopies provide shade coverage over playgrounds, another way to reduce the radiative burden on these sites.** Decisions on tree type can be made by site designers to fit the preferences of playground use in the community throughout the year as coniferous trees have canopies that provide shade throughout the year while deciduous trees only do so during the summer. In addition, winter/summer decisions for tree use can be made with respect to placing trees as a barrier to predominant cold season winds (e.g., N/NW) to reduce wind child and as a way to retain as much heat as possible within the play area.
- **Orientation of radiation-retentive surfaces –** As discussed in Section 3.3, playground equipment under sun exposure throughout the day can reach temperatures that can cause burns to the skin of children within seconds of continuous contact. Proper placement and orientation of these surfaces (such as plastic, rubber, metal), which absorb shortwave radiation in large quantities, retain it, and have a higher conductivity to skin, is an easy and cheap way to decrease their daily accumulated radiative load. Pointing surfaces such as slides or jungle gyms towards the north where they will receive less direct solar radiation due to the geometric relationship between the sun's position in the sky and the earth will allow for increased shading as well as a lower amount of surface area in the direct path of sunlight. Along these same lines, putting equipment on the north side of a building can also increase shading.

There are a number of tools available to assist designers with creating thermally comfortable playgrounds. ENVI-Met (Bruse & Fleer, 1998) is a numerical microclimate model that allows one to quantify the impact of various factors on interactions between vegetation, built environment, and the surrounding air. A number of past studies have investigated how the use of increased urban vegetation as well as introduction of cool surfaces would affect area-wide air temperatures as well as radiant temperatures (Égerházi et al. 2013; Tsoka et al. 2018).

Survey Results & Analysis

4.

Following the literature review, NPPS developed a survey to capture the views and opinions of topical experts on issues relevant to thermal comfort in children's playgrounds: environmental factors influencing children's play, priorities for playground design, environmental factors relevant to thermal comfort, and playground design component, features, and elements that support thermally comfortable design. The following section summarizes responses received, including direct quotes from open-ended questions, and also details the analysis of the results.

4.1 Professional Experience Categories of Respondents who Completed Survey

In collaboration with the CSA Thermal Comfort Task Force, the Standards Council of Canada, the Innovation Bureau at Health Canada, and the National Program for Playground Safety, a list of topical experts were identified to complete a thermal comfort and playground survey. Table 4 provides a summary of the topical expert backgrounds, survey response rate, and those with professional experienced in Canadian climate context. The survey was launched and available from March 4th – March 26th, 2019.

Table 4.

Topical expert summary, response rate by background.

	Survey Invitation	Survey Responses (% Response Rate)	Canadian Context (% of Respondents)
Climate / Environmental Scientist	18	11 (61.1%)	9 (81.8%)
Landscape Architect, Urban Planning, Independent Designer	21	14 (66.7%)	14 (100%)
Manufacturer, Installation, Supplier	14	11 (78.6%)	11 (100%)
Child Health & Wellbeing	12	7 (58.3%)	6 (85.7%)
Educator, Consultant, Risk Management	15	12 (80%)	10 (83.3%)
Total	**80**	**55 (68.8%)**	**50 (90.9%)**

Survey invitations and survey responses were evenly distributed between the five areas for professional background/ expertise. Specifically, the project team invited topical experts from the following areas 1) climate / environment scientists, 2) landscape architect, urban planning, and independent designer, 3) manufacturer, installation, supplier, 4) child health & well-being, and 5) educator, consultant, and risk management. The response rate was a robust 69% overall and strong in all categories. Overall, 50 of the 55 respondents (90.9%) reported professional experience within the Canadian climate, which provides meaningful context for their responses.

4.2 Priorities for Playground Design

Figure 8 illustrates respondents' perceptions on what ***has been a priority*** within playground design. While it is notable that there were no playground design issues rated as receiving ***high-priority*** attention, the expert respondents shared the safety and structural integrity of equipment and maintenance ***have been a priority*** in playground design. However, for child thermal comfort within playgrounds, the **availability of play water features, and availability of drinking water fountains have received less priority** in playground design.

What has been prioritized within playgrounds?

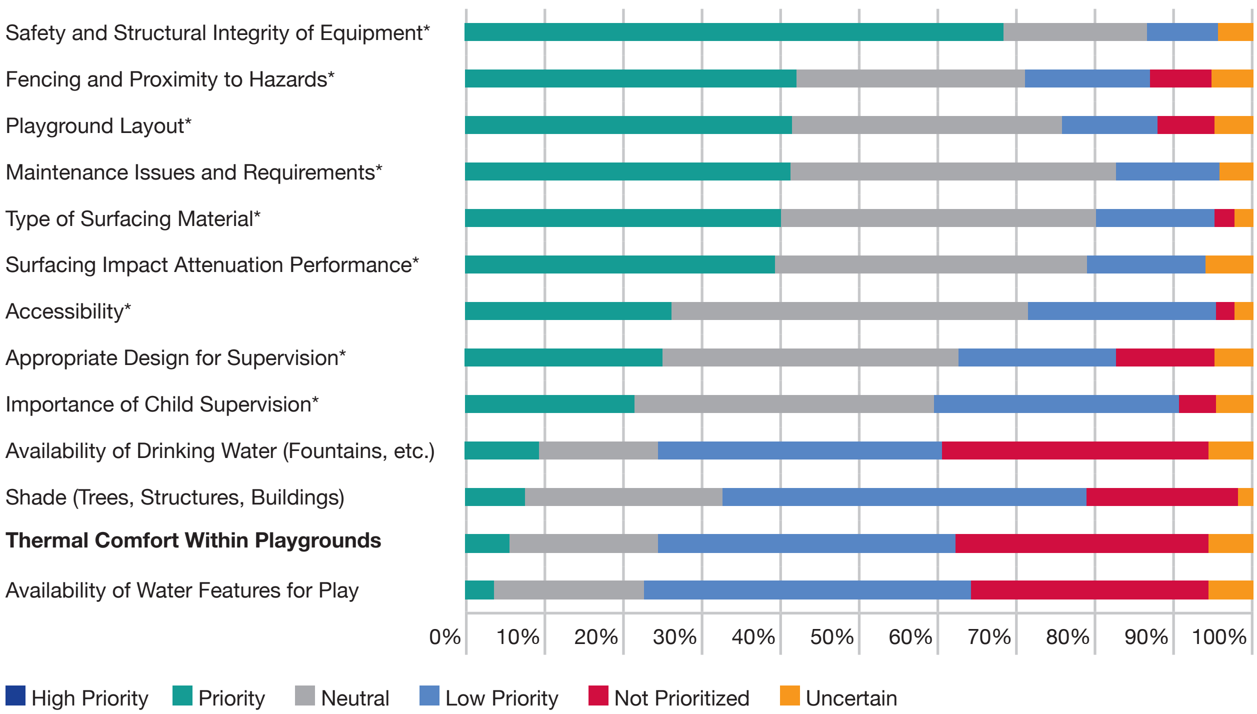


Figure 8.

Perceptions of past prioritization of a variety of playground design issues. Issues that are addressed by CAN/CSA Z614 are indicated with an asterisk (*).

Aspirational priorities for two related thermal comfort features (water and shade) were compared to past priorities in playground design, showing notably higher aspirations for priority of these issues in future playground designs. The availability of water features for play, drinking water, and shade all influence child comfort during play, particularly in hot summertime conditions (which often coincide with peak playground usage).

