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**Do school playground designs adequately protect primary school
children from the risk of skin cancer and overexposure to solar
ultraviolet radiation?**

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Doctor of Philosophy

at
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by
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Abstract

Do School Playground Designs Adequately Protect Primary School Children from the Risk of Skin Cancer and Overexposure to Solar Ultraviolet Radiation?

by

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Excessive exposure to ultraviolet radiation (UVR) from the sun is considered a significant public health risk, particularly for children, because childhood sun exposure increases the risk of developing skin cancer. Schools have been identified as priority settings for sun protection and skin cancer prevention initiatives. Although school-based sun protection programmes have contributed to some improvement, there are limitations. Children remain inadequately protected and are exposed to high levels of UVR, especially during school intervals and lunch breaks. Landscape design has the potential to encourage sun protection behaviour (SPB) and thus help protect children from overexposure. However, little is known about the extent to which school playground designs support necessary SPB among children. No previous studies have integrated three critical factors – UVR protection, microclimatic comfort, and attractive play opportunities – that are needed to support the intended SPB in assessing children’s outdoor recreational areas such as school playgrounds. Additionally, there is currently no effective evidence-based methodology for evaluating and designing school playgrounds that support SPB in children.

This study investigates the role of landscape architectural design in promoting sufficient SPB among young children in existing primary school playgrounds by proposing a novel SPB design methodology (SPB-D). Following a landscape units’ approach and integrating the strengths of existing methods, the methodology evaluates and designs both existing and proposed school playgrounds in support of SPB among children. The methodology was applied to case studies in Christchurch to test its potential and effectiveness in assessing school playground designs in providing SPB. Evaluation indicates that no assessed school playground was designed to support SPB. A substantial proportion of activity zones failed to support all three SPB design objectives. Potential activity zones’ design to meet SPB design objectives was strongly influenced by the type, size and function that collectively determine the overall SPB design level. Among the objectives, attractiveness was most frequently achieved, whereas UVR protection and microclimatic comfort were least addressed. The spatial layout and design of individual activity zones significantly affected the overall school playground SPB design

outcome. The findings suggest that current design approaches tend to focus on the whole-school playground scale, which emphasises the need to shift the focus to the activity zone scale to meet optimal SPB design levels.

This study demonstrates the effectiveness of the novel SPB-D methodology in assisting landscape architects to design and retrofit school playgrounds. The outputs generated at three spatial scales enable designers to make evidence-based design decisions and develop associated design strategies. The application of this methodology advances evidence-based landscape architecture processes through a transparent, flexible iterative process that helps overcome barriers to implementing evidence-based design solutions for complex environmental issues, such as SPB. The process helps maximise SPB design in existing school playgrounds through the development of targeted interventions, identifying SPB design strategies and prioritising activity zones for implementation over time.

Keywords: skin cancer, landscape design, sun protection behaviour, UVR protection, microclimatic comfort, attractive play opportunity, evidence-based design, children, school playgrounds.

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Chapter 1

Introduction

1.1 Problem statement

Overexposure to solar ultraviolet radiation (UVR) poses a significant public health risk, primarily associated with an increased incidence of skin cancer and mortality (Narayanan et al., 2010). Globally, the incidence of skin cancer is rapidly increasing (Sung et al., 2021) particularly among fair-skinned people (Lomas et al., 2012) with lower melanin levels, having reduced natural protection against UVR (Brenner & Hearing, 2008). Additionally, demographic changes and increased UV exposure contribute to this increasing trend (Zhou et al., 2025). Australia and New Zealand have the highest rates of both melanoma (Arnold et al., 2022) and non-melanoma (Perera et al., 2015) skin cancers in the world. In New Zealand, about 100,000 people are affected every year (MelNet, 2025), imposing a considerable economic burden on the health system (O'Dea, 2009). Skin cancer and problems associated with overexposure to UVR are largely associated with excessive sun exposure during childhood, which increases the risk of developing skin cancer in later life (Oliveria et al., 2006). Primary school-aged children (5 to 12 years) are particularly vulnerable because they spend significant time outdoors during school hours (Wright et al., 2007) often during peak UVR levels. Implementing measures to reduce sun exposure and promote sun protection behaviours in schools can significantly help reduce the risk of skin cancer and other related health problems. The World Health Organization (WHO) (2002b) identifies primary schools as priority settings for skin cancer prevention efforts because fostering sun protection awareness and behaviour at an early age, which tends to be most receptive, can significantly decrease health risks and associated health care costs.

Internationally, school-based efforts in skin cancer prevention and the protection of children from excessive sun exposure primarily focus on implementing policy-driven sun protection practices with the creation of a supportive environment such as shade provision and the promotion of sun protection awareness through education and curriculum initiatives (Collins et al., 2006; McNoe & Reeder, 2019). In New Zealand, the Cancer Society's SunSmart Schools Accreditation Programme (SSAP) encourages primary schools to adopt and implement sun protection practices (CSNZ, 2018). Although evidence indicates that these interventions are effective in increasing sun protective behaviours and reducing UV exposure (Community Preventive Services Task Force, 2012), sun protection in schools remains inadequate (McNoe & Reeder, 2019), leaving children unprotected and at increased risk of sun damage (Gage et al., 2017). Though research consistently highlights the importance of shade in reducing UVR exposure, many school playgrounds in New Zealand lack

sufficient shade (McNoe & Reeder, 2019), or the children do not use available shaded areas (Gage et al., 2017). This combination of insufficient shade and low use of shaded areas increases children's risk of overexposure to UVR, highlighting the need for additional sun protection strategies.

Landscape design can play an important role in addressing complex socioenvironmental problems (Deming & Swaffield, 2011) such as protecting people from overexposure to the sun. Studies increasingly highlight that, in addition to providing adequate shade, shaded areas must also offer microclimatic comfort (Mackay, 2003b) and attractive play opportunities (Boldemann et al., 2006) to encourage children to use the spaces and thereby reduce their UVR exposure. Accordingly, this study proposes that three factors: UVR protection, microclimatic comfort and attractive play opportunities, are critical for promoting sun protection behaviour (SPB) among children. In this study, SPB is defined as 'the action of occupying or conducting activities in spaces that are designed to protect people from overexposure to the sun'.

To date, no studies have integrated all three factors in evaluating SPB among children, nor have they examined whether they are present in specific school playgrounds. Particularly activity zones, the key spatial scale necessary to ensure all children are protected regardless of what play activity they choose. Also, if school playgrounds are to be designed (both existing and proposed) to achieve optimal SPB, there is a need for a robust, evidence-based methodology with clear targets for measuring UVR protection, microclimatic comfort and attractive play opportunities. Such a methodology would be valuable for both researchers and designers in evaluating existing playgrounds or developing new designs, ultimately supporting informed decision-making and ensuring that school playgrounds are effectively designed to promote optimal SPB outcomes.

1.2 The research questions and objectives

This study aims to answer one main question and four sub-questions by achieving 10 objectives.

Table 1.1 presents the research questions, the corresponding research objectives for addressing each sub-question, the research methods used and the chapters in which they are discussed.

1.2.1 The research questions

Main research question: What is the role of landscape architectural design in promoting sufficient SPB among young children in existing primary school playgrounds?

Sub-question 1: What new evidence-based methodology would improve the evaluation and design of school playgrounds in support of SPB among children?

Sub-question 2: To what extent do individual activity zones support specific SPB design objectives?

Sub-question 3: To what extent do individual activity zones support overall SPB design?

Sub-question 4: To what extent do overall school playground designs support SPB among children?

Table 1.1: The study's research questions, objectives, research methods and relevant chapters

Research Question	Research Objectives	Research Method(s)	Chapters
Sub-question 1: What new evidence-based methodology would improve the evaluation and design of school playgrounds in support of sun protection behaviour among children?	RO 1: To critically review the theory defining ultraviolet radiation protection, microclimatic comfort and attractive play opportunities in support of sun protection behaviour design for school playgrounds	Critical literature review	Chapter 2
	RO 2: To identify criteria for an effective evidence-based methodology to evaluate and improve sun protection behaviour design in school playgrounds		
	RO 3: To critically review existing design methodologies used in landscape architecture practice and research		
	RO 4: To develop an improved evidence-based sun protection behaviour design methodology that better meets an effective design methodology	Integrating multiple methods: the landscape units' approach, the critical component design approach, shade simulation method, shade protection factor estimation method, empirical wind modelling method and on-site observation method	Chapter 3
		Testing and refining the newly developed sun protection behaviour design (SPB-D) methodology	Chapter 4
Sub-question 2: To what extent do individual activity zones support specific sun protection behaviour design objectives?	RO 5: To evaluate individual activity zones for adequate ultraviolet radiation protection	Apply Steps 1 and 2 of the newly developed methodology	Chapter 5
	RO 6: To evaluate individual activity zones for sufficient microclimatic comfort		
	RO 7: To evaluate individual activity zones for adequate attractive play opportunities		

<u>Sub-question 3:</u> To what extent do individual activity zones support the overall sun protection behaviour design?	RO 8: To evaluate the potential of individual activity zones in support of the sun protection behaviour design integrating the evaluation of the specific design objectives	Applying Step 3 of the new sun protection behaviour design methodology, integrating the results from Steps 1 and 2	Chapter 5
<u>Sub-question 4:</u> To what extent do overall school playground designs support sun protection behaviour among children?	RO 9: To evaluate the potential of an entire school playground supporting sun protection behaviour design integrating the evaluation of individual activity zones	Applying Step 4 of the new sun protection behaviour design methodology, integrating the results from Step 3	Chapter 5
<u>Main research question:</u> What is the role of landscape architectural design in promoting sufficient sun protection behaviour among young children in existing school playgrounds?	RO 10: To discuss the implications of this study for school playground planning and designing in support of improved sun protection behaviour among children in the context of long-term protection from overexposure to harmful ultraviolet radiation	Integrating critical literature review, multiple methods used for developing the new sun protection behaviour design methodology, and results from applying Steps 1 to 4 of the newly developed methodology	Chapter 6

1.3 Organisation of thesis

This thesis comprises six chapters (Table 1.1) plus a concluding section (Chapter 7). Following this introduction, Chapter 2 addresses research objectives one, two and three and provides a critical literature review of: (1) the impacts of overexposure to solar UVR; the factors that determine the amount of UVR exposure in landscapes with children; and the limitations of existing sun protection and skin cancer prevention efforts (introducing the effectiveness of SPB design in the context of improved sun protection); (2) landscape architecture approaches and their effectiveness in promoting SPB; and (3) the criteria for an effective methodology to evaluate existing methodologies for assessing landscapes that support SPB design to inform the development of an improved new methodology.

Chapters 3 and 4 address research objective four. Chapter 3 outlines the study framework and details the methodology. It outlines the multiple integrated methods that support the development of a new approach for SPB design and the evaluation of school playgrounds. It also details the study sites used in the assessment of existing school playground designs for their support of SPB among children. Chapter 4 presents the application of the newly developed SPB-D methodology to a pilot study school to test and refine the approach. The chapter presents a step-by-step process by which the methodology can be applied to evaluate and design school playgrounds to meet optimal SPB, with the pilot school serving as an example.

Chapter 5 addresses research objectives five to nine. It reports the findings of the SPB design assessment conducted in six Christchurch school playgrounds and highlights three key outcomes: the extent to which individual activity zones meet specific SPB design objectives; the extent to which individual activity zones meet SPB design; and the extent to which each school playground meets overall SPB design.

Chapter 6 addresses research objective 10 by discussing the implications of this study for improved SPB design and planning of school playgrounds. It outlines the study's methodological contribution through the development of an evidence-based SPB-D methodology and its substantive contributions from the insights gained through evaluating existing school playgrounds. Chapter 7 concludes the study by outlining its limitations, providing recommendations for improved sun protection planning and suggesting directions for future research.

Chapter 2

The Theory of Landscape Design for Sun Protection Behaviour among Children

Chapter 1 provided an overview of this study and outlined the research questions and objectives developed. In this chapter, a critical review of the literature on the theory of sun protection behaviour (SPB) and the design of school playgrounds in the context of protecting children from overexposure to harmful solar ultraviolet radiation (UVR) are presented. Section 2.1 discusses the impacts of overexposure to solar UVR, its particular significance to New Zealand and the key contributing factors. Section 2.2 outlines children's vulnerability to UVR exposure, identifies primary schools as priority settings for sun protection, discusses existing school-based sun protection measures and the effectiveness of their tools in protecting children. Section 2.3 reviews current landscape architecture approaches to sun protection and outlines the critical gaps. It introduces the concept of sun protection behaviour (SPB) design as an effective sun protection strategy and defines the three key SPB design objectives. Section 2.4 examines landscape approaches to UVR protection, outlines the influencing factors, assessment methods used and the research gaps identified in the literature. Section 2.5 critically reviews landscape approaches to microclimatic comfort, identifies the influencing factors, methodological approaches used and the associated research gaps. Section 2.6 critically reviews landscape approaches to attractive play opportunities, discusses the influencing factors, the evaluation methods used and the research gaps identified in studies. Finally, Section 2.7 introduces evidence-based design (EBD) and its significance in addressing critical health-related issues. It describes the EBD process, the barriers to its integration in practice, identifies the key attributes for an effective methodology, outlines the criteria developed in this study and reviews the effectiveness of existing design methodologies against the outlined criteria.

2.1 The impacts of solar ultraviolet exposure and their significance

Sun is the vital source of energy for all life on Earth and provides numerous health benefits, including the synthesis of vitamin D. However, overexposure to solar ultraviolet radiation (UVR) poses significant health risks. In the short-term, UVR exposure can cause sunburn (erythema) and skin blistering (WHO, 2002b). Long-term exposure is associated with the risk of developing cataracts, characterised by clouding of the eye that can ultimately cause blindness (Delavar et al., 2018) accelerated skin ageing and cellular damage, which subsequently increases the risk of skin cancer and mortality (Narayanan et al., 2010).

2.1.1 The burden of skin cancer

Skin cancers are mainly divided into melanoma and non-melanoma skin cancers (NMSCs). Melanoma is the most serious form of skin cancer, responsible for most of the cancer-related mortalities (Narayanan et al., 2010), while NMSCs are more common than melanoma but have a lower mortality rate (HPA & MelNet, 2017). Globally, both the incidence and mortality of skin cancer have been steadily increasing over the last several decades (IARC, 2022). According to the GLOBOCAN 2022 data, melanoma was the 17th most commonly diagnosed cancer worldwide, with 324,635 new cases and the 23rd leading cause of death among all cancers, resulting in 57,043 deaths in 2020. By comparison, the incidence of NMSCs was approximately 18-20 times higher than that of melanoma (Apalla et al., 2017) and the fifth most common cancer with 1,198,073 new cases, and the 22nd leading cause of deaths with 63,731 deaths in 2020 (IARC, 2022).

Although the incidence of melanoma and NMSCs varies considerably across countries and regions, Australia and New Zealand report the highest melanoma incidence rates in the world (Narayanan et al., 2010; M. Wang et al., 2025). In New Zealand, it has been estimated that nearly 100,000 new cases of skin cancer are diagnosed each year, which was three times more than all other cancers combined (MelNet, 2025). In 2020, melanoma was the third most commonly registered cancer in the country (Te Whatu Ora, 2020). Moreover, skin cancer is by far the most common cause of mortality, with an estimated 500 deaths in 2018, exceeding the number of road fatalities in the same year (MelNet, 2025). The increasing incidence and mortality of skin cancers pose a huge economic burden on the healthcare system in New Zealand. In 2025, the total cost of skin cancer is estimated at \$494.92 million, which includes \$454.58 million of direct healthcare costs (91.8%) and \$40.34 million of lost productivity from mortality (8.2%) (MelNet, 2025) and this is expected to increase with the ageing population.