4.3 Availability of Water Features for Play

Water features can increase the playability during hot summertime conditions by lowering air and body temperatures and thus improving comfort level of playground users. Figure 9 highlights that the majority of respondents (72%) acknowledged that the availability of water features for play has been given either ***low priority*** or ***not prioritized*** during the playground design process. Only 4% of expert respondents indicated that the availability of water features for play has been given some priority in playground design.

Eighteen percent (18%) of survey experts indicated that play water features should receive design priority (Figure 9). Respondents suggested additional consideration be devoted to these water features where applicable, although their seasonal window of usefulness is more limited than other intentional design issues.

Availability of Water Features for Play

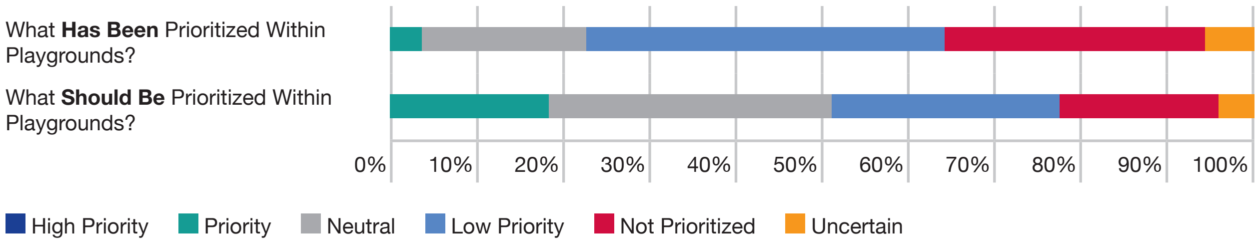


Figure 9.

Perceptions of the historical (*has been*) vs. aspirational (*should be*) prioritization for play-oriented water features within playgrounds.

When asked about the availability of drinking water at playgrounds, the majority of respondents (70%) indicated that the availability of drinking water has been given either ***low priority*** or ***not prioritized*** during playground design, while 9% of expert respondents indicated that the availability of drinking water has been given some ***priority*** in playground design (Figure 10). A larger percentage of respondents believe that drinking water availability should be given a ***priority*** in future playground design (29%) when compared to water features for play (18%).

Availability of Drinking Water (Fountains, etc.)

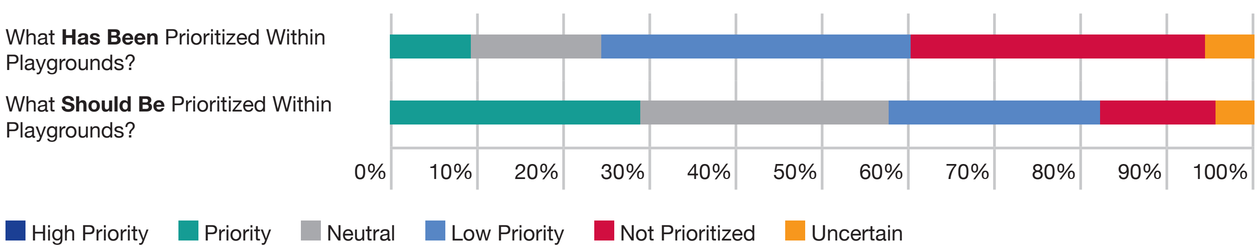


Figure 10.

Perceptions of the past (*has been*) vs. aspirational (*should be*) prioritization for the availability of drinking water at playgrounds.

4.4 Availability of Shade at Playgrounds

Compared to water features, the prioritization of the availability of shade at playgrounds demonstrated the greatest disparity between past and aspirational design practices (Figure 11). Only 8% of respondents indicated that considerations of shade had received ***priority*** in past playground designs. A further 65% indicated that shade had received ***low priority*** or ***no priority*** in past playground designs. In contrast, 73% of respondents indicated that shade should be given a ***priority*** in **future playground design**.

Shade (Trees, Structures, Buildings)

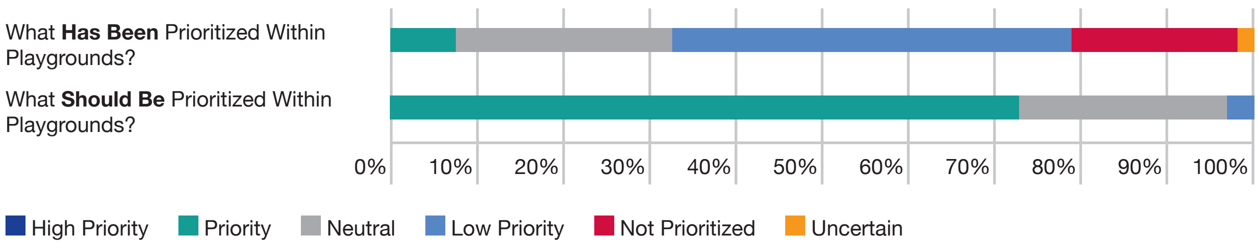


Figure 11.

Perceptions of the past (*has been*) vs. aspirational (*should be*) prioritization for the availability of shade (natural or manufactured) at playgrounds.

Experts were asked to provide suggestions for how to design for thermally comfortable playgrounds. Shade and/or water features were included within the content of **every** open-ended response. All respondents who choose to answer the open-ended question agreed shade and water aid in mitigation of extreme temperatures. A number of experts gave examples of different types of shade (e.g. shade sails, natural, fabric structures, canopy, buildings, photovoltaic structures, and awnings) and water features (e.g. splash pads, water play areas, and misting posts).

Open-ended comments from the expert respondents:

"In order to create effective shade (through a health equity lens), shade audits of these spaces must take place."

Child Health & Wellbeing

"Utilization of materials with low solar reflectance, Location of hardscapes, Utilization of natural shade (shade is great with [Landscape Architects] that know what they are doing for municipal projects but is an afterthought for schools, daycares, resorts and other privately owned playspaces. Different customer types have different levels of knowledge regarding thermal comfort ranging from a lot to none at all."

Manufacturer, Installation, Supplier

"We don't need shade everywhere, but we should invest in shade where activity happens. Agencies responsible for playspaces should reimagine their properties distribution of shade on their property to prioritize places where children play."

Landscape Architect, Urban Planning, Independent Designer

The limited attention to the topic of thermal comfort on playgrounds was highlighted by the expert respondents. Seventy percent (70%) of the expert respondents indicated that thermal comfort had been given either ***low priority*** or ***not prioritized*** during playground design. Only 6% stated that thermal comfort has received design ***priorities*** for playgrounds (Figure 12). When asked about aspirations for future playground design practices, 49% of respondents indicated that intentional design to thermal comfort within playgrounds should be ***prioritized***, while 21% of respondents indicated that thermal comfort should receive ***low priority*** or ***not be prioritized***. These expert sentiments indicate that the development of more educational awareness around thermal comfort and the potential inclusion in playground standards and guidelines could help thermal comfort receive higher priority in the design process.

Thermal Comfort Within Playgrounds

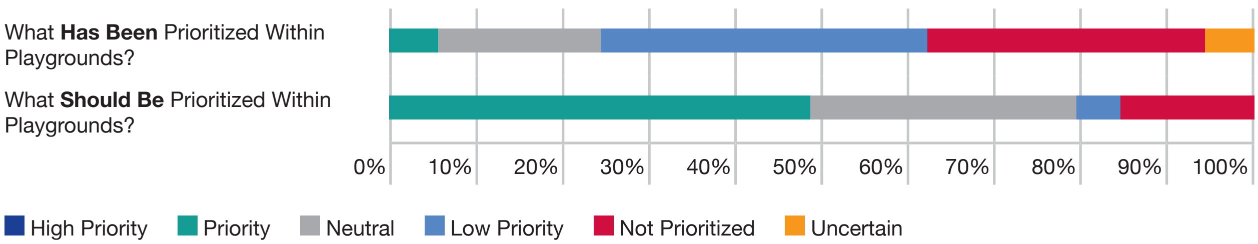


Figure 12.