As the global incidence of skin cancer continues to rise at an alarming rate, with highest rates observed in New Zealand and Australia, largely due to geographical location, population ethnicity and age (HPA & MelNet, 2017; Narayanan et al., 2010). This increasing trend is particularly evident among fair-skinned individuals (Roky et al., 2025; M. Wang et al., 2025) as lower levels of melanin in fair-skinned individuals provide reduced photoprotection (Brenner & Hearing, 2008). Consequently, exposure to high and prolonged UVR levels places these populations at a significantly greater risk of developing skin cancer (M. Wang et al., 2025), highlighting overexposure to solar UVR as a critical risk factor.

2.1.2 Ultraviolet radiation types and their effects

The solar UVR range, a biologically significant spectrum of solar energy is subdivided into three wavelengths: ultraviolet A (UVA ranging 315-400 nm), ultraviolet B (UVB ranging 280-315 nm) and ultraviolet C (UVC ranging 100-280 nm) (Narayanan et al., 2010). Approximately 90-99% of the UVR reaching the earth's surface is UVA, while UVB accounts for only 1-10% and UVC is completely filtered by the stratospheric ozone layer in the atmosphere before reaching earth (Miller et al., 1998; Pastila & Leszczynski, 2007).

Owing to its longer wavelength, UVA penetrates more deeper into the skin and is responsible for inducing immediate and persistent pigmentation or tanning (Miller et al., 1998; Pastila & Leszczynski, 2007). Excessive and long-term exposure to UVA plays an important role in skin carcinogenesis (Benjamin & Ananthaswamy, 2007). In contrast, although present in smaller quantities, UVB is much more effective in causing sunburns and has long-lasting effects compared to UVA (Wang et al., 2019). Consequently, overexposure to both UVA and UVB poses a greater risk to human health.

2.1.3 Ultraviolet Index

Table 2.1: Ultraviolet Index levels and the recommended sun protection measures

UVI level	Category	Recommended protection
1-2	Low	No protection required. You may safely stay outside.
3-5	Moderate	Protection required. Seek shade during midday hours, slip on a shirt, slop on sunscreen and slap on a hat.
6-7	High	Protection essential. Slip, slop, slap and wrap.
8-10	Very high	Avoid being outside during midday hours. Seek shade, slip, slop, slap and wrap.
11+	Extreme	Reschedule outdoor activities for early morning and evening. Full protection essential.

Source: Adapted from WHO (2002a) and Greenwood et al. (2000)

UV irradiance is commonly expressed in terms of UV Index (UVI), a standard measurement tool developed to indicate the intensity of UVR reaching the Earth's surface (McKenzie, 2017). The UVI is internationally adopted, enabling standardised comparisons of UVI levels across different locations and time periods (NIWA, 2022) with a view to promote public awareness of the risks of UVR exposure and sun protection. UVI values range from zero upward, with higher UVI representing greater UV intensity and an increased potential for damage to the skin and eyes (WHO, 2002a). Table 2.1 presents UVI levels ranging from zero to 11, indicating the potential risk associated with UVR

exposure, along with recommended sun protection measures and colour coding as recommended by the World Health Organization (WHO).

2.1.4 Skin type and sun protection

Individual susceptibility to UVR exposure varies according to skin type commonly classified by the Fitzpatrick skin phototype classification system. This system categorises skin type based on the reaction to solar UVR exposure, which is primarily determined by the amount of melanin in the skin. It provides an estimate of the effect of UVR exposure and associated risks (Fitzpatrick, 1988). Table 2.2 presents the Fitzpatrick skin phototypes, and the approximate UVR exposure estimates to cause sunburn on unprotected skin.

Table 2.2: Fitzpatrick skin phototypes, typical characteristics and estimated ultraviolet radiation exposure likely to cause sunburn on unprotected skin

Skin type and colour	Characteristics	UVR sensitivity and sunburn history	UVR exposure required to elicit sunburn (SED units)
I - White	Fair skin, blue or light eyes and freckles	Extremely sensitive; always burns on minimal exposure	2 – 3
II – White	Red or blonde hair, blue, hazel or brown eyes and freckles	Very sensitive; burns very readily, freckles common	2.5 – 3
III – White or light brown	Brown hair and blue, hazel or brown eyes	Moderately sensitive; may burn on regular exposure with no protection, tans slowly	3 – 5
IV – Light brown	Brown hair and dark eyes	Relatively tolerant; burns rarely, tans rapidly with minimal exposure	4.5 – 6
V – Brown	Brown eyes and dark brown or black hair	Variable sensitivity; higher pigmentation, may burn easily on exposure	6 – 20
VI - Black	Brown eyes and dark brown or black hair	Relatively insensitive; rarely burns, though sunburn is difficult to detect on heavily pigmented skin	6 – 20

Source: Adapted from Wright et al. (2011)

According to the Fitzpatrick classification, pale or fair skin, characterised by lower melanin levels, burns easily when exposed to UVR and therefore needs more sun protection (Fitzpatrick, 1988). The amount of exposure to UVR required to produce the first detectable reddening of the skin is called the minimum erythral dose (MED). The time taken to receive the MED varies considerably between individuals, depending on their skin type (Greenwood et al., 2000). Because sunburn is strongly related to an increased risk of melanoma, the MED is a useful measure of the intensity of biologically effective UVR (Greenwood et al., 2000). The standard erythral dose (SED) is a standardised unit used to quantify the amount of erythemally effective UVR radiation (UVR_{eff}) where $1 \text{ SED} = 100 \text{ Jm}^{-2}$ (McKenzie & Lucas, 2018). It is independent of skin type. At UVI 2, the UVR_{eff} in

standard erythematous doses (SEDs), would be 1.8 SED per hour (Mackay, 2009). For fair-skinned individuals, the first signs of skin reddening 24 hours after exposure are typically at 2.0 to 2.5 SED (McKinlay & Diffey, 1987). In other words, the dose required to achieve minimum sunburn (the MED) is about 2.5 SED (McKenzie & Lucas, 2018).

In contrast, darker skin, which contains more melanin, provides effective natural filtration of approximately twice the UVB radiation of fair skin, resulting in a reduced tendency to burn (Narayanan et al., 2010). Consequently, the UVR dose required to produce minimally perceptible erythema has been estimated to be 6–33 times greater in individuals with darker skin than those with fair skin (Gloster & Neal, 2006). This contributes to the lower incidence of cutaneous malignancies in darker-skinned groups (Narayanan et al., 2010). However, cumulative and incremental UVR exposure increases the risk of developing skin cancer in all individuals, including those with more darkly pigmented skin (Pennello et al., 2000). Therefore, the appropriate levels of sun protection required depend on skin type, ambient UVR level and exposure duration (Mackay, 2009).

2.1.5 Factors contributing to the higher incidence of skin cancer in New Zealand

New Zealand has been called the ‘melanoma capital of the world’, with age-standardised incidence and mortality rates for melanoma slightly exceeding those in Australia and twice as high as in the United Kingdom (McKenzie, 2017). For its latitude, New Zealand has relatively high peak UVI at 40% greater than at the equivalent latitude in North America (McKenzie et al., 2006). **Figure 2.1** shows the mean UVI measured at solar noon for sites in New Zealand compared with locations in Australia and the United Kingdom.

Several possible factors have been proposed to explain the high melanoma rates and relatively higher ambient UVR levels in New Zealand and Australia compared with countries at similar northern latitudes. These include their unique geographical location, ethnicity, age distribution and outdoor lifestyle and behaviour (McKenzie, 2017). However, the relatively higher rates of skin cancer in New Zealand compared with Australia (IARC, 2022) and the underlying reasons for the difference are not yet fully understood (McKenzie, 2017). The difference may be influenced by environmental factors, such as a relatively cooler microclimate that encourages sun-seeking behaviour or sociological factors (e.g., genetics) or could be attributed to variations in healthcare services (McKenzie, 2017; McNoe, 2021). This is a significant knowledge gap that highlights the need for further research (McKenzie, 2017).

		Lat (S)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Darwin	AUS	12	12	13	13	11	9	8	9	10	12	13	12	12
Brisbane	AUS	27	12	11	10	7	5	4	4	5	7	9	11	11
Perth	AUS	31	12	11	9	6	4	3	3	4	6	8	10	11
Sydney	AUS	33	11	10	8	5	3	2	3	4	5	7	9	10
Adelaide	AUS	35	11	10	8	5	3	2	2	3	5	7	9	11
Canberra	AUS	35	11	8	7	5	3	2	2	3	5	7	9	11
Auckland	NZ	37	10	8	7	4	2	1	2	2	3	6	8	9
Melbourne	AUS	38	10	9	7	4	2	2	2	3	4	6	8	10
Wellington	NZ	41	9	8	6	3	1	1	1	2	2	5	7	8
Hobart	AUS	43	8	7	4	3	1	1	1	2	3	4	6	7
Christchurch	NZ	44	8	7	5	2	1	1	1	1	2	4	7	8
Invercargill	NZ	46	7	6	4	2	1	0	0	1	2	3	5	6
		(N)	Lagged by six months for NH											
London (Chilton)	UK	52	5	4	3	1	0	0	0	1	1	3	4	5
Leeds	UK	54	5	4	3	1	0	0	0	1	1	2	4	4
Glasgow	UK	56	4	3	2	1	0	0	0	0	1	2	3	4

Figure 2.1: A comparison of mean noon ultraviolet indexes for selected sites in New Zealand, Australia and the United Kingdom

Source: McKenzie (2017)

Geographical location

New Zealand's geographical location is characterised by a combination of factors, including its lower summer ozone level, closer Earth-Sun separation during summer and generally clear, unpolluted skies, that together contribute to higher UV levels compared with corresponding northern latitudes (McKenzie, 2017). The location influences UVB intensity through its effect on the length of solar path through the atmosphere (Matthews & Hogg, 1996). When the sun is high in the sky, the atmospheric path length is shorter and less UVB is absorbed by ozone. Therefore, at high altitudes, the UVB intensity is higher than at low altitudes. Conversely, during winter, lower solar elevation increases the effective path length, leading to greater absorption and reduced UVB intensity (Matthews & Hogg, 1996).

Because of the Earth's elliptical orbit and the southern hemisphere being closer to the sun during summer, the intensity of the incoming solar radiation is higher (Matthews & Hogg, 1996).

Consequently, biologically damaging UVB intensity is 10-15% greater than at the same latitude in the northern hemisphere summer (Matthews & Hogg, 1996). Additionally, atmospheric turbidity increases path length and can reduce UVB (Matthews & Hogg, 1996). This effect is more pronounced in the tropics and the northern hemisphere. It is relatively weak over New Zealand because of a low aerosol load and minimal atmospheric pollution (McKenzie, 2017). The combination of clear skies and sun closeness in its southern summer allows greater levels of UVB to reach the earth's surface.

Finally, ozone plays a critical role in absorbing UVR and shielding the earth's surface. However, ozone concentrations vary spatially and temporally because of several atmospheric processes. In general, geographical location is an important factor; there is a natural gradient of increasing ozone with increasing latitude (Matthews & Hogg, 1996). Most ozone is produced in the tropics and is transported towards temperate latitudes, with local concentrations influenced by diurnal variability, seasonal cycles and stratospheric wind patterns (Matthews & Hogg, 1996). In New Zealand, these processes contribute to relatively low summer ozone levels. Evidence of ongoing ozone decline suggests that these effects may persist with both short and long-term implications for human health and ecological systems in New Zealand (McKenzie, 2017).

Ethnicity and age

The higher incidence of melanoma in New Zealand is largely attributed to ethnic differences and associated skin type differences (HPA & MelNet, 2017). According to the 2023 census, people of European ethnicity comprise 67.8% of New Zealand's population, followed by Māori at 17.8% (Stats NZ, 2024). Consistent with this population profile, over 95% of melanomas are diagnosed among those identified as European (MelNet, 2025). Melanomas are substantially less common in Māori and Pacific people, less than 2% of diagnoses in 2013 (HPA & MelNet, 2017). The higher incidence of melanoma among ethnic Europeans is mostly associated with individuals' skin type – typically fair skin that freckles or burns easily (Fitzpatrick, 1988), particularly under New Zealand's high summer UVI levels.

Although melanoma incidence is lower in Māori, the cases that occur are more likely to present with significantly thicker melanoma, making them more difficult to treat, or the patients may present with more advanced cutaneous malignant melanoma (CMM), resulting in a poorer prognosis (Hore et al., 2010). This pattern may reflect barriers to early detection, such as lower awareness of melanoma because of the low rate (relative rareness), it being more difficult to detect in people with darker skin, and reduced access to health care (Hore et al., 2010).

Epidemiological evidence demonstrates that the incidence of both melanoma and NMSCs increases with age (HPA & MelNet, 2017), which likely reflects cumulative lifetime exposure to UVR and age-related decline in DNA repair capacity (Zamudio et al., 2025). In New Zealand, data from 2008 to 2012 show that the median age at diagnosis of melanoma was 62 years for females and 66 years for males (HPA & MelNet, 2017). Although NMSCs are not routinely recorded by the New Zealand Cancer Registry, which prevents accurate estimates of age at diagnosis, both melanoma and NMSCs are uncommon in individuals under 40 years old (Brougham et al., 2011; HPA & MelNet, 2017). Notably, despite its overall rarity in younger persons, melanoma remains the most commonly registered cancer among male New Zealanders aged 20–44 years (Ministry of Health, 2016), highlighting the

contribution of early-life UVR exposure to risk accumulation that manifests as increased incidence with age.

NMSCs are not comprehensively captured in national cancer statistics because of their low case fatality rate, sheer case volume and associated resource constraints. Consequently, only NMSC-related deaths are routinely recorded (Sneyd & Gray, 2018). In 2015, 157 deaths in New Zealand were attributed to NMSCs (Ehinz, 2019). Lifetime risk estimates indicate that by age 80 years, approximately 52% of males and 33% of females in New Zealand will have received treatment for NMSCs (Brougham et al., 2011). Collectively, this evidence indicates that the burden of skin cancers in New Zealand is both high and will increase over time (Brougham et al., 2011).

Outdoor lifestyle and behaviour

An outdoor lifestyle and sun-seeking behaviours are important contributing factors to the higher incidence of melanoma in New Zealand (McKenzie, 2017). A recent survey showed that 82% of adults spent over 15 minutes outdoors between 10 am and 4 pm at least once a week. This proportion rose to over 90% among young adults aged between 18-24 years (McNoe et al., 2025). Nearly two-thirds (64%) of respondents reported at least one sunburn during the 2024–25 summer, and 26% reported a severe sunburn. Notably, over one-third of young adults reported experiencing over three sunburn episodes over the summer (McNoe et al., 2025).