Perceptions of the past (*has been*) vs. aspirational (*should be*) prioritization of intentional design efforts to affect thermal comfort within playgrounds.

4.5 Environmental Factors and Children's Play

Topical experts were surveyed and asked whether specific environmental factors support or hinder children's play, with 79% of the experts ranking environmental factors as "extremely important" or "important". Furthermore, 91% of the experts stated that environmental factors have not received as much priority as other playground safety factors (e.g. materials, structural integrity, inspection, and maintenance) that are presented throughout CSA Z614.

Experts were asked to provide open-ended suggestions or comments on whether or not they believe environmental factors influence children's play at playgrounds. They were also asked if environmental factors could or should be included in standards and/or guidelines.

Survey open-ended responses gathered from experts included:

> **"I'd recommend not being overly prescriptive, but setting out the broad *considerations* and tradeoffs and high-level *descriptions of best practices* … and *relevant to* those people using it in *different regions across Canada*."**
>
> Climate/ Environmental Scientist
>
> **"*Construct an annex* [to existing playground standards] with soft language (not mandatory) about what can be done to accommodate more comfort (thermal comfort, longer retention) in playspaces by providing a more comfortable environment."**
>
> Educator, Consultant, Risk Management

The inclusion of safety-related topics in playground standards is broad. Safety related topics cover an array of important issues. However, the topic of environmental and thermal comfort has received much less priority in playground planning and design compared to other risk factors. This aspect within the survey was made clear by the respondents.

4.6 Survey Data on the Environmental Components

The survey gathered perceptions on the four thermal comfort environmental components. Figure 13 illustrates respondents' perceptions on which components **should be a priority** for management within a playground. Respondents indicated that sun exposure in the surrounding environment (77%), temperature of equipment (90%), temperature of the surfacing material(s) (83%), and sun exposure on or near the playground equipment (89%) should receive ***priority*** or ***high-priority*** with regard to thermal comfort management.

What Should be Prioritized Within Playgrounds?

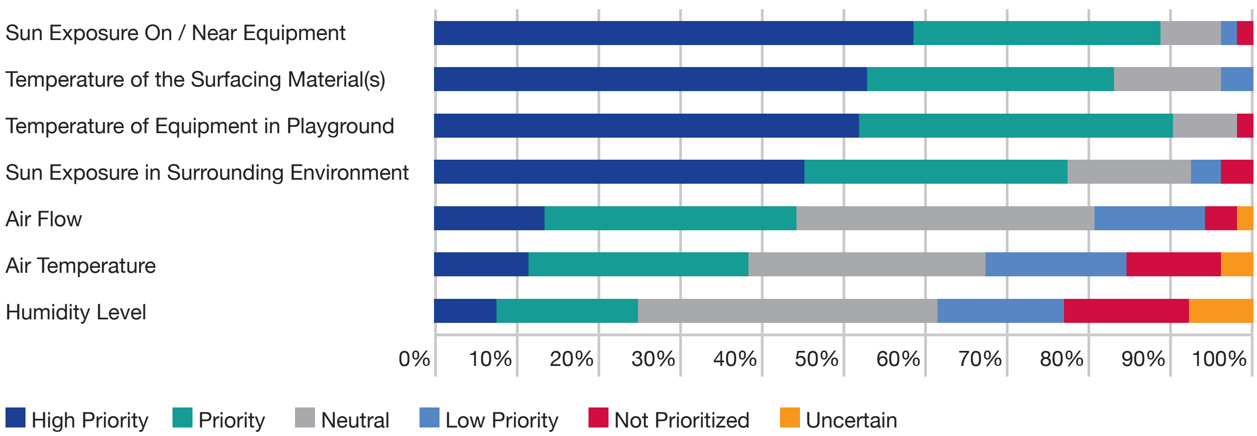


Figure 13.

Perceptions of how the four environmental components should be prioritized in playground design.

Respondents indicated ***priority*** or ***high priority*** responses less frequently on the topics of air flow (wind) (44%), air temperature (38%), or humidity levels (25%), indicating that they would place less overall priority on the management of these components. Temperatures of surfacing and equipment and sun/ UV exposure are important drivers in the perception of thermal comfort. Experts perceptions included the idea that wind and ventilation are overlooked as influencers of thermal comfort, perhaps because these environmental features are perceived to be more difficult to control and/or manage than the other components.

4.7 Features and Elements in Thermally Comfortable Design

Experts were asked about the importance of various features and elements that are known to affect thermal comfort of playgrounds. A perception map was created to show the past and aspirational priorities (Figure 14). Notably, all design features and elements are shown below the neutral axis on the vertical scale, indicating that **these elements and features have historically been given** *low priority* **in playground design –** although the respondents believe that ***slightly more*** attention has been given to colour, existing treelines, artificial shade installation, orientation or direction of equipment, and the materials utilized for playground equipment. All features and elements are perceived to require ***priority*** in playground development, with very little overall differentiation between elements. Results showed natural shade received slightly ***higher priority*** relative to the other features and elements.