These patterns reflect a strong cultural preference for an outdoor lifestyle among New Zealanders (McKenzie, 2017). A large proportion of New Zealand's population tends to spend longer outside in some form of sporting activity and beach or water activities that were associated with the highest number of sunburn episodes (McGee et al., 1995). McLeod et al. (2017) reports that 13.5% of respondents had experienced unintended sunburn during the survey weekend but had not attempted to obtain a tan that summer. Those reporting unintended sunburn were more likely to have been near water and in unshaded areas.

Environmental factors further shape sun-seeking behaviours. Compared with Australia, New Zealand's relatively cooler microclimate and variable wind conditions often encourage people to seek warmth in the sun, even when UV levels are high (Mackay, 2003a). Peoples' preferences and decisions on the use of outdoor environments, such as using shaded areas, are strongly shaped by microclimatic conditions and the urban qualities of the space (Tavares, 2015). In outdoor living areas attached or adjacent to indoors, people are unlikely to wear sunscreen, hats or protective clothing and are likely to remain outdoors for extended periods (Mackay, 2003a).

Despite widespread awareness of the skin cancer risk, sun protective behaviour remains inconsistent (McNoe et al., 2025). Evidence highlights three significant points. First, the increased prevalence of

unintended sunburns may have patterns of high intermittent UV exposure because of a lack of preparation for being outdoors (McLeod et al., 2011) and a lack of available sun protection during outdoor activity (McLeod et al., 2017). Second, this pattern is important in the development of melanoma, and the relative importance of the contributing factors is less known or is under-explored thus requiring more research (McLeod et al., 2017). Finally, future public health initiatives should focus on increasing sun protection (e.g., shade) and reducing potential barriers to sun protection (Dobbinson et al., 2014; McLeod et al., 2017).

Section 2.1 has outlined the significance of excessive UVR exposure as a primary contributor to the development of skin cancer and associated health risks. The global burden of skin cancer continues to rise; New Zealand and Australia experience the highest incidence and mortality rates for both melanoma and NMSCs, underscoring the critical need to address the problem. Several factors contribute to the increased incidence in New Zealand including, geographical location, ethnicity, age, lifestyle and behaviour. Despite widespread awareness of the skin cancer risk, sun protective behaviour remains inconsistent and there may be other environmental factors (e.g., a cooler microclimate influencing less shade use); their relative importance remains unclear, which highlights the need for further research.

2.2 Children's ultraviolet radiation vulnerability and sun protection in primary schools

Chronic exposure to UVR is a significant risk factor for many adverse health impacts, and children are most vulnerable to the harmful effects of excessive UVR exposure (Vanos, 2015). Exposure to UVR during childhood and adolescence is important in the development of skin cancer (Kricker et al., 1994; Whiteman et al., 2001). It is estimated that 25 to 50% of total UV exposure (or erythema dose) that a person receives before age 60 occurs during childhood (i.e., before age 18) (Green et al., 2011). Both cumulative UVR exposure received over time and episodes of overexposure resulting in sunburn are strongly associated with the development of skin cancers (Whiteman et al., 2001).

Childhood sun exposure is associated with the development of melanocytic nevi (moles) that are a risk factor for melanoma (Bauer & Garbe, 2003). The anatomical and functional characteristics of children's skin make it more sensitive, or susceptible, to UV radiation damage compared with that of adults (Seidenari et al., 2000; Stamatas et al., 2010). Evidence suggests that the development of melanocytic nevi occurs mainly in childhood, and the associated risk is more prevalent among children with light coloured skin living in low latitudes, such as Australia, where the ambient UVR levels are high (Green et al., 2011) and among children experiencing intermittent but intense exposure to excessive solar UVR during outdoor sport or other recreational activities (Mahé et al.,

2011). Children's increased vulnerability to infections and reduced immune competence may further increase their susceptibility (Norval, 2011), placing them at an even higher overall risk.

2.2.1 Primary schools as a critical setting for sun protection

The World Health Organization (WHO) identifies young children and primary schools, in particular, as critical settings for promoting healthy sun protection behaviour and reducing the burden of skin cancer (WHO, 2002b). A growing body of evidence demonstrates that school-based intervention targeting children's attitude and behaviour at an early age can effectively promote positive sun protection outcomes (WHO, 2002b). For example, the consistent use of personal sun protection measures, such as wearing a hat, protective clothing and using sunscreen, represents practical easy ways to implement a strategy. The provision of attractive shade areas is likely to promote active shade seeking behaviour during outdoor activity. Embedding sun protection practices into routine outdoor activity, including school breaks, sports lessons and outdoor learning, helps reinforce protective habits and normalises sun-safe behaviour.

Organisation and structural sun protection strategies, supported by policy, daily routines and environmental design, are highly effective in achieving sustained behaviour change and positive long-term outcomes (WHO, 2002b). They provide a practical demonstration of how such sun protective measures are simple to adopt and can be implemented beyond schools at other times. Similar setting-based interventions have been successful across multiple health domains, such as healthy eating behaviour (Racey et al., 2016) reducing obesity-related outcomes (Dabravolskaj et al., 2020) and increasing physical activity levels (Viskari et al., 2025). This approach is particularly relevant in the context of sun protection, because intervention that focuses on increasing awareness of UVR-related health risks, fostering positive attitudes towards sun protection measures, and establishing habitual sun protection practices during outdoor activities are most effective when implemented in early life.

A primary school setting provides greater opportunities to establish sun protection norms and practices, because these children are generally more receptive to the need for sun protection. In contrast, adolescents are more often influenced by peers and fashion trends and are likely to perceive a tan as attractive and healthy. Despite awareness of the long-term health risks, adolescents tend to be more reluctant to adopt sun protection measures (WHO, 2002b). Studies consistently show that primary school children spend substantial periods outdoors during interval and lunch breaks, often engaged in high levels of recreational activity such as running and chasing (Ridgers et al., 2011; Ridgers et al., 2012), resulting in higher levels of UVR exposure (Diffey et al., 1996; Wright et al., 2007), particularly because these periods coincide with peak UV times and when sun protection is inadequate. Children's outdoor physical activity increases the time they are exposed to

ambient UVR and can elevate the cumulative UV exposure across childhood (WHO, 2002b). Accordingly, children's higher UVR exposure during primary school years combined with their developmental receptiveness to behaviour change underscores the importance of primary schools as critical settings for sun protection intervention.

Beyond health benefits, school-based sun protection programmes can substantially reduce future health care costs and are highly cost-effective (WHO, 2002b). An economic evaluation of various health interventions implemented in Australia identified the SunSmart program as one of the most cost-effective initiatives, with a significant positive impact on public health outcomes (Vos et al., 2010). Importantly, the benefits of these programmes extend beyond children, with the capacity to influence teachers, families and the larger community, thereby amplifying their population-level impact (Fagan & Mihalic, 2003).

2.2.2 School-based sun protection programme

Over the years, increasing awareness of the harmful effects of sun exposure and the associated risk of skin cancer has led to worldwide implementation of numerous sun protection and skin cancer prevention initiatives. Early efforts primarily focused on mass media campaigns, most notably the 'Slip, Slop, Slap' Campaign that advocated individual sun protection behaviours such as the use of sunscreen, hats and protective clothing (McNoe, 2021). These initiatives have since evolved into more comprehensive, settings-based approaches that target a range of environments, including educational settings, workplaces, sports and recreational facilities and public spaces.

The WHO developed the Ottawa Charter as a key health promotion framework to guide the planning and implementation of public health initiatives (WHO, 1986). In promoting public health, the charter outlines five action areas: building a healthy public policy, creating supportive environments, strengthening community action, developing personal skills and reorienting health services. Central to the charter is the emphasis on everyday settings and organisations, such as schools and sports bodies, as critical contexts for establishing policies, programmes and interventions that seek to improve population health. These settings also offer centralised access to large groups of people and existing infrastructure that supports the effective delivery of health promotion initiatives (WHO, 1986).

Aligned with these principles, school-based sun protection programmes have an integrated approach to help students, teachers, staff and the wider community to avoid the health risks of UVR exposure during school hours and beyond (WHO, 2002b). The key components of the programme are: (i) *a school-endorsed sun protection policy* that formalises schools' commitment to sun protection; (ii) *a healthy school environment* that aims to significantly reduce children's UVR exposure level; (iii)

community and family involvement to support the adoption and sustained healthy sun-protective practices through consistent information, reinforcement and support across the family, school and wider community; (iv) **sun protection education**, which aims to develop the knowledge, attitudes, values and life skills required to make positive health-related decisions and translate these into daily practice, which therefore must be culturally and geographically relevant (WHO, 2002b).

In line with these WHO principles, several school-based sun protection programmes have been developed and implemented internationally. Notable examples include Australia’s SunSmart School Program (Cancer Council, 2015), the SunWise Schools program in the United States (Geller et al., 2002), the Sun Safe Schools Programme in the United Kingdom (Skcin, 2009), and the SunSmart Schools Programme in New Zealand (CSNZ, 2023). Table 2.3 summarises the key measures adopted in these programmes.

Table 2.3: International key school-based sun protection programmes

Programme	Country & year established	Coordinating body	Key measures adopted
SunSmart Schools (SSS) Program	Australia, 1988	State and Territory Cancer Councils of Australia	Schools required to implement and maintain a comprehensive sun protection approach based on a set of guidelines. These include developing a written sun-protection policy; requiring students to wear broad-brimmed hats; integrating sun-safety education into the school curriculum; ensuring adequate shade provision; and regularly reviewing the process
SunWise Schools Program	United States, 1999	U.S. Environmental Protection Agency (EPA)	A voluntary programme in which schools commit to implementing at least one sun safety action, including the adoption of cross-curricular classroom lessons; measuring and reporting UV information on the internet; enhancing school infrastructure (make changes to school policy or sun-protection structures); engaging with the community; promoting school-wide sun-safety activities
SunSmart Schools Accreditation Programme (SSAP)	New Zealand, 2005	Cancer Society of New Zealand (regional divisions)	A voluntary accreditation programme through 12 criteria that includes, a written sun protection policy; shade provision and planning; hat and protective clothing requirements; sunscreen use; scheduling and supervision of outdoor activities; community engagement; curriculum integration; and regular reviews.
Sun Safe Schools Programme	United Kingdom, 2012	SKCIN - the Karen Clifford Skin Cancer	A free national accreditation programme that guides schools through a four-step process to develop a sun safety policy, educate children, promote protective behaviours and engage parents and caregivers in sun safety practices.

Although these programmes share a common underlying framework, they differ slightly in their implementation. Australia and New Zealand adopt structured accreditation and policy compliance models (McNoe et al., 2022); the United States emphasises flexible education-based adoption (Emmons et al., 2008); and the United Kingdom focuses on guided awareness supported by school-led implementation (Joshy et al., 2025). Given this study’s context, the New Zealand SSAP is described in detail.

The SunSmart Accreditation Programme (SSAP)

In New Zealand, the SunSmart Accreditation Programme (SSAP) was developed by the Cancer Society of New Zealand (CSNZ), a non-governmental organisation. The 'SunSmart' - Schools Programme, which was originally developed by the Cancer Council Victoria in 1993, used 'accreditation' as the way to implement sun protection measures (Montague et al., 2001) in childcare centres and primary schools in Australia. Building on this model, the CSNZ adapted and launched SSAP in 2005, a school-based national programme for New Zealand primary schools.

Aligned with the WHO guidelines, the SSAP is administered nationally, with resources coordinated centrally. Programme delivery is managed regionally by each of the six CSNZ divisions (CSNZ, 2018). The programme operates with no government funding or support and is entirely voluntary. Primary schools have the autonomy to apply for enrolment and become accredited under the programme. A school's Board of Trustees comprising its principal, staff representatives, elected parents and community representatives can decide whether to enrol in the programme and implement sun protection measures. It is important to note that, under the National Administrative Guidelines (NAGs), each school Board of Trustees is required "to provide a safe physical and emotional environment for students; and comply in full with any legislation currently in force or that may be developed to ensure the safety of students and employees" (Ministry of Education, 2013). Accordingly, to enrol and become accredited under the SSAP, the schools must comply with 12 sun protection criteria established by the CSNZ (see Table 2.4).

As in Table 2.4, schools must have a written sun protection policy that formalises the sun safety practices identified in the programme criteria and be implemented in terms 1 and 4. Policies are developed collaboratively with Boards of Trustees (or school committees), parents, staff and pupils that are most effective, well accepted and easily sustained. A comprehensive school sun protection policy should include expected sun protection behaviour, including the use of protective hats, clothing and sunscreen; outline environmental measures that promote shade provision and its use, as well as procedures for rescheduling activities; support curriculum-based education on sun protection and skin cancer prevention, ensure staff role modelling and supervision of sun-safe practices, and include a requirement for regular review (at least every three years) to maintain effectiveness and alignment with current health guidance.

Table 2.4: The minimum criteria for SunSmart Accreditation Programme

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Source: CSNZ (2018)

2.2.3 The effectiveness of the sun protection programme

Globally, though sun protection initiatives have successfully increased sun protection knowledge and awareness (Kingstone & Nicolson, 2020), cross-sectional surveys reveal a poor prevalence of sun protection behaviour in both adults and children (Gage et al., 2017; McKenzie et al., 2023; Watts et al., 2002). In New Zealand, since the launch of the SSAP in 2005, two nationwide surveys were conducted in 2009 and 2017 to evaluate the implementation level of the 12 programme criteria and their outcomes.

The 2009 survey findings reveal that most schools were significantly lagging in fully implementing all 12 accreditation criteria (Reeder et al., 2009). Schools were generally implementing only specific criteria of the programme, such as developing sun protection policies, encouraging the use of sun protective hats and promoting protective clothing (Reeder et al., 2009). These findings align with international studies (Dono et al., 2014; Jones et al., 2008; Turner et al., 2014) that also report that schools frequently implement only certain sun protection measures rather than adopting the comprehensive approach recommended in the WHO guidelines.

The 2017 survey findings, i.e., 12 years after the programme launch, showed substantial improvement in sun protection practices in New Zealand primary schools (McNoe & Reeder, 2019). The key improved areas included a significant increase in the number of schools having sun protection policies (rising from 58% in 2009 to 94% in 2017) that encouraged the use of sun protective hats and protective clothing (McNoe & Reeder, 2019). Despite this result, adequate shade provision remained limited and overall sun protection remained inadequate in many schools.

The following sections address the effectiveness of the SSAP in relation to two key tools, the sun protection policy and supportive environment, because they directly influence the implementation of measures that help directly reduce UV exposure and, therefore, in sun protection outcomes. Other tools, such as sun protection education and community and family support, are not considered here because they are beyond this study's scope.

Sun protection policy

As outlined in the WHO guidelines, having a school-endorsed sun protection policy strengthens sun protection efforts in schools and signals the expectations of the school community regarding sun protection (Collins et al., 2006; McNoe & Reeder, 2019). According to the national survey (McNoe & Reeder, 2019; Reeder et al., 2009) schools with written sun protection policies demonstrated better implementation of sun protection practices, compared to those without policies (McNoe & Reeder, 2019), a trend also observed in a study conducted in Australia (Harrison et al., 2016). Moreover, having a written sun protection policy was a key area that showed significant improvement in terms of a higher number of schools implementing the criteria. However, studies have also noted that the policies are often not comprehensive and having a policy does not necessarily translate into full or consistent implementation of all recommended measures (McNoe & Reeder, 2019). This suggests that while sun protection policies are an important enabling tool, their effectiveness depends on policy quality, comprehensiveness and mechanisms to support implementation.

A supportive environment

The WHO guidelines emphasise the importance of providing a supportive school environment, particularly in the provision of shade, in reducing children's UVR exposure level. Shade reduces the need for personal sun protection and encourages children to engage in spontaneous sun protection behaviour – playing in shaded areas (Boldemann et al., 2006). Accordingly, shade is considered a highly effective environmental tool in the sun protection programme for reducing UVR exposure (HPA & MelNet, 2017).

Despite this widely recognised effectiveness, the findings from two national surveys indicate that the supportive environment component of the SSAP remains inadequately implemented. Shade provision was identified as the least attained criterion in 2017, with only 14% of schools (compared

with 10% in 2009) providing sufficient shade for activity areas in school playgrounds (McNoe & Reeder, 2019). This indicates a significant implementation gap that undermines the potential of shade to reduce children's UVR exposure.

Key barriers to implementation include a lack of public funding for shade provision, which places a significant financial challenge on schools (Collins et al., 2006; McNoe & Reeder, 2019). Additionally, the absence of clear, comprehensive guidelines for shade planning and the design of activity areas, particularly for large sports fields and active play areas, has been identified as an important barrier (Collins et al., 2006). As noted by McNoe and Reeder (2019), without adequate support (e.g., from the New Zealand Ministry of Education) in terms of funding, mandatory requirements and clear guidelines, improved shade provision is unlikely to occur.

It is known that children are vulnerable to overexposure to harmful UVR, with primary schools identified as priority settings to address sun protection and skin cancer prevention efforts. Accordingly, the school-based sun protection programme has been successful in promoting sun protection knowledge and awareness and in supporting schools to implement specific sun protection practices. However, studies show that these tools do not achieve the required protection level; children remain insufficiently protected. This underscores the need for more supportive strategies such as landscape design interventions to promote sufficient sun protection behaviour among children and so help reduce their exposure to harmful UVR.

2.3 Landscape architecture approaches to sun protection in schools

As environmental challenges continue to grow and their impact on human health becomes increasingly complex, landscape architecture can play a vital role in addressing the issues (Brown & Corry, 2011). It has been argued that landscape architecture “has the potential to be as important to the health and well-being of the landscape and the populations in it as medicine is to humanity” (Brown & Corry, 2011, p. 329). As discussed above, schools are widely recognised as ideal settings for public health promotion because they reach large populations and are supported by existing infrastructure that enables effective delivery of health initiatives (WHO, 1986). In this context, the role of a supportive environment is increasingly acknowledged for its capacity to foster positive healthy behaviour in everyday life, particularly among children (Boldemann et al., 2006; Mårtensson et al., 2009).

Growing evidence suggests a strong association between the qualities of children's outdoor environment and their behaviour. The presence of an outdoor environment with appropriate physical qualities, especially a well-designed school playground, can increase children's physical activity levels (Dyment & O'Connell, 2013) and improve sun protection outcomes (Boldemann et al.,

2006). In a study of 11 preschool outdoor environments in Sweden, Boldemann et al. (2011) identified a positive correlation between a green outdoor environment and children's play behaviours that result in lower sun exposure levels. Outdoor environments characterised by dense trees, shrubs and varied topography not only increased play but also reduced UV exposure by 35-40%. According to the study, children's free movement in green outdoor environments and their playful use of the physical surroundings contributed to effective sun protection. Importantly, without explicit instruction to seek shade, children were naturally drawn to playing in and around trees and bushes, thereby triggering spontaneous sun protection behaviours and reducing their UV exposure levels.

Other studies reinforce that green outdoor preschool environments promote physical activity and spontaneous sun protection behaviours, resulting in low UV exposure (Boldemann et al., 2006; Mårtensson et al., 2009). Boldemann et al. (2011) observed that outdoor play during childhood may help protect against the development of malignant melanoma. For example, one study found that swings located in fully unshaded areas, which attracted many children, contributed significantly to higher UV exposure (Boldemann et al., 2011) highlighting the importance of integrating adequate shade into attractive play spaces to effectively reduce children's UV exposure levels. Studies suggest that when substantial changes to outdoor environments are difficult or not feasible, prioritising shade over play structures or activity areas may offer an effective strategy to support both sun protection and physical activity.

Research also increasingly highlights the importance of microclimatic comfort in influencing children's choice and use of playground areas that, in turn, affects their UVR exposure. Research on sun protection practices in New Zealand primary schools found that most children (78.4%) were not in the shade, so they were potentially exposed to high levels of UVR, increasing their risk of sun damage (Gage, Barr, et al., 2018). A study by Mackay (2003b) identifies that many existing shaded areas, such as verandas, porches and covered walkways, were not used by pupils for play. New Zealand's seasonal and highly variable microclimatic conditions pose significant challenges in the design and use of shade (Gage et al., 2022; Mackay, 2003b). Conversely, in warmer regions, poor microclimate conditions significantly contributed to thermal stress and thermal burns in children (Antoniadis et al., 2020; Cheng, 2020; Vanos et al., 2017). This suggests that, regardless of the climate zone, school playgrounds should provide a comfortable microclimatic environment that supports adequate play and physical activity (Cheng, 2020) while remaining adequately protected.

In summary, research on children's outdoor environment use shows that well-designed school playgrounds potentially can lower children's UVR exposure levels by promoting spontaneous sun protection behaviours. Playgrounds with high play potential, adequate shade and comfortable

microclimatic conditions encourage children to play or engage in activities in protected spaces, thereby affecting sun protection. Therefore, based on this critical literature review, this study hypothesises that spontaneous sun protection behaviour can be promoted when school playgrounds incorporate three critical factors: (1) UVR protection, (2) microclimatic comfort and (3) attractive play opportunities (Figure 2.2).

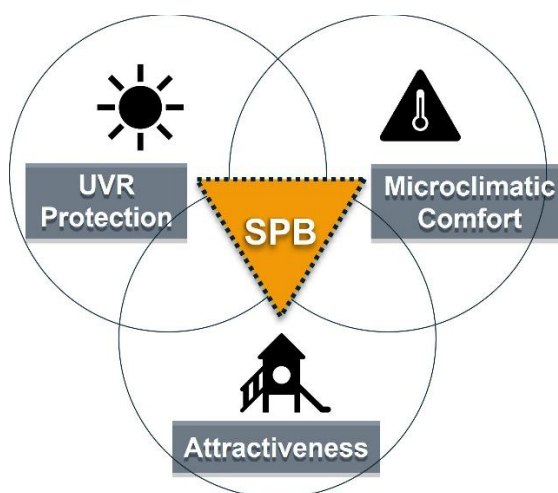


Figure 2.2: The three critical factors necessary to promote sun protection behaviour (SPB)

Note. SPB – Sun protection behaviour

Various definitions exist for the terms ‘school playgrounds’, ‘sun protection behaviour’ and ‘activity zones’, so this study adopts the following definitions that will be consistently applied throughout the thesis to ensure clarity. **Sun protection behaviour (SPB)** is the action of protecting oneself from overexposure to solar UVR, such as sunscreen use and protective clothing. In terms of landscape design, it is the action of occupying or conducting activities in spaces that are designed to protect people from overexposure. Accordingly, the design of school playgrounds that supports the intended SPB refers to **SPB design**. The three critical factors: (1) UVR protection, (2) microclimatic comfort, and (3) attractive play opportunities, needed to support SPB design are collectively referred to as **SPB design objectives**. A **school playground** comprises all outdoor areas, also referred to as ‘activity zones’, that have the potential for play and other outdoor recreational activities in a school. A typical playground may comprise multiple activity zones. An **Activity zone (AZ)** is a designated space in a larger environment, such as a playground, that is specifically designed for or supports a particular activity.

2.3.1 Current approaches to school playground design and planning in support of sun protection behaviour

As established above, in this study, for school playgrounds to effectively support spontaneous SPB, there are three key SPB design objectives: UVR protection, microclimatic comfort and attractive play

opportunities, that must be in place. Given this, the literature was critically reviewed for existing studies on children's outdoor environments, including school playgrounds, urban parks and activity areas, to understand current landscape design and planning approaches that support SPB in children.

Table 2.5 summarises the studies on children's outdoor environments and the SPB design objective assessed. The review indicates that existing studies predominantly examined only individual SPB design objectives; very few studies jointly assessed a maximum of two SPB design objectives. There is a clear lack of studies that integrate all three objectives in a single evaluation framework. Therefore, it is unclear whether, and to what extent, current school playgrounds are designed to promote sufficient SPB among children. Also, it is unclear whether all three objectives are adequately addressed to achieve the intended SPB outcomes, indicating a potential need to integrate the three SPB design objectives and evaluate the school playgrounds.

Table 2.5: A summary of studies on playgrounds and the factors investigated

Studies	Author(s) and Year	Country	Setting	Factors Investigated
Sunshade design in New Zealand primary schools	Mackay (2003)	New Zealand	Primary schools	Effectiveness of shade structures
Measurements of the solar UVR protection provided by shade structures in New Zealand primary schools	Gies & Mackay (2004)	New Zealand	Primary schools	Shade protection factor and UVR attenuation
Shade in urban playgrounds in Sydney and inequities in availability for those living in lower socioeconomic areas	Anderson et al. (2014)	Australia	Urban playgrounds	Shade availability and equity
Wellington playgrounds uncovered: An examination of solar ultraviolet radiation and shade protection in New Zealand	Gage et al. (2018)	New Zealand	Urban playgrounds	Shade coverage, UVR exposure levels, and protection effectiveness
Using Google Earth to assess shade for sun protection in urban recreation spaces: Methods and results	Gage et al. (2018)	New Zealand	Urban open space activity areas	Remote shade assessment methods and shade availability
Shade provision in public playgrounds for thermal safety and sun protection: A case study across 100 play spaces in the United States	Olsen et al. (2019)	United States	Public playgrounds	Shade provision, UVR protection and thermal comfort
Shade in playgrounds: Findings from a nationwide survey and implications for urban health policy	Gage et al. (2019)	New Zealand	Urban parks and playgrounds	Shade availability
Exposed children, protected parents: Shade in playgrounds as a previously unstudied intervention field of cancer prevention	Schneider et al. (2020)	Germany	Public playgrounds	Shade protection and health protection
An evaluation of the amount, type and use of shade at public playgrounds in Guelph, Ontario, Canada	Cimino et al. (2022)	Canada	Urban playgrounds	Shade quantity, type and use
Sun-Safe zones: Investigating integrated shading strategies for children's play areas in urban parks	Cherian & Subasinghe (2023)	Australia	Urban parks	Integrated shade strategies and UVR protection
Swedish pre-school children's UVR exposure - A comparison between two outdoor environments	Boldemann et al. (2004)	Sweden	Preschool environments	Influence of outdoor environment design on UVR exposure
Impact of preschool environment upon children's physical activity and sun exposure	Boldemann et al. (2006)	Sweden	Preschool environments	Relationship between playground design, UVR exposure and physical activity
Preschool outdoor play environment may combine promotion of children's physical activity and sun protection. Further evidence from Southern Sweden and North Carolina	Boldemann et al. (2011)	Sweden & United States	Preschool environments	Interaction between playground design, UVR exposure and physical activity

Suberythral sun exposures at Swedish schools depend on sky views of the outdoor environments – Possible implications for pupils' health	Pagels et al. (2016)	Sweden	Elementary schools	Sky view factor, shading and UVR exposure levels
Pupils' use of school outdoor play settings across seasons and its relation to sun exposure and physical activity	Pagels et al. (2020)	Sweden	Primary schools	Seasonal play behaviour, UVR exposure and physical activity
The relationship between school ground design and intensity of physical activity	Dyment et al. (2009)	Australia and Canada	Primary schools	Relationship between school ground design and physical activity intensity
Outdoor environmental assessment of attention promoting settings for preschool children	Mårtensson et al. (2009)	Sweden	Preschool environments	Outdoor environmental characteristics and physical activity
Where do children choose to play on the school ground? The influence of green design	Lucas & Dyment (2010)	Australia	Primary schools	Effect of green design and play choice
Primary school playgrounds: Features and management in Victoria, Australia	Chancellor (2013)	Australia	Primary schools	Playground characteristics and activity
An assessment of schoolyard features and behaviour patterns in children's utilization and physical activity	Anthamatten et al. (2014)	United States	Elementary schools	Influence of school playground features on play behaviour and activity patterns
A microgeographic analysis of physical activity behaviour within elementary school grounds	Anthamatten et al. (2014)	United States	Elementary schools	Spatial distribution of playground features and physical activity intensity
Evaluation of thermal perception in schoolyards under Mediterranean climate conditions	Antoniadis et al. (2016)	Greece	Primary schools	Thermal comfort
Effects of physical activity and shade on the heat balance and thermal perceptions of children in a playground microclimate	Vanos et al. (2017)	United States	Elementary schools	Thermal comfort and shade assessment
Hot playgrounds and children's health: A multiscale analysis of surface temperatures in Arizona, USA	Vanos et al. (2017)	United States	Urban playgrounds	Surface temperatures and heat exposure risks
Schoolyard shade and sun exposure: Assessment of personal monitoring during children's physical activity	Vanos et al. (2017)	United States	Elementary schools	Personal UVR exposure during physical activity
Design of thermally comfortable and UVR - health schoolyards for children in low latitude urban areas in North America (College Station, TX)	Cheng (2020)	United States	Primary schools	UVR protection and thermal comfort

Moreover, if school playgrounds are to be systematically evaluated for their potential to support SPB design through an integrated design approach, there is a need to better understand the variables associated with each objective appropriate spatial targets, and measurement methods required for assessment. Therefore, to address this and develop a more comprehensive understanding, the literature relating to each of the three SPB design objectives was reviewed separately and accordingly discussed in detail in the sections below.

2.4 Landscape design for ultraviolet radiation protection

2.4.1 Effective ultraviolet radiation protection: Definitions and influencing factors

Solar UVR exposure in outdoor environments is from two main sources: **direct UVR**, which is received directly from the sun (Greenwood et al., 2000) and **indirect UVR**, which comprises diffuse radiation scattered by the atmosphere and reflected radiation from surrounding surfaces (Mackay, 2016). As noted by Mackay (2016, p. 15), in open field conditions, the UV exposure a person receives is approximately 50% from direct and 50% from diffuse UV radiation. Given this, UVR protection studies and shade design guidelines emphasise that effective UVR protection can be achieved only when outdoor environments are designed to mitigate both the direct and indirect UVR components (CDC, 2008; Greenwood et al., 2000; Parisi & Turnbull, 2014). Therefore, effective UVR protection is defined as *the provision of adequate protection from both direct and indirect solar UVR*.

2.4.2 Environmental design strategies for controlling direct and indirect ultraviolet radiation

As noted above, direct UVR, which is the radiation received directly from the sun, is most commonly mitigated by placing a barrier and creating shade (Greenwood et al., 2000). Shade that provides a complete barrier to incoming direct UVR is considered highly effective in reducing exposure to direct UVR (Mackay, 2009). In contrast, environmental strategies to control indirect UVR are much more complex, because that radiation comprises diffuse (or scattered) radiation and smaller amounts of reflected UVR from surrounding surfaces (Mackay, 2016). These components are now discussed separately.