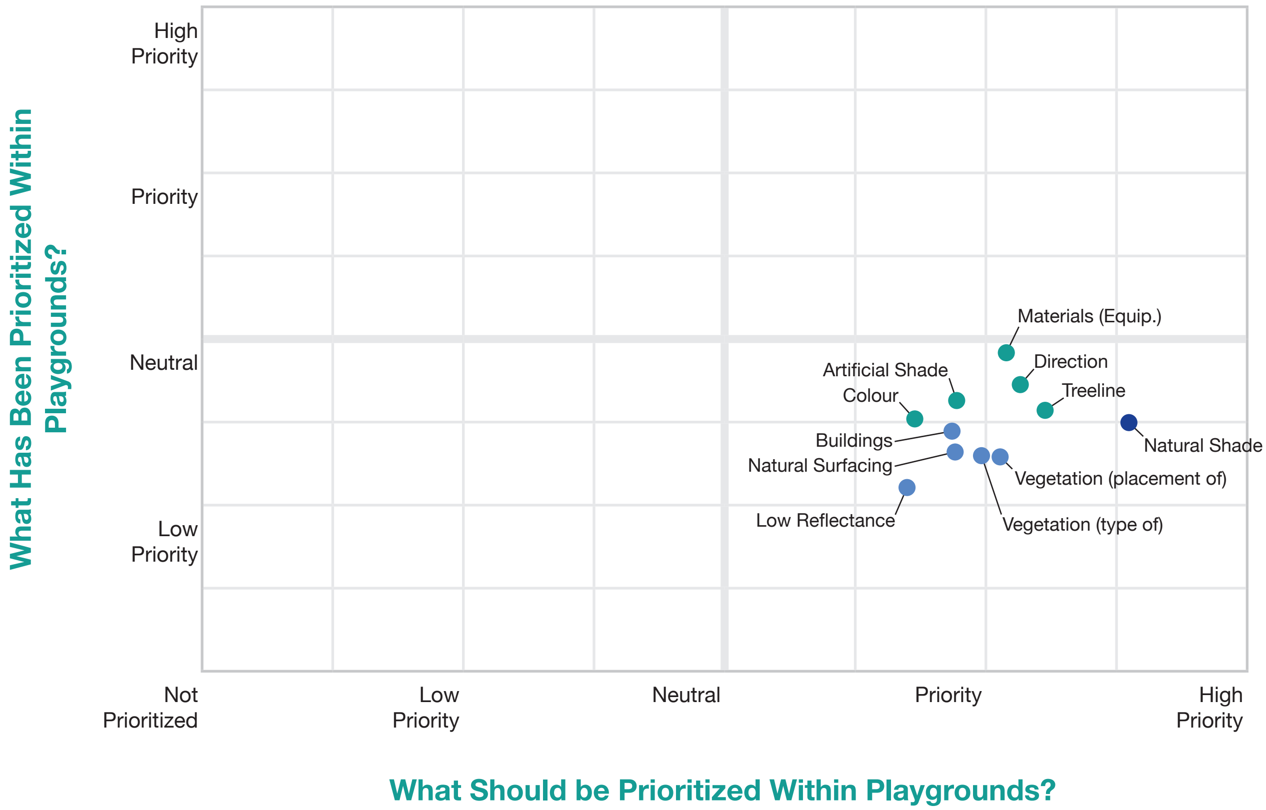


Figure 14.

A perception map detailing expert responses regarding their response to the historical (*has been*) vs. aspirational (*should be*) prioritization of commonly used design elements and features for thermally comfortable playgrounds. On the vertical axis, items ***above the neutral axis*** would have been historically been given ***priority*** or ***high-priority*** in design, while items ***below the neutral axis*** would have historically received ***low or no priority in design***. A corresponding relationship is true for the horizontal axis, with ***items to the right of neutral demonstrating a need for priority*** or ***high priority*** in design.

Survey responses **from** experts were useful in eliciting their perceptions on thermal comfort management. Figure 15 shows respondents' perceptions on which features and elements **should be a priority** for playgrounds. The two most strongly held perceptions are that the location for the playground with respect to existing buildings and existing tree lines should be given ***priority*** or ***high-priority*** attention (81%), while the utilization of natural shade to benefit thermal comfort on playgrounds is supported as a ***priority*** or ***high-priority*** by 89% of expert respondents. Other features and elements have strong support for prioritization, with 55-75% of expert respondents reporting as either as a ***priority*** or ***high-priority***.

What Should Be Prioritized Within Playgrounds

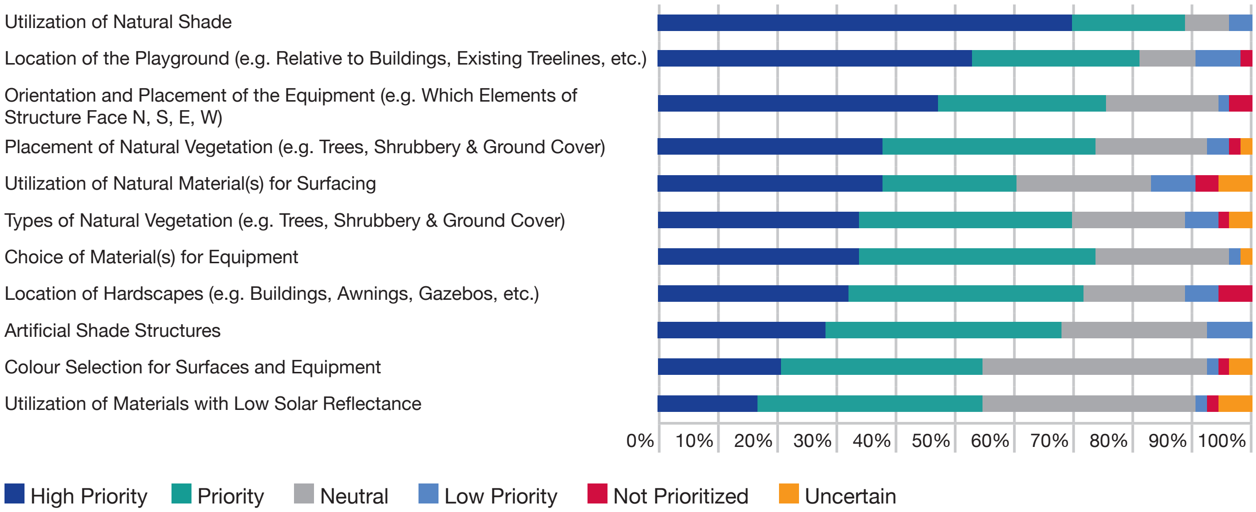


Figure 15.

Perceptions of how commonly used design elements and features for thermally comfortable playgrounds should be prioritized in playground design.

The introduction of design elements to mitigate environmental effects and improve thermal comfort is a complex issue that is best handled on a case-by-case basis. **The best thermal comfort-minded design choices for a playground hinge on specifics of the site, periods of use, and climate zone.** The best solutions are specific to the particular details of the playground and it is reassuring to see that experts are not disproportionately prioritizing particular elements over other factors. This site-specific potentially suggests an awareness of the contributions that each might have towards the overall thermal comfort of a space.

An expert open-ended comment:

> **"Prompting people to consider the conditions of the site should go a long way towards increasing awareness of thermal comfort. Site constraints may prevent designers from adhering to strict guidelines for provision of shade or wind protection (for example), but adding in something to kick-start the site analysis process should be beneficial."**
>
> Manufacturer, Installation, Supplier

At the same time, the survey results may also indicate an opportunity for increased emphasis on education, particularly for designers, on the relative influence of different design factors. For example, the importance of lighter colour surfaces that absorb less solar energy is dramatically affected by the presence of shade and the potential orientation of the equipment with the respect to the shade and wind flow.

An expert open-ended comment:

> **"Implementation of best practices in playground equipment and playspace design that reflects thermal comfort. Education of thermal comfort for manufacturers, designers, and planners (e.g. landscape architects)."**
>
> Educator, Consultant, Risk Management

5 Discussion

Research efforts are needed to increase playground use, expand opportunities for outdoor play, and boost children's activity levels while limiting unsafe and unhealthy environmental exposures. This report begins to explain the need for a more holistic health and safety approach for playgrounds.

Past playground injury prevention work, such as standard CAN/CSA-Z614 *Children's playspaces and equipment*, has focused on the integrity, design, and compliance of equipment and materials in order to minimize playground injuries (e.g. fatalities, fractures, contusion, and traumatic brain injury-TBI). Interestingly, no study has comprehensively examined environmental factors in playgrounds and how they affect child's play or the safety of children's play. In addition, children's thermal comfort has been understudied as no research has examined the effect of safety standards or exposures to heat and radiation on playgrounds.

To support outdoor play while simultaneously raising awareness on the lack of attention given to playground environmental conditions, future work should begin to broaden the scope of what child health concerns are important within playgrounds. Due to the number of playground-related injuries and environmental exposures to children, new research might consider investigating playground design on child risk factors in order to improve child's play, deepen understanding of children's thermal comfort and the effects of comfort on playability, and most importantly promote short- and long-term health. Lastly, more tools and resources are needed for planners and community developers, health officials, school administrators, early childhood professionals, affordable housing providers, playground designers, and urban planners to advance the design of cool, protected, and green playgrounds in Canada and elsewhere.

As a result of the current report's literature review and in-depth analysis of the detailed responses gathered in the expert survey, a number of avenues for future research on thermally safe and comfortable playgrounds have become apparent. The recommendations are generalized and can be applicable throughout Canada and elsewhere. From the literature review and from the topical experts, it is also apparent that thermal comfort is an important topic for creating a space that is conducive for play. In fact, topical experts suggest more research and outreach efforts are needed on this topic.