Diffuse radiation

Diffuse radiation refers to the portion of solar UVR that reaches the earth's surface after being scattered by clouds or other atmospheric particles, rather than travelling directly from the sun (Greenwood et al., 2000). Unlike direct UVR, which travels straight from the sun, diffuse radiation may come from any direction. As a result, diffuse radiation constitutes a significant component of total UV exposure and is more difficult to minimise because it can reach areas that are otherwise shaded from direct UVR (Parisi et al., 2000).

Diffuse radiation, which is generally assumed to be evenly distributed around the hemisphere (Mackay, 2016) needs an environmental strategy because it is strongly influenced by the proportion of visible sky (Greenwood et al., 2000) commonly expressed as the sky view factor (SVF). SVF is defined as the proportion of open sky visible from a specific point under a shade canopy (Mackay, 2009). It represents the degree of openness of an outdoor environment and is directly proportional to the amount of diffuse radiation received (Erell et al., 2011), with higher SVF values corresponding to a greater exposure to diffuse radiation. In other words, shade that screens 87% of the sky view can effectively shield diffuse radiation (Mackay, 2016).

Reflected radiation

Reflected radiation refers to solar radiation that is reflected from surrounding surfaces such as walls, pavements, snow and sand (Greenwood et al., 2000). Although it typically represents a smaller component of total UVR exposure than direct and diffuse radiation, reflected UVR contributes to overall UV exposure in two main ways. First, direct reflection from nearby surfaces significantly increases the intensity of UVR received by a person (Chadyšiene & Girgždys, 2008). Second, reflected radiation contributes to diffuse radiation, thereby increasing total UVR, but its relatively low proportion makes it less significant (Turner & Parisi, 2018).

The reflectance of a surface is commonly expressed as albedo, which is defined as the fraction of incident sunlight that is reflected by a surface (Turner & Parisi, 2018). In UVR studies, the standard definition of UV albedo is the ratio of reflected (upwelling) irradiance to incident (downwelling) irradiance (Turner & Parisi, 2018). Accordingly, the UV albedo of surfaces is widely used to assess the contribution of reflected UVR in outdoor environments. Surfaces with a higher UV albedo typically reflect more UVR, contributing significantly to total UV exposure (Turnbull & Parisi, 2003; Turner et al., 2008). The UV albedo of natural surfaces is generally low, often around 5% or lower, with grass being 2% - 3% (Parisi & Turnbull, 2014). The UV albedo of sand typically ranges from 15% to 30%; snow can be as high as 90% (Parisi & Turnbull, 2014). As a general guideline, hard, smooth surfaces, such as concrete, tend to reflect more UVR than softer, varied surfaces such as grass (Greenwood et al., 2000). Consequently, the use of grass or other low UV albedo materials is commonly recommended in place of concrete or paved surfaces as a strategy to reduce reflected UVR in shaded areas (Parisi & Turnbull, 2014).

Table 2.6 summarises the UV albedo of various surfaces commonly used in outdoor recreational areas. The magnitude of reflected radiation is also influenced by solar altitude angle (i.e., the sun's position in the sky) and surfaces' orientation (Turner et al., 2008) at the exposure time. Most ground surfaces do not reflect UVR uniformly in all directions, but depend on the direction of incoming radiation (Greenwood et al., 2000). Notably, at higher solar angles, such as around solar noon,

horizontal ground surfaces reflect a greater proportion of UVR because of their larger surface area directly incident to the sun's angle, leading to increased directional reflection (Erell et al., 2011).

Table 2.6: Ultraviolet albedo of ground surfaces commonly used in outdoor areas

Ground surface material	UV Albedo (%)	Reference(s)
Synthetic turf / Tennis court	1.2 to 1.5	Loveday et al. (2019)
Grass	2	Greenwood et al. (2000) Chadyšiene and Girgždys (2008)
Bare ground	4.3	Turner and Parisi (2018)
Natural wood (clear) / Timber deck	5	Cherian and Subasinghe (2023) Turner and Parisi (2018)
Soil-Clay / Humus / Wood mulch	5	Cherian and Subasinghe (2023) Turner and Parisi (2018)
Open water	5	Cherian and Subasinghe (2023)
Brick	5.7	Turner and Parisi (2018)
Asphalt / Bitumen	6	Turner and Parisi (2018) Greenwood et al. (2000)
Gravel	7	Chadyšiene and Girgždys (2008) Turner and Parisi (2018)
Tarmac road	8.7	Turner and Parisi (2018)
Rubber mat	10	Cherian and Subasinghe (2023)
Concrete (dark – light)	10 - 15	Greenwood et al. (2000) Cherian and Subasinghe (2023) Turner and Parisi (2018)
Stone	20	Cherian and Subasinghe (2023)
Sand (dry)	20	Cherian and Subasinghe (2023)
Snow	88	Chadyšiene and Girgždys (2008) Greenwood et al. (2000) Turner and Parisi (2018)

In most instances, reflected UVR comprises only a small component of total UVR exposure at a given location, with some notable exceptions for locations characterised by high UV albedo surfaces such as ski-fields or sandy beaches (Turner & Parisi, 2018). Therefore, the relative importance of reflected UVR varies according to the surface type, UV albedo, surface orientation and time of the day (Turner & Parisi, 2018) and should be carefully considered in the design of outdoor areas.

2.4.3 Shade assessment and planning for ultraviolet radiation protection

Shade is a key environmental strategy to provide effective UVR protection, defined as the provision of adequate protection from direct and indirect UVR. Accordingly, the effectiveness of UVR protection can be determined through shade assessment. Shade assessments are essential in creating highly effective shade environments because they help determine whether existing shade is appropriately located of proper size and help identify additional shade requirements to protect children and adults from overexposure to UVR (Parisi & Turnbull, 2014). Shade assessments are

primarily used to determine the adequacy of existing shade in terms of **shade quantity**, which refers to the proportion of shade available, and **shade quality**, which refers to the level of protection offered by the shaded areas (Greenwood et al., 2000).

The assessment of shade quantity

Shade quantity refers to the amount or proportion of shade available at a given location. It is measured by assessing the percentage of shade covering the given area at various times of the day and year. The assessment of shade quantity helps determine whether the amount of shade is adequate for the number of people using the site and/or the need for additional shade.

To assess the amount of shade, most UVR protection studies estimate mean shade coverage, defined as the ratio of shaded area to the total surface area of a given location or site (Anderson et al., 2014; Gage, Robinson, et al., 2018) and use pre-defined intervals such as none (0% cover), some (0% to 50% cover), majority (> 50% to < 100% cover), or complete (100% cover) (Cimino et al., 2022; Gage, Wilson, et al., 2018). This helps identify areas with insufficient shade and which requires shade improvement.

Several shade design guidelines, such as the Shade Handbook (Cancer Council Western Australia, 2007); Creating Shade (Stoneham et al.); Under Cover (Greenwood et al., 2000) and the Center for Disease Control and Prevention (CDC) on Shade Planning in Schools (CDC, 2008) are comprehensive documents on shade assessment and planning. They provide general recommendations for shade provision across different activity types, including active play areas, seating areas and outdoor learning areas. However, these guidelines typically classify shade requirements only in broad terms, such as 'partial' or 'complete' shade, without clearly defining the categories in terms of measurable indicators such as mean shade cover.

The Under Cover shade guideline recommends a minimum shade requirement of around 25 m² per student for school settings (Greenwood et al., 2000). Though this offers a measurable target, it applies to the school as a whole and does not provide clear guidelines on how shade should be spatially distributed, or how much shade coverage is required in specific activity areas. Consequently, the shade recommendations remain relatively broad, providing limited guidance on the proportion of shaded area needed in different activity zones.

Globally, shade assessment studies in outdoor recreational areas, such as urban parks and playgrounds, consistently find that, regardless of the setting, the overall shade coverage was low, limiting the opportunity for site users to seek shade (Anderson et al., 2014; Cherian & Subasinghe, 2023; Cimino et al., 2022; Gage, Barr, et al., 2018; Schneider et al., 2020). A shade audit of eight New Zealand schools found that all had inadequate shade for sports and activity areas, with many sand pit

areas and fixed play equipment areas being completely unshaded during summer (Watts & Meikle, 2008). A similar survey of New Zealand primary schools revealed that only 14% had enough shade for the main play areas in their school playgrounds (McNoe & Reeder, 2019), which indicates that children in most New Zealand schools are unnecessarily exposed to high levels of UVR while participating in school activities.

Evidence from shade assessments conducted across outdoor recreational settings in New Zealand, including parks and playgrounds, indicates that 86% of playground activity areas lacked shade (Gage et al., 2019) with 70% of activity areas containing large structures or play equipment for play and 97% of fixed play equipment areas having no shade cover (Gage, Barr, et al., 2018). A German study reported that, although 41% of overall playground areas were shaded, shade coverage decreased to just 22% when only designated activity areas were considered (Schneider et al., 2020). This finding indicates that shade was not located where it was most needed or functionally appropriate for playground use. Similar results were reported in an Australian study that records a low mean shade coverage of 37% across playground activity areas (Anderson et al., 2014). Research in New Zealand recorded a significantly lower level - a mean shade coverage of only 11% (Gage, Robinson, et al., 2018), further reinforcing the pattern of inadequate shade provision in playgrounds and activity areas.

These findings highlight the importance of shade location, rather than overall shade quantity alone, as a critical determinant of effective sun protection. Studies consistently demonstrate a strong association between shade distribution and the type of activity area (Anderson et al., 2014; Schneider et al., 2020). Areas designated for sitting and eating, which were often located around the periphery of playgrounds, are more likely to be shaded (Cimino et al., 2022; Schneider et al., 2020). In contrast, the main activity areas and fixed play equipment areas, where children spend prolonged periods engaged in active play, are identified as the least shaded or are entirely unshaded (Cimino et al., 2022; Gage, Barr, et al., 2018; Gage, Wilson, et al., 2018; Schneider et al., 2020). This uneven spatial distribution of shade further increases the significant UVR exposure risk for children because high-use activity areas are inadequately protected.

Shade assessment studies further highlight an important association between the type of shade structure and overall shade coverage at a given location. Permanent shade structures, such as pavilions and covered outdoor learning areas, provide greater mean shade coverage than natural shade provided by trees (Anderson et al., 2014). Trees' ability to span larger areas and accommodate more users allows them to provide broader, more consistent shade provision, making them better suited for protecting high-use activity areas (Gies & Mackay, 2004). Accordingly, permanent shade structures are commonly observed as the dominant shade sources in settings such as sports grounds,

outdoor pools (Gies et al., 2013; Potente et al., 2011) and, to some extent, in schools (Dobbinson et al., 2014; Gies & Mackay, 2004). A study of toddlers' pools shows that 83% of the shade was provided by permanent shade; only 23% came from natural shade (Gies et al., 2013). In contrast, natural shade tends to be more prevalent in playgrounds and beach environments (Gage, Barr, et al., 2018; Gage et al., 2019; Schneider et al., 2020).

In addition to differences in shade type, studies also highlight socioeconomic (SES) disparities in shade provision across settings. Findings consistently report that playgrounds in higher SES neighbourhoods exhibit greater shade coverage than those in lower SES areas (Anderson et al., 2014; Crawford et al., 2008). This disparity is largely attributed to the greater presence of natural tree shade, with public open spaces in higher SES (Crawford et al., 2008) having approximately 72% shade cover from trees, compared with 44% in lower SES areas (Anderson et al., 2014). Additionally, the study shows that up to 54% of the activity areas of playgrounds in lower SES areas had no shade at all (Anderson et al., 2014), a result supported by a New Zealand study that reported that playgrounds in lower SES areas were 43% less likely to have at least one source of shade (Gage et al., 2019). Interestingly, the study by Schneider et al. (2020) reports that playgrounds in the city centre, where trees are larger, had more shade than those located towards the wealthier outskirts.

The assessment of shade quality

Shade quality refers to the level of UVR protection offered by shaded areas. It indicates the usability of shade by determining whether the available protection is adequate for the intended period of use (Greenwood et al., 2000). Shade quality can be assessed by estimating the protection factor (PF) of shaded areas. The PF is defined as the ratio of UVR measured in full sun to that measured in the shade (Gies & Mackay, 2004) and is expressed as:

$$\text{PF (protection factor)} = \frac{\text{UVR in open}}{\text{UVR under shade}}$$

The PF used to rate the effectiveness of shade is conceptually very similar to the sun protection factor (SPF) applied to sunscreen products (Mackay, 2009). For example, a PF 15 means that only 1/15th of UVR penetrates the shade covering, effectively blocking 93% of UVR and offering sufficient protection (Parsons et al., 1998). The protection level offered by shaded areas, expressed as PF, must be appropriate for the proposed period of use, the ambient UVI levels of the geographic location and the users' skin type (Gies & Mackay, 2004). At most locations in New Zealand and Australia, the daily total UVR dose on clear summer days can reach approximately 60 SED (NIWA, 2024), where 1 SED is equivalent to 100 J/m² effective (McKenzie & Lucas, 2018). Generally, 2 SED is considered sufficient UVR to cause erythema or sunburn in people with sensitive or fair skin (Fitzpatrick, 1988).

Consequently, for shade structures to be effective for all-day use, the UVR dose should be reduced to less than 2 SED. As noted by Mackay (2016), if total daily UVR is approximately 60 SED, the biologically effective direct and diffuse components can be assumed to contribute approximately 30 SED each. While shade structure can effectively block most of the direct component, the remaining diffuse UVR (i.e., 30 SED) must be reduced. A shade structure with a PF greater than 15 can reduce this diffuse component to below 2 SED (Gies & Mackay, 2004) and is therefore considered effective, providing 94% protection from direct solar UVR as well as reducing indirect UVR (Parsons et al., 1998). Accordingly, shade structures with a PF of 15 or above are considered desirable for outdoor activities by offering satisfactory protection for midday and whole-day use (Gies & Mackay, 2004).

Evidence from New Zealand suggests that, in school environments, the primary role of shade structures during summer is to provide protection during the midday lunch break, when UVR reaches its daily peak (Gies & Mackay, 2004). During this period, the maximum UVR dose received over a one-hour period typically ranges between 8 and 10 SED across most locations in New Zealand (NIWA, 2024). Under these conditions, shade structures with PF values in the range of 4-6 will provide sufficient protection to limit UVR exposure to below 2 SED during the lunch break, particularly when combined with other personal sun protection measures (Gies & Mackay, 2004). Nevertheless, shade structures with higher PF values would offer greater protection and are therefore preferable.

Studies examining shade structures consistently demonstrate that the characteristics of shade structures strongly influence their PF (Gies & Mackay, 2004; Parisi & Turnbull, 2014) and, consequently, the level of sun protection provided in shaded areas. For easier understanding, shade structures are commonly categorised into natural, built and composite types (Greenwood et al., 2000). Natural shade structures include trees, large shrubs, vines and ground cover. Built shade structures are primarily designed and constructed of manufactured components, and they may be either permanent (e.g., solid roofs made of concrete, timber, metal; covered walkways; verandas) or temporary (e.g., shade sails, shade umbrellas). Composite structures use a combination of natural and built elements, such as a trellis or pergola with climbers or vines (Greenwood et al., 2000).

Evidence indicates that built shade structures generally provide higher, more consistent PF values than natural shade, particularly when solid, opaque roofing materials are used (Cheng, 2020; Gies & Mackay, 2004; Mackay, 2016). Research indicates that the PF of built shade structures varies according to the structure's size, composition and orientation (Cheng, 2020; Mackay, 2016). Measurements in New Zealand primary schools report PF values between 4 and 8 for most built shade structures, which is sufficient to provide protection during school lunch breaks. Exceptionally high PF values (up to 140) have been recorded under large, well-oriented structures with solid roofing and minimal sky exposure (Gies & Mackay, 2004). A study examining shade structures in

outdoor recreational areas identified that only a small proportion of the structures achieved a high protection level (i.e., PF 15 and greater), whereas canopies used at swimming and cricket venues for all-day events offer lower UVR protection of approximately PF 5 (Mackay, 2016). This was largely as a result of the flat, open design of the shade structures, with high canopy sides intended to maintain sightlines and/or views that increase the SVF and allow greater penetration of diffuse UVR (Mackay, 2016).

Natural shade structures, an important, widely used component of shade provision outdoors, exhibit varying PF values strongly influenced by canopy characteristics such as size, height and foliage density (Cheng, 2020; Greenwood et al., 2000). Empirical studies examining PF of trees demonstrate that, under a number of conditions, the PF ranged from 2 to 20 (Gies et al., 2007). For example, sparse canopy density gum trees provide a relatively low PF of 2–6, whereas denser oak trees have higher PFs, approximately 3 to 20 (Parisi et al., 1999). Longitudinal measurements of multiple tree species over several months report PFs in the range of 5–10, with seasonal fluctuations largely attributed to changes in canopy density (Gies et al., 2007). International evidence supports the role of canopy density in the PF of trees. For instance, a United Kingdom study reports PFs as low as 4 for trees with sparse canopies, increasing to around 20 for trees with dense foliage, particularly when located near other trees or structures (Diffey & Diffey, 2002). Modelling studies suggest that a cluster of trees providing canopy cover of 90% improves PF values to around 10 (Grant et al., 2002).

Another study reported that PF values under a single tree were generally lower than those recorded under clusters of the same species (Cheng, 2020), highlighting the importance of tree arrangement in reducing the SVF and enhancing overall protection. The study emphasises the concept of creating ‘effective shade’, which refers to the shaded area on the ground, rather than canopy cover area above the head. A study by Mackay (2006) reports that the average PF of shade under the canopy was 4.8, whereas the average PF of canopy shadow open to the sky was a substantially lower 2.8. These findings highlight a critical distinction in PF values between the shaded area on the ground under the canopy and the canopy shadow open to the sky. This difference is particularly important because users may perceive both conditions as equivalent shade, even though the UV protection level varies substantially, potentially increasing their risk of UVR exposure (Mackay, 2006).

Finally, the PF under temporary shade structures such as shade sails and shade umbrellas was found to be substantially lower, ranging from 1.3 to 2.5, largely because of diffuse radiation coming in from the side (Kudish et al., 2011). In many cases, stand-alone shade structures in open areas without nearby buildings, trees or vegetation tend to have a higher SVF, which further increases multidirectional diffuse UV exposure and reduces the PF (Turnbull & Parisi, 2004). Importantly, radiation under the shade does not originate solely from overhead sky but also from multiple

directions (Cheng, 2020). Under an artificial canopy, protection is often uneven and, for this reason, the placement of play features or equipment beneath shade structures should be carefully planned according to the geographic orientation to minimise exposure to incoming diffuse radiation (Cheng, 2020).

Overall, evidence across all shade types indicates two important determinants of PF: the UV transmissivity of the shade, where lower transmissivity contributes to a higher PF, and the SVF beneath the shaded area, where a lower SVF contributes to a higher PF. Accordingly, built structures with a solid roof and low SVF typically achieve the highest PF values. Natural shade, while beneficial, provides more variable protection depending on canopy density and spatial arrangement. Temporary structures with permeable materials and high SVF tend to offer the lowest PF.

2.4.4 Methodologies used in ultraviolet radiation protection assessment

Several approaches can be used to assess UVR protection at a given location. The method choice depends on the component being assessed, which includes shade quantity, shade quality and the contribution of reflected UVR. For the purpose of this discussion, existing approaches for UVR protection assessment can be broadly grouped into shade audit, shade modelling and simulation, and instrument-based measurements. Each approach has its own strengths and limitations; they are often used in combination to provide a comprehensive assessment.

Shade audits

Shade audits are the most commonly used methods in UVR protection assessment studies (Parisi & Turnbull, 2014). Their primary purpose is to evaluate shade quantity and so determine the need for additional shade. Depending on the resources and project scale, shade audits can be conducted using either direct field observation or digital image analysis (Parisi & Turnbull, 2014). Direct field observation involves on-site inspection, where existing shade patterns are measured or mapped on the ground. Assessments are often conducted at the critical protection time (CPT) (i.e., the period of highest UVR risk) determined by both time of day and season (Greenwood et al., 2000). This method provides spatially accurate information but requires extensive fieldwork and can be time-consuming depending on the sample size and the distribution of audit sites. Without the need for a specialist, this method can be used by a layperson and is suitable for small-scale projects (Parisi & Turnbull, 2014). However, the method may be subject to observer bias in interpreting shade estimates and is often limited by temporal variation if seasonal and daily changes are not incorporated.

Digital image analysis involves shade analysis using aerial photographs, publicly available satellite imagery such as Google Maps, Google Earth Street View, and Google Earth satellite images (Gage, Wilson, et al., 2018; Gage et al., 2019; Schneider et al., 2020). These images provide a bird's-eye view

of the existing shade pattern of the location from which shade estimates can be made. The method enables large-scale analysis without the need for extensive fieldwork and time and reduces bias without being limited by geographical location (Gage, Wilson, et al., 2018). However, there are some limitations in using this method. First, the images used for assessment may be outdated, so it is more suitable for regions with recent aerial and street view images (Gage, Wilson, et al., 2018). The method may be less suitable for locations where images are not available or are blocked by other amenities (Gage, Wilson, et al., 2018). Resolution constraints may limit accuracy, and temporal variations may not be considered.

Shade modelling and simulation

The shade modelling and simulation approach involves projecting shade patterns using 3D shadow simulation software such as AutoCAD, SketchUp (Trimble Inc.) or geographic information system (GIS) based shadow analysis tools. The method is primarily used to estimate shade quantity and, when combined with other techniques such as SVF estimation, can be used to assess shade quality.

A key strength of modelling is its ability to integrate temporal variability because simulations can be run across multiple times and dates, which is often difficult to do with a shade audit. Secondly, the output generated by this method is spatially explicit, supporting designers and decision-makers in targeted design intervention (Lin & Brown, 2021). This approach facilitates scenario testing, which is especially valuable for planning and landscape design. With suitable spatial data inputs, modelling can be applied to large-scale studies, and it allows comparisons across many sites.

However, the approach requires technical expertise and some specialised tools such as web-based platforms (e.g., WebShade) involving licence costs that may limit accessibility. In addition, the output accuracy depends on input data's quality (e.g., building geometry, tree canopy). Despite its analytical advantages, there has been limited use of this method in UVR assessments.

Instrument-based measurements

Instrument-based techniques are the most frequently used methods for UVR assessment (Parisi et al., 2010). They involve direct measurement of UV irradiance and personal UV exposure using radiometers, spectroradiometers or personal UV dosimeters. Radiometers and spectroradiometers measure incident UV irradiance (W/m^2) or erythemally weighted UV, which can be expressed in biologically relevant units such as SED. Personal UV dosimeters measure cumulative individual UV exposure over time, converted to a quantifiable dose (usually expressed in SED) (Parisi et al., 2025). They estimate the actual UV dose received by individuals, rather than ambient environmental UV level. Using these tools and comparing UVR levels measured in open and shaded locations, the measurements can be used to estimate shade quality and determine the level of protection offered.

Spectral UV measurements enable assessment of the relative contribution of UVA and UVB and the material or canopy transmission characteristics (Parisi et al., 2025).

The strengths of these methods are the high precision and objective quantification of UVR (Caetano et al., 2024). Studies show that equipment cost and the calibration requirements can constrain large-scale application (Caetano et al., 2024). Because of their limitations in terms of spatial data, they are frequently combined with shade audits or modelling to integrate precise UV data with the spatial distribution pattern, thus enabling a more comprehensive assessment (Cherian & Subasinghe, 2023).

2.4.5 Research gaps in ultraviolet radiation protection studies

Evidence indicates that both internationally and particularly in New Zealand, sun protection studies in school settings have predominantly focused on sun protection policies and implementation practices (Gage et al., 2017) rather than assessment of shade provision. Shade assessment studies have largely been confined to outdoor recreational areas such as urban parks and playgrounds (Anderson et al., 2014; Gage, Barr, et al., 2018).

In New Zealand, only two studies have specifically measured shade or shade availability in school playgrounds to determine primary school children's sun protection levels. A study by Gage et al. (2017) examined sun protection among primary school children across eight schools in the Wellington region of New Zealand, assessing both shade availability and children's shade use. A key finding was that most children were not under the shade cover and were significantly exposed to sun, indicating an elevated risk of sun damage for most children. The study also highlights the lack of evaluative studies on sun-safety intervention in primary and intermediate schools, apart from SSAP.

Another New Zealand study by Gies and Mackay (2004) measured the UVR protection provided by shade structures in 10 primary schools. Of the 29 shade structures assessed, only six demonstrated a PF greater than 15; many provided PF values between 4-8, indicating moderate to low protection. Although the study aimed to measure UVR protection levels in primary schools, it assessed only 29 purposefully selected shade structures and did not examine overall shade availability or usability across the schools' playgrounds.

Wright et al. (2007) investigated UVR exposure of 345 primary school children in 23 New Zealand schools using electronic UVR monitors. The mean total daily UVR exposure was 0.9 SED at measured sites, with higher levels on weekdays than weekends. This highlights the important role of school settings in sun protection. However, the study did not assess the availability of shade in schools nor its contribution to the observed exposure levels among primary school children.

Broadly, shade assessment studies in outdoor recreational areas have predominantly focused on assessing shade quantity, whereas the protection level provided and the functional usability of shade (i.e., whether the PF adequately supports the required periods of use) remain insufficiently understood. The relative importance of this component in the overall assessment of UVR protection effectiveness has not been comprehensively investigated.

Another underexplored area is the contribution of reflected UVR and the tangible effects of albedo values to individual UV exposure (Cherian & Subasinghe, 2023). Although many surfaces have low UV reflectivity, the potential cumulative effect of reflected radiation, particularly in environments with sand or light pavements, such as school playgrounds, remains poorly quantified. Because of the low prioritisation of this component, empirical UV albedo data are available for only a narrow range of materials (Turner & Parisi, 2018) leaving many commonly used surfaces uncharacterised.

Consequently, UVR assessments often lack accurate representation of the reflected UV contribution.

Numerous studies have called for the development of clear shade performance indicators, spatial metrics and UVR protection benchmarks to support evidence-based shade planning and policy implementation (Gage et al., 2019; Holman et al., 2018). The lack of such standards currently limits the translation of research findings into practical design and management strategies for school settings that better protect both children and adults from overexposure to UV radiation (Queensland University of Technology, 2021).

Overall, existing UVR protection research reveals three important limitations. First, there is a lack of clearly defined targets and measurable indicators for assessing and planning shade provision in playgrounds, particularly for specific activity zone types. Second, much research emphasises the analysis of shade quantity (e.g., percentage shade cover) rather than shade effectiveness, indicating an important limitation in methodologies capable of simultaneously evaluating multiple interrelated factors. Third, studies predominantly focus on urban parks and playground settings, with comparatively limited attention given to school playgrounds, particularly in New Zealand.

Therefore, it remains unclear whether New Zealand school playgrounds provide sufficient shade to protect children and associated adults from UVR exposure; to what extent existing shaded areas are effective; how shade is spatially distributed across school playgrounds; which activity zones are most and least shaded; to what extent are they effective in protecting children engaged in different activities; the relative importance of all components in UVR protection assessment; and the underlying factors that influence their effectiveness in UVR protection.

2.5 Landscape design for microclimatic comfort

2.5.1 Microclimatic comfort: Definition and influencing factors

As defined by Brown and Gillespie (1995, p. 1), microclimate is the 'condition of the solar and terrestrial radiation, wind, air temperature, humidity and precipitation in a small outdoor space'. According to this definition, microclimatic comfort therefore refers to creating conditions in outdoor environments that are comfortable for most individuals in the environment.

An individual's outdoor comfort is shaped by several factors. The most influential are thermal comfort, which relates to the energy balance of individuals (Brown & Gillespie, 1995) and wind comfort, which relates to the mechanical impact of wind on individuals (Ebrahimabadi, 2015; Lawson, 1978). It is important to clearly distinguish wind comfort from the role of wind in thermal comfort because they are two separate components in microclimatic comfort assessment discussed separately below.

Thermal comfort

Thermal comfort is defined as a condition of the mind that expresses satisfaction with the thermal environment (ASHRAE, 1989). In thermal comfort studies, two approaches are commonly identified: the energy-balance approach (Brown & Gillespie, 1995) and the adaptive approach (Djongyang et al., 2010). The energy-balance approach is based on the principles of heat exchange between the surroundings and the human body (Brown & Gillespie, 1995). According to Brown and Gillespie's (1995) energy-budget model, an individual in the landscape is considered thermally comfortable when the energy received nearly equals the energy lost. The thermal comfort model based on the energy-balance approach is the most extensively used model in outdoor thermal comfort studies and is the focus of this study. The adaptive approach is based on the perceptual dimensions of thermal comfort perception and considers psychological factors (Nikolopoulou & Steemers, 2003), cultural background and preferences (Thorsson et al., 2007). This study uses the first approach.

Wind comfort

Wind comfort refers to the mechanical effect of wind, including its force on people and objects, that affects an individual's outdoor comfort (Blocken & Carmeliet, 2004). Impacts include disruption of clothing and hair, making walking difficult, and buffeting the body and carried objects (Arens & Ballanti, 1977). At higher wind speeds, grit and dust particles can be carried to the eyes, causing discomfort (Arens & Ballanti, 1977).

The different effects of increasing wind speed on people and their ability to perform outdoor activities have been widely investigated, leading to the development of various wind comfort criteria (Penwarden, 1973; Ratcliff & Peterka, 1990; Sanz-Andres & Cuerva, 2006). These criteria were

developed to classify the effects of wind speed on human comfort and activity. Traditionally, the Beaufort scale has been used to describe different wind velocity ranges, from calm conditions (Beaufort 0 and 1) to hurricane (Beaufort 12) (Stathopoulos, 2006). Other notable comfort criteria were proposed by Lawson (1978). The criteria have four categories as presented in Table 2.7.

Table 2.7: Wind comfort criteria proposed by Lawson

Material removed for copyright compliance

Source: Lawson (1978)

Broadly, according to the relevant standards and most research, it can be said that a mean wind speed of 5.0 m/s represents the onset of discomfort; speeds greater than 10 m/s are unpleasant and speeds greater than 20 m/s can be dangerous (Cheng & Ng, 2006; NEN, 2006; Willemsen & Wisse, 2007).

As outlined above, wind comfort assessment and the criteria address only the mechanical effects of wind on human comfort and activity, characterised by wind velocity, magnitude and frequency. However, the role of wind in thermal comfort, through convective heat exchange and its influence on the human energy balance, is conceptually different and is therefore discussed separately in the next section.