5.1 Thermally Comfortable Considerations for Playground Design

It is vital to make a distinction between playgrounds that already exist (and then may be retrofitted to attempt to improve thermal comfort), versus new playgrounds that may be built (and thus can consider these additions from the beginning of design). When spaces are already designed (e.g., a certain surface is already in use), some modifications may be very difficult to employ.

For new playground development, it is recommended that during initial decision-making, the existing and expected weather and climate conditions for a given playground should be considered. Such information can be assessed through onsite weather measurements with a low-cost weather station, the use of wind roses, local weather station's data acquisition, and/or using a handheld thermal infrared thermometer to collect surface temperature. Additional early stage considerations include:

1. **Identification of expected times of peak utilization of the playgrounds and volume of traffic.** This identification includes assessment of the annual usage periods and in particular if the given playground experiences considerable seasonal or time-of-day variation in child usage (e.g., playgrounds that are adjacent to sports fields, at seasonally popular parks, at schools that see peak usage during the day vs. public playgrounds that see less-periodic periods of use). Knowledge of these factors may suggest different target optimizations (e.g. designed for year-long usage, limited summer use, limited winter use, etc.)
2. **A shade study should be conducted to identify availability of shade from existing manmade structures as well as natural options such as trees, natural features, land forms, and other vegetation.** This assessment may assist in both optimal placement, orientation of equipment or play areas, as well as the determination of how shade elements and other benefits (wind blocking) could be introduced and oriented. These could include additional natural plantings, fencing options, storage or maintenance structures, and other novel options.
3. **Wind roses or weather radials should be used to understand weather patterns** such as prevailing summer and winter wind directions during the hottest and coldest days, respectively, and best understand expected weather factors that will consistently influence the thermal comfort at the planned site.
4. **Water access is an important consideration for all playgrounds**, particularly if access to a local water supply can be ensured during the design and/or construction phase of a new project. Water access provides an opportunity for drinking or for cooling during play, but additionally enhances the maintenance capabilities, including watering of trees, vegetation, gardens, and natural materials

There are a number of tools available to assist designers with creating thermally comfortable playgrounds. The National Program for Playground Safety encourages an adoption of implementing guidelines for developing new or retrofitted thermally safe and comfortable playgrounds (Appendix A). These guidelines are developed to serve as a concise summary of practices and useful design suggestions to support thermally comfortable play.

5.2 Advocacy Efforts and Future Research

There is limited research in Canada on thermally safe and comfortable playgrounds. The combination of heat extremes, cold extremes, a changing climate, intermittent sun exposure, lack of physical activity, and child obesity are a cause for concern, and may synergistically interact. Viewing playground environments and safety factors more holistically may offer more effective and sustainable long-term solutions for child long-term health. A systematic approach to gather best-practices and expert evidence is needed to increase safe physical activity for health promotion while coping with the expected consequences of a changing climate. Emphasizing the provision of safe playgrounds by mitigating thermal and radiant extremes is a possible solution to ensure that children have the needed access to comfortable playgrounds and to both encourage space usage and support active play.

ADVOCACY EFFORTS

Many factors influence recommendations and best practices for the initiation and progression of improving playground use and safety. This report has provided a baseline understanding of thermal comfort and the intersection of this topic with contemporary playgrounds. This project has found that there is minimal dissemination and outreach efforts on thermally safe and comfortable play. NPPS presents dissemination strategies needed as follows:

1. **Develop a working group to investigate thermal comfort and safety during all seasons of play.** A professional network of individuals should be commissioned to build a research infrastructure, identify cross-cutting risk and health factors, develop best practices for site analysis and data collection, and to determine how to develop and/or implement interventions to address thermal comfort and safety through outreach, training, and implementation. This group is needed to conduct comprehensive, forward-thinking, and holistic research that truly enhances playground usability and comfort.
2. **Disseminate information about safe playground best practices, injury and illness prevention, and thermally comfortable playgrounds to keep the public attention on the issue.** Dissemination efforts at the local, provincial, or federal level must be identified. The involvement of a number of professional organizations, school groups, early childcare agencies, and parks departments is needed for maximum benefit. It is important to consider prevention strategies that are effective in urban and suburban areas, which may not be equally effective or appropriate in rural communities or in disparate climate zones. Thus, research is needed to develop outreach efforts for effective interventions strategies for a variety of geographical regions in urban, suburban, and rural communities.

RESEARCH EFFORTS

Research is needed on the topic of thermally safe and comfortable play and other environmental issues at playgrounds that affect child comfort, playability, safety, and long-term health. (e.g. heat extremes, UV radiation, air pollution, soil contamination). Recent research has called for implementation of evidence-based solutions that are effective in supporting children's health and physical activity through thermal comfort (Xu et al. 2012; Vanos 2015). To improve access to outdoor playgrounds and increase play movement, it is important to research and evaluate design strategies to limit unsafe environmental conditions and promote thermally safe, active, and comfortable playground environments. Future research opportunities involve:

1. **Quantify factors that influence playground usage.** Investigations are needed to better understand why users come to a given playground and what factors makes them stay and actively play. There is limited research to date investigating factors that influence playground use and behaviour and playground selection by children and parents, particularly when combining issues of thermal comfort, weather, and other factors frequently associated with playground usage and safety.

   An investigation between the playground environment and users, such as identifying the underlying behavioural and situational factors associated with thermal discomfort and play (e.g., how active are children in shaded versus sunny locations? How might high surface temperature inhibit play?) or investigating what types of environmental conditions are of most importance to users (e.g., protection from sun, wind, and/or precipitation) may shed light on the appropriate design of future playground spaces. For example, a research study to investigate the correlations between a child's activity level and individual perception of thermal comfort to environmental factors such as sunlight exposure and temperatures would be useful to better understand the level to which these factors influence child's play.
2. **Quantify the effect and influence of design features and elements on the four environmental components of thermal comfort – particularly in different climate zones.** A deeper understanding of the effects of various mitigation features and elements, including quantification of their effects on the four environmental variables (solar radiation, wind/ventilation, temperature, and relative humidity) of thermal comfort is required. Field assessment research relating thermal comfort and environmental conditions to the overall design of playgrounds should be conducted under a variety of geographical regions across Canada so as to ensure a diverse, site-specific approach.

Additional research for standardized methods of quantifying the amount of shade protection and measuring surfacing and equipment temperatures are also needed. Without consistent techniques and tools to evaluate these issues, and to therefore evaluate thermal comfort, it will be challenging to develop consistently effective playground design guidelines to assist playground designers and owners/operators.

3. **Investigate playground surfacing materials for their performance in balancing demands for impact attenuation, accessibility, and influence on playground thermal comfort.** More attention is needed to incorporate environmental safety elements alongside traditional safety metrics due to the continued playground-related injury trends, and growing concerns of rising global temperatures and the need for comfortable outdoor playgrounds in the warm season. Because 60–80% of playground related injuries involve falls and much of the playground safety metrics have focused on improving impact attenuation performance of surfacing materials, research should include developing and testing outdoor surfacing materials in relation to thermal comfort. Playground surfaces may protect children from life-threatening injuries, but they are also known to reach dangerous temperatures that result in unsafe environmental exposure. Researchers should study children's thermal comfort, human tolerances or impact biomechanics, and ideal surface characteristics.