In summary, microclimatic comfort refers to creating comfortable conditions in outdoor environments for most individuals. It is primarily influenced by thermal comfort and wind comfort in the environment, so the assessment of microclimatic comfort includes the assessment of two components: thermal comfort and wind comfort.

2.5.2 Thermal comfort assessment and the design of outdoor environments

Thermal comfort is defined as a condition of mind that is satisfied with the surrounding environment (ASHRAE, 1989). In assessing people’s thermal comfort needs, the human energy-balance approach is

appropriate because it offers an objective assessment of the landscape and an understanding of the conditions of comfort in outdoor environments (Brown & Gillespie, 1995). Central to the energy-balance approach is the principle that heat produced by a human body should equal the body's heat loss (Brown & Gillespie, 1995).

In the energy-balance approach, various thermal comfort indices have been developed. Among the most widely used indices are the Predicted Mean Vote (PMV) model developed by Fanger (1970), which predicts mean thermal sensation on a seven-point scale from -3 (cold) to +3 (hot). The Physiological Equivalent Temperature (PET), developed by Höppe (1999), converts complex outdoor conditions into an equivalent indoor air temperature. Other well-known indices for outdoor heat stress prediction include the Standard Effective Temperature (SET) (Gagge & Gonzalez, 1974), the Universal Thermal Climate Index (UTCI), developed by an international collaboration of biometeorologists and physiologists, is one of the most advanced multi-node thermo-physiological models and is widely adopted in biometeorology (Krzysztof et al., 2013). The COMFA energy budget model of Brown and Gillespie (1995) is the most comprehensive approach (Coccolo et al., 2016) for modelling the human energy budget and linking microclimatic variables to design-scale environmental modifications. Collectively, these indices use different modelling approaches but share a common foundation in human energy-balance principles, enabling objective evaluation of outdoor thermal environments.

Among the models, the COMFA approach is particularly helpful in understanding how landscape characteristics influence a person's thermal comfort, and it is therefore widely used in landscape architecture research. The basic COMFA equation to determine a person's thermal comfort level in an outdoor environment is Brown & Gillespie's (1995) model:

$$Budget = M + R_{abs} - Conv - Evap - T_{Remitted}$$

where: M is the metabolic energy for heating up the body (W/m^2); R_{abs} is the absorbed solar and terrestrial radiation (W/m^2); Conv is the sensible convective heat exchange (W/m^2); Evap is the evaporative heat loss (W/m^2); and $T_{Remitted}$ is the emitted terrestrial radiation (W/m^2).

According to this equation, the principal heat gains affecting thermal comfort are through the amount of metabolic heat generated in the person and the total amount of solar and terrestrial radiation absorbed by the person. Conversely, heat losses from a person's body primarily occur through convection heat exchange by the wind and evaporation of water from the person, either from the lungs, through respiration, or by perspiration through the skin and, finally, the terrestrial radiation emitted by the person contributing to the heat loss.

Metabolic heat production (*M*)

The metabolic heat produced by a person depends on the activity level. It significantly influences the comfort level (Brown & Gillespie, 1995). The amount of heat generated by a person can be estimated from specific activities. Understanding the activities, estimating the metabolic heat generated and designing the surrounding microclimate appropriately are important considerations in designing for human thermal comfort (Brown & Gillespie, 1995). This is particularly significant in the design of children's outdoor recreational areas, such as school playgrounds. The metabolic output is one of the strongest predictors of the energy balance (Vanos et al., 2012). Children are regularly involved in outdoor physical activities that induce heat stress, especially in warm summer months (McGarr et al., 2021). Moderate to vigorous intensity physical activity in warm ambient conditions is associated with elevated heat strain (Kerr et al., 2013; McGarr et al., 2021; Vanos et al., 2017) because of accelerated fluid imbalance and raised skin and core temperatures (Morrison & Sims, 2014).

The amount of heat produced during a specific activity is estimated using the metabolic activity rate, commonly expressed as metabolic equivalent (MET) (Jetté et al., 1990). The MET is a simple, practical, widely understood method for quantifying energy expenditure during activity (Jetté et al., 1990). MET is the unit that indicates the activity energy expenditure, which is multiplied by resting metabolic rate (RMR) to give the activity heat production.

The assessment of different physical activities and the estimation of their energy expenditure have important applications, especially in the design of school playgrounds for children's thermal comfort. A youth compendium of physical activities (Youth Compendium) was developed by Butte et al. (2018). It categorises 196 specific activities into major categories and provides children's activity metabolic rates in METS. Table 2.8 summarises the different activity types and their associated metabolic rates into three broad categories: light, moderate and vigorous metabolic rate.

Absorbed solar and terrestrial radiation – *R_{abs}*

Radiation is normally discussed in terms of two types: solar radiation (short-wave radiation emitted by the sun) and terrestrial radiation (long-wave radiation emitted by objects on Earth). Together, these radiations strongly affect people's comfort in the landscape (Brown & Gillespie, 1995). Both solar and terrestrial radiation vary considerably across time and space and are significantly affected by landscape elements, making radiation a key component considered in design for outdoor thermal comfort (Brown & Gillespie, 1995).

Radiant energy reaching the human body, whether solar or terrestrial, is either absorbed or reflected. The human body absorbs a large proportion of incoming terrestrial radiation, whereas the absorption of solar radiation depends more on factors such as clothing and surface characteristics (Brown & Gillespie, 1995). The amount of energy emitted as terrestrial radiation is a function of the

temperature of the emitting object (Brown & Gillespie, 1995). The higher the object's temperature, the more radiation is being emitted (Brown & Gillespie, 1995), e.g., an asphalt surface exposed to direct sun emits more radiation than shaded asphalt. Most natural surfaces absorb the majority of terrestrial radiation they receive, only a small fraction is reflected or transmitted (Brown & Gillespie, 1995).

Table 2.8: A classification of physical activities into three intensity levels based on their metabolic equivalent value

Metabolic activity level and METS	Activity type
Light activity (< 3 METS)	Casual walking; stretching; sitting; reading; writing; talking with friends; playing with toys, bricks or loose parts; board games; video games; arts and crafts
Moderate activity (3 to 6 METS)	Brisk walking; skating; cycling; riding a scooter; playing on school playground equipment; free play (swinging, sliding, rope, hoop, climb, ladder); 4-square; dodgeball; low-impact aerobics
Vigorous activity (> 6 METS)	Jogging/running; jumping rope; jumping jacks; competitive games (basketball, tennis, soccer, rugby, kickball, swimming); hopscotch; catch and throw balls; ball games

Source: Adapted from Butte et al. (2018) and Brown et al. (1999)

Since most natural and built surfaces absorb most of incoming long-wave radiation and emit radiation according to their temperature, the net radiant load on a person depends on the radiative balance between energy emitted from the body and energy received from surrounding surfaces and the sky (Brown & Gillespie, 1995). Considering both the solar and terrestrial radiation helps determine the amount of radiation received and identifies the source and spatial location of the objects emitting that radiation in the landscape.

Because all objects in the landscape continuously emit and receive terrestrial radiation, the key consideration in thermal comfort design is to maintain the radiative balance between energy emitted from a person or building and the energy received from the immediate environment (Brown & Gillespie, 1995). Thus it is a particularly critical component in children's outdoor play environments (Vanos, 2015). Children are considered a vulnerable group in thermal environments because their thermoregulatory system is less efficient than that of adults and they may experience greater cardiovascular strain under heat stress (Smith, 2019). Considerations are also necessary because of their developing nervous system and limited capacity for self-regulation; children may not recognise or respond to thermal discomfort until it progresses to more serious health consequences (Vanos, 2015).

Children are especially sensitive to radiant heat load because their physical and physiological characteristics differ from those of adults, which influences their capacity to store and dissipate heat. Physically, children have a higher surface-area-to-mass ratio (Falk & Dotan, 2008; Tsuzuki, 2023) and smaller blood vessels (Falk, 1998), both of which affect thermal regulation. Physiologically, differences in body composition (Tsuzuki, 2023), a relatively higher metabolic rate (Smith, 2019), less effective sweat mechanism (Falk, 1998) and higher skin temperature (Tsuzuki, 2023) further influence their thermoregulatory response. Together, these factors can reduce children's ability to cope with heat stress.

Numerous studies on outdoor thermal comfort demonstrate that school grounds are characterised as having extreme heat stress conditions (Antoniadis et al., 2018; Cheng, 2020; Moogk-Soulis, 2002). Intense solar radiation is consistently identified as the dominant factor affecting thermal perception and heat stress in these environments (Pfautsch et al., 2020; Vanos et al., 2017; Vanos et al., 2016). The mean radiant temperature (T_{mrt}), which is expressed as a combination of short- and long-wave radiation fluxes, is a key determinant in the human energy balance, with the long-wave radiation governed by the temperature of surrounding surfaces (Lauster et al., 2014) making a substantial contribution (Vanos, 2015).

School playgrounds exhibit significantly higher surface temperatures than their surroundings, largely because of limited tree cover, a large proportion of artificial surfaces, and the proximity to other hot areas (Moogk-Soulis, 2002). The biophysical environment of children's outdoor spaces, especially school playgrounds, urban parks and sports fields, involves physical parameters such as vegetation, surface type and shade cover that directly affect outdoor thermal comfort (Vanos, 2015). For example, in the study by Schulman and Peters (2008), an analysis of school playgrounds of 258 US public elementary and middle schools found that the predominant use of impermeable surfaces like asphalt, brick, concrete, rubber and artificial turf was associated with high heat storage, heat release and heat absorption, with tree canopy being the smallest proportion of school playground coverage.

Lowering the surface temperature is one of the most effective strategies to reduce T_{mrt} . It is achieved through shading to minimise incoming short-wave radiation and surface modifications to decrease long-wave radiation exchange (Vanos et al., 2016). A growing body of evidence identifies shade provision as the most effective intervention to decrease T_{mrt} and improve outdoor thermal comfort (Brown et al., 2015; Vanos et al., 2018; Vanos et al., 2017). Solid shade structures can block all short-wave radiation and have been shown to reduce the human energy budget by approximately 126 W/m^2 (Brown et al., 2015). Though both natural and artificial shade can reduce surface temperatures, studies indicate that T_{mrt} values are typically lowest under tree canopies and may be several degrees higher (approximately 3°C) in building shade (Ketterer & Matzarakis, 2014).

Additionally, the provision of shade over playground surfaces and equipment plays a significant role in limiting heat accumulation and retention and is, therefore, considered critical in designing school playground environments (Vanos, 2015). Materials with high heat capacity and thermal conductivity, such as black rubber, concrete, asphalt, artificial turf, steel and aluminium, absorb and retain large amounts of heat when exposed to direct sunlight, substantially increasing both air and surface temperatures (Vanos et al., 2018; Vanos et al., 2016). These materials, when left unshaded, not only pose a risk of sunburn but also emit high amounts of sensible heat (long-wave radiation), leading to potential heat stress (Olsen et al., 2019; Vanos et al., 2017; Vanos et al., 2016).

As noted, the school built environment is often characterised by varied surface materials and surrounding features that contribute to energy fluxes and children's high metabolic activities, increasing internal heat production. The high levels of solar exposure common in open playgrounds mean that microclimatic conditions must be a central consideration in school playground design because they have direct implications for children's thermal comfort, physical activity and related health outcomes.

Convective heat exchange – The role of wind

As reflected in the human energy budget equation, thermal comfort is achieved when the energy gained by the body nearly equals the energy lost. One main way of heat loss is through convection, driven by wind. Wind removes heat from the body surface. The convective heat transfer rate depends on the temperature difference between the skin and the surrounding air and the air speed, and can be expressed as (Brown & Gillespie, 1995):

$$C = f(W) \times (T_{skin} - T_{air})$$

where: C is the convective heat exchange; $f(W)$ is a function of wind speed; T_{skin} is the skin temperature; and T_{air} is the ambient air temperature. An increase in wind speed increases convective heat loss, and a greater temperature difference between the body surface and the air increases convection.

A person's mean normal skin temperature ranges from 28°C to 37°C at ambient temperatures of 9.5°C and 35°C, respectively (Brown et al., 2015). Skin temperatures above or below these values cause the thermal sensation of being warm or cold, with the intensity of thermal discomfort increasing as the difference grows (Tuller, 1980). In a neutral environment, the human body loses about 75% of its heat through convection (Arens & Zhang, 2006). So, at higher air temperatures, when the evaporation heat loss is low, hot winds may cause the skin to warm, resulting in sensible body heat gain (Arens & Zhang, 2006), causing heat stress and thermal discomfort (Antoniadis et al., 2020). Conversely, at lower air temperatures, increasing wind speeds increase convective cooling

(Brown & Gillespie, 1995) by carrying metabolic heat away from the body and causing the 'wind chill' effect. 'Wind chill' is a combination of air temperature and wind speed that produces an 'equivalent temperature' that reflects how the body perceives cold conditions (Brown & Gillespie, 1995). For example, an air temperature of 0°C with a wind speed of 7 m/s may produce a cooling effect comparable to still air conditions at approximately -13 °C (Brown & Gillespie, 1995). In cold environments, wind chill significantly increases the risk of thermal discomfort, cold stress and potential health impacts such as frostbite or hypothermia (Zhao et al., 2024). Consequently, considering wind chill provides a more accurate representation of thermal comfort and safety in outdoor winter conditions than air temperature alone (Brown & Gillespie, 1995).

Research shows a strong correlation between thermal comfort perception, air temperature and wind speed (Metje et al., 2008). In temperate climates, comfort increases with increasing temperature and reduces with increasing wind speeds (Metje et al., 2008; Oliveira & Andrade, 2007). Studies suggest that optimal outdoor thermal comfort occurs between 17.5°C and 22.5°C, with a wind speed threshold of 5 m/s. Beyond this, people feel uncomfortable (Metje et al., 2008). Studies have found that the preferred and acceptable wind speed decreases with a reduction in air temperature (Oliveira & Andrade, 2007). This indicates that the perception of wind is closely linked to the perception of the air temperature, as noted by Nikolopoulou and Lykoudis (2006).

Wind speed and direction in a landscape are highly variable across space and time and have a strong influence on outdoor thermal comfort (Brown & Gillespie, 1995). Variations in wind patterns are shaped in multiple ways by the elements in the landscape. Objects' characteristics such as size, location, orientation, porosity and proximity affect wind patterns. Broader landscape elements, including topography, vegetation and built form, further shape wind conditions (Brown & Gillespie, 1995). Like solar radiation, wind is an important microclimatic variable that can be modified through landscape design and is a very important component considered in microclimatic-responsive landscape design (Brown & Gillespie, 1995).

Evaporative heat loss

Energy can be dissipated from the body through evaporation, which occurs by normal respiration, because moisture from the lungs evaporates, and through the evaporation of sweat from the skin (Brown & Gillespie, 1995). Because a substantial amount of energy is required to convert water from liquid to vapour, evaporation has a strong cooling potential. In practice, however, this cooling mechanism is most effective under conditions of high temperature and low humidity (Brown & Gillespie, 1995).