   Research is needed on how to best combine injury prevention, accessibility requirements, and thermal comfort, which are all important components intended to ensure children will have equal access and safe play to thermally comfortable outdoor spaces without negative confounders to health or safety. Common playground surfaces which lesson injury producing forces and promote access may have different trade-offs with respect to thermal comfort or other environmental/chemical exposures (TURI 2018). Balancing these various needs (high temperature, material selection and chemical composition, impact attenuation) for various types of safety requires holistic, solutions-based approaches, which can have important implications for overall health for children and safety of playgrounds.

   Further research and data collection in the field are needed to ascertain the direct benefit of playground surfaces on playground injuries, to understand if these surfaces are used correctly in practice (e.g., orientation to sun, proper cushioning in the long-term, chemical off-gassing), their lifetime and maintenance needs, as well as testing of their performance in outdoor conditions under a range of environments. Research should identify materials and mechanisms that will accomplish all design objectives.

4. **Develop methodology to collect and disseminate localized playground environmental conditions.** Most city weather observations are taken at airports that can be kilometres outside of the city center and detached from the localized environmental conditions at playgrounds. The use of weather stations and meteorological sensors within playgrounds is a novel way to understand exposures during play for health protection, and there is future potential to incorporate "smart city" initiatives to improve our ability to link environmental indicators to health risks in parks and playgrounds (e.g., Morabito et al. 2015; Ramaswami et al. 2016).

5. **Develop tools and resources for cooling and greening of playgrounds.** Integrating thermal comfort planning may increase visitor use, children's activity levels, and enjoyment of playgrounds. Educational tools can guide early childhood programs, school programs, and agencies serving youth on the importance of thermal comfort management. The development of resources for practitioners on how to design playspaces and equipment for thermal comfort in all seasons in the context of broader climate-sensitive design is needed. Toolkits could include guidance documents, design standards, mapping tools, training materials, educational information such as course curriculums, online courses and classroom informational posters. The purpose of this outreach would be to develop accessible tools and resources needed at the local and national level to advance the design of cool and green playground in Canada.

6. Conclusion

Play is important to the development of children, both physically and mentally. Outdoor play provides exercise, fresh air, and a connection to nature, but prolonged exposure to the sun also increases potential long-term health risks. In 2014, CSA Group published the fifth edition of CAN/ CSA Z614, *Children's playspaces and equipment* which "addresses safety measures that help minimize exposure to serious injuries" (CSA 2014). While the existing version of the standard includes several references to heat, considerations for designing play equipment and spaces for extreme heat has not systematically been integrated into the document. An informational thermal comfort annex was developed and submitted to CSA for considerations to be included in the next updated addition of the standard based upon the literature review and survey results.

The practical and actionable design considerations to improve thermal comfort on playgrounds detailed in Appendix A can be implemented today by designers, and integrated into future design and equipment standards. The National Program for Playground Safety strongly recommends an increased emphasis on the topic of thermal comfort and relationship with play and child health to raise both professional and public awareness and understanding of the issue. Although the concept of thermal comfort was introduced in the 1970's, limited research efforts have occurred at the intersection of thermal comfort, children, and play.

Child health professionals and experts within the playground industry agree significant efforts should focus on the topic of thermally safe and comfortable playgrounds and should be included in future research, as well as playground standards and guidelines. While playground-related standards address topics such as installation of equipment, impact attenuation performance of surfacing, inspection and maintenance, playground layout, requirements for access/ egress and accessibility with respect to persons with disabilities, and many other important issues – there are no widely promoted or adopted guidelines or standards related to the development of thermally comfortable playgrounds. Because of the number of playground-related injuries and environmental exposures to children, research should begin to investigate playground design on child risk factors (e.g. UV exposure, environmental hazards, impact attenuation, fall injuries, and other common injuries) in order to improve child's play, deepen understanding of children's thermal comfort, and most importantly promote short- and long-term health.

Playground safety is a complex issue. To be successful and to ensure that Canada's playgrounds are safe, inclusive, and thermally comfortable, playground safety has to be a partnership at the federal, provincial, and local levels. Future improvements on developing a thermally safe and comfortable playground framework, along with research models which encompass all playground design elements and risk factors is critically need to help communities across Canada examine these issues. The National Program for Playground Safety encourages the implementation of recommended guidelines for developing thermally safe and comfortable playgrounds (Appendix A). With the concerted efforts of all, increased playground use will be safely enjoyed by all children and families.

APPENDIX A

RECOMMENDED GUIDELINES FOR DEVELOPING THERMALLY SAFE AND COMFORTABLE PLAYGROUNDS

Introduction

The microclimate of a playground has a significant influence on children's use of play areas and levels of physical activity (Semenzato et al., 2011). Sun exposure, air movement, humidity, and temperature combine to affect what is known as "thermal comfort", a description of the condition of being satisfied with current environmental conditions. Each playground has its own distinct micro-climate, with unique patterns of temperature, wind, and radiation.

Studies have shown that when thermal conditions become uncomfortable in the summer, the use of the playgrounds by children decreases. Some design elements of parks and playgrounds can also increase heat-related health risks to children (Vanos et al., 2016).

Children are particularly vulnerable to hot ambient environments and heat stress compared to adults (Berry et al., 2014). They are also more susceptible to sunburns and burn injuries on playgrounds because of their more sensitive skin (Volkmer and Greinert, 2011). Making playground equipment and spaces thermally comfortable in summer helps ensure that children can go outdoors, play, be active and remain at a play area for a longer period of time.

Designing thermally comfortable outdoor spaces is an important adaptation in the context of climate change. As a result of climate change, the numbers of very hot days (≥ 30°C) in many parts of Canada is expected to become much more common, with significant impacts on human health (Berry et al., 2014). For example, in the City of Windsor, Canada's southernmost city, the number of very hot days is expected to double from 24 days annually to over 40 days by 2050 from the 1976-2005 reference period (Climate Atlas of Canada, 2018). In summary, in the context of climate change, understanding how to design for thermal comfort is increasingly essential for Canadian playgrounds.

Purpose of Guidelines

The purpose of these guidelines is to provide practical advice for the management of thermal comfort in the design (or retrofit) and maintenance of both new and existing playgrounds in the context of Canadian climates. While focused on improvements to thermal comfort in the summer season, the guidelines touch on how to design for thermal comfort in all seasons, given that many parts of the country experience four distinct seasons, including long and cold winters. Canada is a vast country characterized by large variations in regional climate. These guidelines are designed to not be limited to one geography, but instead provide high-level considerations that could apply across various geographic and climatic zones. Thermally comfortable playgrounds and play areas can help achieve the important benefits children gain through active outdoor play. Additionally, thermally comfortable play areas can help create cool and vegetated spaces within towns and cities (i.e. "park cooling islands"). This is increasingly important given the growing "urban heat island" effects in Canadian cities.

Four Components of Thermal Comfort

Table A.1 discusses the four environmental components that are the principal factors related to thermal comfort. These thermal comfort factors are provided in the order of those most easily changed, to those more challenging to manage through design. Further, radiation and sun exposure reduction have the greatest potential influence on health benefits.

Table A.1

Four Components of Thermal Comfort

Description of Thermal Comfort Factor	Playground Design Recommendations
Solar Radiation Playgrounds often lack adequate protection from sun exposure, which can result in direct skin damage due to high energy ultraviolet (UV) radiation and increased risk of skin cancer (American Cancer Society, 2013). Intense radiation exposure further connects to many thermal comfort and safety factors, including: thermal discomfort, heat stress, dehydration, skin damage from UV light, sedentary behaviour, degradation of equipment, and high temperature(s) of protective surfaces and playground equipment. Solar Radiation is the most important determinant of thermal comfort in warm conditions. Equipment and surface temperatures are directly related to sun exposure. When these items are exposed to the sun, they can reach temperatures that can burn a child's skin—manufactured materials often pose the greatest risk of a burn. Moreover, higher surface temperatures radiate intense infrared energy (heat) toward a child, thus decreasing comfort and increasing risks of heat illness, such conditions reduce the usability of playgrounds and can become dangerous.	Properly placed shade and the type of shade can improve thermal comfort. In the summertime, the most impactful improvements to thermal comfort can be improved by reducing solar radiation exposure through manufactured or natural shade elements. Ensuring low transmissivity and appropriate orientation of shading to block south and southwest sun with trees or manufactured shade is an important consideration when either adding shade to current playgrounds or designing new playgrounds. In the wintertime, solar radiation can have a warming effect that can improve comfort levels, and this should be considered in choice of shade type. Owner/operators and planners/designers should be aware that overexposure to solar radiation can negatively impact long-term child health through multiple avenues. Short term effects on hot days in summer may include early departure from a playground or play area, burns from hot surfaces, and painful sunburns. Intentional changes in design can have numerous co-benefits to child health, safety, and the usability of a space (see Table A.2).
Wind / Ventilation Wind / ventilation (air flow) can aid thermal comfort in warm temperature environments. Ensuring wind movement and ventilation in the summer is an important factor for thermal comfort as it helps with convective cooling of the skin for thermal comfort. Low wind movement (stagnant air) can cause discomfort on hot days, especially in humid regions of the country. Wind flow can also exacerbate conditions on cold days. In the wintertime, high winds can exacerbate and reduce thermal comfort and the wind chill factor.	Ensuring that prevailing winds are able to flow through a play area in the summertime can significantly improve thermal comfort by aiding evaporation of sweat. Alternatively, blocking prevailing winter winds is important for thermal comfort. Vegetation and structures that may block prevailing winter winds to improve thermal comfort in the cold season. Knowledge of the prevailing wind directions and speeds each season using seasonal wind roses (i.e. a diagram showing the relative frequency of wind directions at a specific place and season, see Figure A.1), or alternate means is suggested in order to aid ventilation and for optimizing wind blocks. Because winds will vary by location and season, these layout decisions for thermal comfort should be site-specific and planned carefully.
Temperature The temperature of the playgrounds — including air, surface, and equipment temperature – can have a dramatic effect on children's movement, health, physical activity, and behaviour. Both hot and cold temperature extremes affect overall thermal comfort. User experience of temperature is a key driver of a comfortable safe play experience and total time spent at a playground. If temperature is not considered in the planning stage, it can limit the use of the space as users could depart prematurely. While air temperature is difficult to change on a large scale, it can be influenced through design. In the summer, air temperature is reduced through vegetation (via evapotranspiration), shading, and lowering surface temperatures through natural materials (e.g. trees, shrubs and plans), water, shade, and cool surface coverings.	Air temperature is a weather variable that is difficult to change on a large scale, but can be influenced through intentional design. For example, in hot weather, the use of vegetation (e.g. trees, shrubs and plants) and shading can provide increased cooling and a reduction in surface temperatures. Management of factors such as air movement, direct sunlight exposure, and other factors play an important role on cold temperature impacts in the winter. When properly managed, design choices can impact localized air temperatures and help improve thermal comfort across different seasons. Cold wintertime air temperatures are best managed through children's clothing protection as well as through wind blocks and designs that allow for sunlight exposure. (See Table A.2 and Table A.3)
Relative Humidity Relative humidity significantly factors into how a human feels, yet it is difficult to control within the space of a playground area. The humidity varies minimally within a city as compared to wind, radiation, and temperature. Higher air humidity reduces thermal comfort in warm weather by restricting evaporation of sweat, which is essential for comfort in warm conditions. Higher humidity and low air flow leads to less evaporation from the skin, resulting in high thermal discomfort.	Air movement from the wind can aid in the evaporative process on humid days (See Table A.3). Ensuring wind flow is therefore a more important consideration in humid cities (such as Toronto, Windsor, Ottawa, and Montreal). In dry locations (such as the Prairies), where humidity is less of an issue, sweat evaporates more freely, causing less heat discomfort. Dryer locations are often sunnier on hot days; thus, shade elements are comparatively more important for thermal comfort.

Site and Design Practices that Influence Thermal Comfort

Prior to the implementation of physical design elements at a playground, the prioritization of factors that influence thermal comfort and other considerations for safety and use (e.g. impact attenuation of surfacing, design for accessibility, etc.) must be well-understood. For thermal comfort, it is recommended that during initial decision-making, existing / expected weather and climate conditions be well-understood for a given playground. Such information can be assessed through onsite weather measurements with a low-cost weather station, the use of wind roses, and/or through data acquisition from a nearby weather station, as well as surface temperature analysis in the summertime with a handheld thermal infrared thermometer. Further issues that should be addressed are:

1. **Identification of expected times of peak utilization of the playgrounds and volume of traffic.** This identification includes assessment of the annual usage periods and, in particular, if the playground experiences considerable seasonal or time-of-day variation in usage (for example, those playgrounds that are adjacent to sports fields, at seasonally popular parks, or at schools that see peak usage during the day *versus* public playgrounds that see more variable periods of use). Knowledge of these factors may help with choosing different design interventions focused on designs for year-long usage, limited summer use, limited winter use, etc.
2. **A shade study should be conducted to identify availability of shade from existing manufactured structures as well as natural options such as trees, natural features, land forms, and other vegetation.** This assessment may assist in both optimal placement, orientation of equipment or play areas, as well as the determination of how shade elements and other design features (wind blocking) could be introduced and oriented. Design features could include additional natural plantings, fencing options, storage or maintenance structures, and other options.
3. **Wind roses or weather radials should be used to understand weather patterns** such as prevailing summer and winter wind directions during the hottest and coldest days, respectively, and best understand expected weather factors that will consistently influence the thermal comfort at the planned site (see Figure A.1).
4. **Water access is an important consideration for all playgrounds**, particularly if access to a local water supply can be ensured from the outset of the design/ construction phase of a new project. Water access provides an opportunity for drinking and cooling during play. It also allows for the introduction of water play options, and enhances maintenance capabilities, including the watering of trees, vegetation, and gardens.

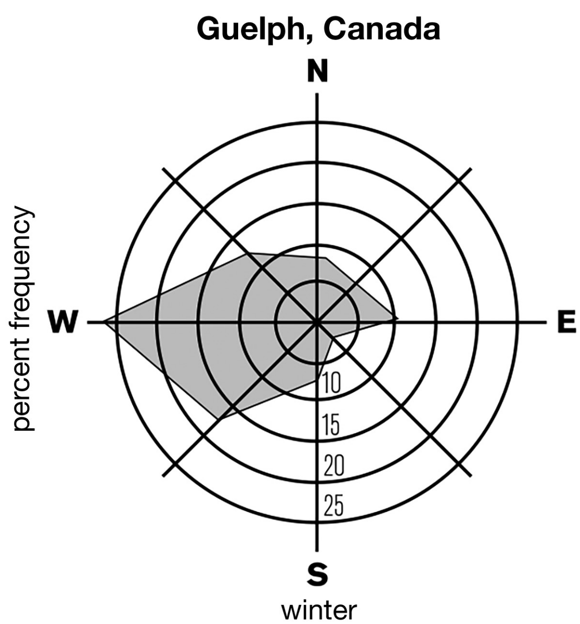


Figure A.1

Example of a simple windrose for the winter season in Guelph, Ontario. The windrose shows that in this location, the winds blow predominantly from the west in the winter (up to just over 25% of the time), and thus designers would want to consider blocking cold westerly winter winds.Image enhanced from Brown and Gillespie (1995) by Graphic Artist at the Julie Ann Wrigley Global Institute of Sustainability, Arizona State University.

Features and Elements that Influence Thermal Comfort

There are multiple physical design elements that can influence thermal comfort. Table A.2 provides features/strategies along with a brief description of how each influences thermal comfort. These are in no specific order.

Table A.3 presents detailed information on how design features may improve or reduce thermal comfort in the warm and cold seasons, focusing on the four environmental factors (solar radiation, wind/ventilation, temperature, and relative humidity) that together influence thermal comfort. When making a decision for thermal comfort, consider the users of the space (e.g. age, stage of development), the predominant time of use, and related safety factors.

Table A.2

Thermal Comfort Considerations

Feature	Category	Thermal Comfort Considerations
Shade: canopy-level vegetation and manufactured shade within and around playgrounds *Note: Sun-path diagrams are helpful to use for designing for shade considerations at different latitudes.*	Deciduous	Deciduous trees are recommended to be placed on the south and southwest side of a playgrounds to provide summertime shading through the greatest part of the day while also allowing wintertime radiation transmission, which is affected by tree size and canopy density, with multiple trees allowing for park cooling islands to form.
	Coniferous	Given their tall and long canopies, coniferous trees are recommended to be used to provide shade at high and low solar angles. These trees can also act as wind blocks in the winter for prevailing winds.
	Manufactured	Shade sails are recommended to be used to shade smaller, high-use play areas from intense solar radiation. Shade sails can be placed slightly to the south and southwest of play equipment to block the south and southwest sun; rectangular sails should be orientated east-west. *Note: some shade sails can be installed and removed seasonally to allow warmth from the sun in winter.*
Ventilation from wind	--	To ensure adequate wind flow in the summertime, it is recommended to use a seasonal wind rose. Based on the prevailing wind direction during heat events (e.g. south), one should be careful to not block cooling winds from ventilating the area. It is suggested to block winter prevailing winds and consider snow drifting.
Ground-level vegetation	--	For the surrounding area, grass, shrubs, and native plants are recommended to provide cooling through increased evapotranspiration, lower heat capacity, and lower albedo.
Playground site location and equipment placement	--	Both the orientation, placement, and location of equipment within the playground can influence thermal comfort. For new playgrounds, locating the site to the north side of buildings, or landforms or embankments, can provide shade and a source of coverage. Equipment location selections within a playground can help to utilize available shade, wind block, etc.
Material selection	Equipment	Ensuring metal is painted, galvanized or otherwise treated is important. Also ensuring that plastics, when used, have lower exposure to sun is important for safety. Utilizing paints and plastics that are on the lighter in colour can assist in lowering surface temperatures (see Colour Selection below).
	Surfacing	Considerations should be given to the type of surfacing material. Try selecting material with low thermal storage and low heat conductivity whenever possible. Intentional shading strategies on surfaces that reach high temperatures, including the planting of shade trees, is vital to reduce burn potential and thermal discomfort.
Colour selection *Note: While colour selection will influence equipment surface temperatures, the overall influence to thermal comfort may be less dramatic than other design features, particularly if shaded.*	Equipment	Recommended to use lighter colours on materials to minimize hot surface temperatures.
	Surfacing	Considerations for light surfacing colours (e.g. grey versus black) to minimize the absorption of heat. Caution with bright/ reflective colours (e.g. white surface, sand) as the reflected solar radiation will exacerbate potential sunburn. The reflective colours can also be uncomfortable on the eyes. Consider shading these surfaces whenever possible.

Table A.3

Intentional strategies that can improve (↑) or reduce (↓) thermal comfort, based on changing the main factors of sun exposure, wind/ventilation, temperature, and relative humidity. A dash (-) indicates no well-known or significant relationship between that mitigation and its influence on thermal comfort. For example, planting of deciduous trees in summer can improve thermal comfort by decreasing sun exposure and air temperature, but can have a slight effect in increasing humidity.

		Warm Season			Cold Season		
Feature	Category	Sun Exposure	Wind	Temperature	Sun Exposure	Wind	Temperature
Shade	Deciduous	↑	-	↑	↑	-	↑
	Coniferous	↑	↑[a]	↑	↓	↑[a]	-
	Manufactured	↑	-	↑	↓	-	↓
Ground-level Vegetation	All	↑	-	↑	-	↑	↑
Lighter Colour Materials	Surface	↓[b]	-	↑	↑[b]	-	↓
	Equipment	↓[b]	-	↑	↑[b]	-	↓

a Focus on blocking prevailing winter winds and not blocking summer winds.

b Due to reflection of sunlight towards person.

Definitions

Albedo: Reflective power; specifically, the fraction of incident radiation (such as light) that is reflected by a surface or body (such as the moon or a cloud).

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC).

Evapotranspiration: The process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants; uses energy and thus cools the air.

Evaporative Cooling: A reduction in air temperature due to the evaporation of a liquid (water), which moves latent heat from the surface from which evaporation takes place. For example, when we sweat, evaporation of the sweat will remove heat from the skin's surface.

Convective Cooling: When heat is transferred from a hot medium (e.g. object, air) to a cold medium. Our skin will cool via convection when it is warmer than the air, which is the normal process.

Relative Humidity: The amount of water vapor present in air, expressed, as a percentage –100% would be saturation (or a water droplet). Relative humidity increases as the air temperature decreases, and vice versa.

Solar Radiation: Radiation emitted by the sun in the visible shortwave part of the electromagnetic spectrum.

Thermal Comfort: Condition of mind that expresses satisfaction with the thermal environment.

Urban Heat Island: Built-up areas that are hotter than nearby rural areas. Built surfaces in urban areas such as roofs, paved roads, and parking lots can absorb large quantities of radiant heat from the sun, resulting in increases in both surface and air temperatures (Health Canada 2009).

Park Cooling Island: The potential of urban parks to mitigate the urban heat island effects of their surroundings (Slater 2010).

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- Resource: ENVI-Met: https://www.envi-met.com ENVI-Met is a numerical microclimate model that allows one to quantify the impact of various factors on interactions between vegetation, built environment, and the surrounding air.
- Resource: i-Tree tool: https://www.itreetools.org. The USDA Forest Service helps with quantifying the benefits and values of trees, for using in communities around the world. The tool is based on peer-reviewed research in the public domain.
- Resource: Shade Audit Information Guide + Tool: https://www.regionofwaterloo.ca/en/health-and-wellness/resources/Documents/ShadeAudit_GuideTool.pdf
  This guide is published by the Waterloo Region Shade Work Group and provides information on shade audits, including a tool for conducting a shade audit.
- Resource: Natural Learning Initiative: www.naturalearning.org NLI is a research and professional development unit at the College of Design, NC State University, Raleigh, NC, USA. NLI was founded in 2000 with the purpose of promoting the importance of the natural environment in the daily experience of all children, through environmental design, action research, education, and dissemination of information.
- Resource: National Program for Playground Safety: playgroundsafety.org The National Program for Playground Safety (NPPS) at the University of Northern Iowa's mission is to raise awareness about playground safety and the necessity for appropriate, healthy spaces to support child development and wellbeing.

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