Air's capacity to hold water vapour increases with temperature and, therefore, warmer air can absorb more moisture than cooler air. Evaporation from the skin occurs only when the surrounding

air can absorb additional moisture (Brown & Gillespie, 1995). Thus, when the air temperature is high and humidity is low, sweat evaporates readily, promoting effective cooling. Conversely, under low air temperature conditions or high humidity, the air has limited capacity to take up moisture, slowing or inhibiting evaporation, which reduces its cooling effect on the body (Brown & Gillespie, 1995).

In summary, the metabolic activity rate, radiation (both solar and terrestrial) and wind are key variables that strongly influence the human energy balance and can be modified through landscape design of children's outdoor environments. There are other factors that affect human thermal comfort, but these cannot be controlled or affected by design.

2.5.3 Methodological approaches used in microclimate and thermal comfort studies

A range of approaches has been developed and applied in microclimate and outdoor thermal comfort research. These can be broadly grouped as: field monitoring and analysis; numerical modelling and thermal comfort models; spatial modelling and simulation-based assessments; and remote sensing and GIS-based assessments. The evolution of these methodologies has led to the development of key attributes that support their wider adoption and application in microclimate studies (Bherwani et al., 2020).

Field monitoring and analysis

Field monitoring is a widely used methodology to investigate urban microclimates and outdoor thermal comfort, because it provides, *in situ*, real-world measurements of environmental conditions (Lai et al., 2019). In earlier periods, when technological resources were limited, direct field observations were the most effective, reliable methods for investigating microclimates and thermal comfort. With advances in instrumentation and data processing, contemporary field studies now use sophisticated sensors and monitoring systems capable of capturing fine-scale microclimatic variations, such as the influence of surface materials and urban geometry on local thermal conditions (Bherwani et al., 2020).

Commonly used field techniques include: the use of meteorological sensors to record air temperature, relative humidity, wind speed and direction, and solar radiation; globe thermometers or net radiometers to estimate mean radiant temperature (T_{mrt}); surface temperature sensors or infrared thermography to assess materials' thermal properties; portable weather stations and fixed monitoring networks for continuous or spatially distributed data collection (Bherwani et al., 2020).

In outdoor thermal comfort studies, physical environmental measurements are often combined with questionnaire surveys to capture subjective thermal perceptions. Surveys collect information on demographics, clothing insulation, activity level and thermal sensation responses, enabling a linkage

between measured conditions and human experience (Eliasson et al., 2007; Nikolopoulou & Steemers, 2003). This integrated approach is particularly useful to assess the influence of urban geometry and microclimatic variation on user comfort (Sharmin et al., 2019).

Although field monitoring methods provide highly accurate, site-specific data, they are often criticised for limitations in the parameter range that can be assessed (Bherwani et al., 2020). Despite ongoing technological advances that allow additional parameters to be measured, the field monitoring approach is constrained by time and resource demands and is also restricted to specific geographical locations. As a result, field monitoring today is frequently used to validate outputs from numerical models or interpretations derived from remote sensing, rather than serving as a standalone method for large-scale microclimatic assessment (Bherwani et al., 2020).

Numerical modelling and thermal comfort models

Thermal comfort indices based on the human body's energy balance are used to quantify the physiological component of thermal comfort by accounting for thermoregulatory processes such as vasodilation and constriction, sweating and heat exchange between the body and the surrounding environment (Martinelli & Matzarakis, 2017). There have been 165 thermal indices developed using a variety of approaches (Cheng & Brown, 2020). The most commonly used ones are: PET, PMV, UTCI, SET* (Potchter et al., 2018) and the COMFA energy budget model (Cheng & Brown, 2020). PET, PMV, UTCI and COMFA are considered universal indices applicable across both cold and hot climates, with broad thermal sensation or stress classifications (Potchter et al., 2018). Other indices, such as SET*(Standard Effective Temperature), THI (Temperature Humidity Index), WBGT (Wet-bulb globe-temperature) and OUTSET*, are designed for hot areas and encompass a smaller range of thermal sensations, ranging from mild to very hot (Potchter et al., 2018).

The thermal comfort models are widely used for their capacity to integrate multiple environmental and physiological variables. They have been extensively validated in international research (Potchter et al., 2018). However, their applicability across different population groups is limited because most models are based on adult physiological assumptions, which reduces their accuracy for vulnerable groups such as children. The COMFA model has been identified as one of the most comprehensive approaches (Coccolo et al., 2016) because it has been modified for use with different population groups such as active adults and high-performing athletes (Vanos et al., 2012). It also has an open architecture where all equations and methods are available for modification, making it more flexible for population-specific applications (Cheng & Brown, 2020).

Thermal comfort indices are typically calculated using meteorological data and are then compared with questionnaire responses to relate objective environmental conditions to subjective thermal perception (Herrmann & Matzarakis, 2012; Ketterer & Matzarakis, 2014). This integration allows

model validation, improves context-specific calibration, and strengthens evidence-based design by aligning objective microclimate data with actual human thermal perceptions.

Spatial modelling and simulation-based assessments

Modelling and simulation approaches have become increasingly prominent in urban microclimate research, with assessment techniques continuing to evolve (Bherwani et al., 2020). Computational Fluid Dynamics (CFD) is widely applied because of the availability of built-in solver packages that streamline analysis. Early CFD applications focused primarily on air temperature and wind flow, but models have progressively incorporated additional parameters such as latent heat exchange, air quality, urban canopy processes and three-dimensional airflow dynamics (Pothiphan et al., 2019; Toparlar et al., 2017). These developments are often complemented by satellite observations and mesoscale models such as Weather Research and Forecasting (WRF) that are increasingly integrated with CFD to improve our understanding of microclimatic processes (Bherwani et al., 2020).

Among current tools, ENVI-met (Windows-based) and OpenFOAM (Linux-based) are widely used CFD platforms for simulating complex three-dimensional urban canopy environments (Ambrosini et al., 2014). ENVI-met supports a broad range of microclimate analyses, including solar radiation, building physics and wind flow, and can be applied at spatial scales from small sites to neighbourhoods or small cities. Its graphical output is clear and accessible, aiding interpretation. ENVI-met requires substantial user expertise in both microclimate theory and software operation (Lin et al., 2022).

As the application of modelling and simulation techniques expanded, a clear understanding of the abilities and constraints of different tools has become increasingly important (Naboni et al., 2017). Advances in satellite observation and complex modelling simulations led to finer insights into microclimate and its processes. Various simulation programs can generate insights into thermodynamic parameters and micro-scale indicators such as air temperature (T_a), mean radiant temperature (MRT), relative humidity (RH), wind speed and thermal comfort indices like PMV (Albdour & Baranyai, 2019) supporting the analysis of interactions between microclimate and urban design. However, comparisons of CFD tools show considerable discrepancies; in particular, the software selection should be guided by user expertise and project objectives (Brook-Lawson & Holz, 2020). No single simulation tool can fully capture the spatial and temporal variability of the microclimate (Hwang et al., 2018).

Although ENVI-met is often regarded as a more suitable tool for outdoor microclimate simulation (Albdour & Baranyai, 2019) it has limitations. These include restricted flexibility in defining hourly solar radiation inputs, potential overestimation of leaf surface temperature and underestimation of vapour flux in tree physiological modelling, particularly during summer midday conditions.

Simplification in vegetation modelling can lead to underestimation of the thermal effects of trees when comparing shaded and unshaded areas (Liu et al., 2018)

Remote sensing and GIS-based assessments

Since the late twentieth century, remote sensing has become increasingly popular in climate and microclimate studies, using measurements from various sensors and satellites, including Advanced Very High Resolution Radiometers (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper (ETM), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Bherwani et al., 2020). They have been widely used to study parameters such as land surface temperature, vegetation indices, albedo and other parameters of reflected and emitted radiation (Bherwani et al., 2020). The application of remote sensing and the availability of multispectral thermal data have facilitated the assessment of multiple parameters using a range of mathematical modelling approaches.

Although satellite-based approaches provide extensive measurements, their application to predictive modelling and decision-making remains limited because much of the research is focused primarily on observation and data collection (Bherwani et al., 2020). Recently, the application of ArcGIS and other GIS-based tools has complemented remote sensing by enabling spatial analysis, mapping and the integration of environmental variables with land use and urban form data (Bherwani et al., 2020). ArcGIS is increasingly used to visualise spatial distributions, perform overlay analyses and assist scenario-based planning (Hossain et al., 2025).

The strengths of remote sensing and GIS approaches include broad spatial coverage, from regional to city scale, and the ability to provide consistent temporal monitoring. However, the limitations include their primary focus on surface conditions, with limited representation of pedestrian-level microclimates (Stathopoulou & Cartalis, 2007) and comparatively lower spatial and temporal resolution relative to detailed CFD simulations (Toparlar et al., 2015). The limited ability to directly predict human thermal comfort necessitates the integration of other advanced modelling and measurements (Liu & Zhang, 2011).

Overall, remote sensing and GIS-based approaches are powerful for large-scale environmental assessment and spatial pattern analysis, and they are most effective when combined with field measurements and modelling techniques to provide a more comprehensive understanding of microclimatic conditions and human thermal comfort.

2.5.4 Research gaps in existing microclimate and thermal comfort studies

Children are commonly identified as a vulnerable population experiencing detrimental health effects in adverse environmental conditions (Vanos, 2015). The outdoor thermal environment plays a crucial role in children's physical and social development. Children are most sensitive to temperature extremes (heat and cold) (Diaz et al., 2004), and children aged 0-15 years are particularly vulnerable to heat-related mortality (Nitschke et al., 2011; Xu et al., 2012) and morbidity (Tchidjou et al., 2010). At higher ambient temperatures, children are subjected to dehydration, renal disease, hyperthermia (Semenza et al., 1999; Xu et al., 2012), thermal burns, sunburn and respiratory illness. Uncomfortable environmental conditions can lead to poor behaviour, lowered work rate and performance, subsequently resulting in the overall decline of outdoor physical activity (Vanos, 2015). Thermally uncomfortable environmental conditions can result in unsafe, dysfunctional outdoor spaces, negatively impacting children's health and overall performance. Consequently, studies increasingly call for well-designed, functional and thermally comfortable outdoor environments for children (Antoniadis et al., 2016; Vanos, 2015).

Recently, the field of children's outdoor thermal comfort has received increasing attention, particularly in the context of climate change and the urban heat island effect and their implications for children's health (Cheng & Brown, 2020). Globally, research on microclimate and thermal comfort, and particularly studies focusing on children's outdoor environments, has identified four main research gaps.

First, though thermal comfort standards for adults are well-established, research focused specifically on children remains limited, especially with regard to the development of thermal comfort guidelines and their integration into environmental design (Kennedy et al., 2020; Vecellio et al., 2022).

Conventional playground designs have predominantly focused on activity zone configurations, plant and facility layouts and safety considerations, with relatively little attention paid to thermal comfort and safety (Vanos, 2015), particularly the potential risks associated with the surface temperatures of materials under varying climatic conditions (Antoniadis et al., 2020). Existing playground design standards around the world provide minimal guidance on design for thermal comfort (Vecellio et al., 2022).

Additionally, age-specific differences in children's outdoor thermal perception remain insufficiently explored, resulting in a lack of clear references and standards to inform age-specific outdoor site design (S. Wang et al., 2025). Children differ substantially across age groups, with enormous variations across different stages in terms of physiology, psychology and cognition (Vanos, 2015). Younger children are generally more sensitive and less adaptable to temperature extremes, with narrower acceptable air temperature ranges (S. Wang et al., 2025). However, current assessment

methods and population-based thermal comfort models rarely incorporate child-specific parameters, outputs or age-dependent threshold values (S. Wang et al., 2025). This is a significant research gap in developing outdoor environments that respond to the distinct thermal requirements of different age groups. It underscores the need for playground design strategies that explicitly consider developmental differences and children's specific needs and characteristics, including consideration of the thermal environment (S. Wang et al., 2025).

Second, research in microclimate and thermal comfort has increasingly shown that some factors have been more widely studied than others, e.g., air temperature and the urban heat island (UHI) effect (Bherwani et al., 2020; Hashemi et al., 2024). The growing body of work on these areas has generated extensive references and contributed to the development of bioclimatic design principles and strategies aimed at optimising these factors. For example, detailed design guidelines have been developed to improve shade provision as a means of improving thermal comfort. Other critical microclimatic parameters like wind speed, relative humidity, albedo, solar insolation, urban canyon effect, and 'street canyon' effect remain comparatively underexplored, and their interactions and combined influences on thermal comfort are being explored to a very limited extent and are often addressed in a fragmented, isolated manner in the literature (Bherwani et al., 2020).

The wind environment is widely recognised as an essential aspect of urban microclimate and is commonly studied as an important factor affecting human wind comfort and thermal comfort in public open space (Liu et al., 2019). However, considerably less research has investigated how the wind environment influences school playgrounds that serve children and teenagers who are more sensitive to air temperature and thermal stress (Liu et al., 2019; Xu et al., 2022). Because wind is an important factor in shaping children's comfort in outdoor spaces in both summer and winter, this gap emphasises the need for more studies in the area (Xu et al., 2022). This imbalance in the focus of existing research highlights the need for a more comprehensive investigation of the underrepresented microclimatic variables and their interdependencies (Bherwani et al., 2020; Hashemi et al., 2024). Such research is essential to establishing more robust thermal comfort benchmarks and developing optimised design strategies for children's activity spaces and ultimately supports the creation of safer, more comfortable outdoor environments in different seasons.

Third, because children spend a substantial proportion of their time at school, a comfortable microclimate is essential for adequate play and physical activity. However, designing climate-responsive outdoor spaces for children requires an understanding of complex landscape elements and processes by which microclimatic factors interact and influence thermal comfort (Lin et al., 2022). As noted above, the existing imbalance in the variables studied and the practical challenges associated with the application of microclimatic concepts in design practice (Cortese & Lenzholzer,

2022; Lin et al., 2022) highlight the need for more effective methodologies capable of integrating multiple interdependent microclimatic factors in assessment frameworks (Bherwani et al., 2020).

A commonly identified barrier is the lack of tools and methods to visualise design ideas at various stages of the design process. Since most microclimatic elements are invisible and intangible, integrating these parameters into the design process is significantly difficult (Li et al., 2023; Lin & Brown, 2021). Additional constraints include the technical complexity involved in measuring and using climatic data (Eliasson, 2000), the lack of user-friendly tools (Eliasson, 2000; Lin et al., 2022), and the tendency for scientific knowledge to be presented in forms difficult for practitioners to interpret (Eliasson, 2000).

As pointed out by Vanos (2015) a distinction exists between biophysically 'effective' green spaces that are cost-effective and beneficial, versus 'ineffective' green spaces that fail to provide thermal benefits despite their presence. This is partly attributed to the lack of sufficient observation data, which limits the development of evidence-based guidelines and policies aimed at protecting children's health. These limitations highlight a significant research gap in developing practical, integrative and design-oriented methodologies to address microclimates and thermal comfort in children's outdoor environments.

Finally, research on microclimate and thermal comfort reveals a notable scarcity of studies conducted in cities classified under the Köppen Cfb climate zone (Hashemi et al., 2024; Turba et al., 2024) and, more particularly, in New Zealand (Hashemi et al., 2024; Jalali et al., 2022). A recent review of existing microclimatic studies indicates that only 2% of previous microclimatic research in temperate climates has focused on Cfb cities; a significant number of studies in temperate climates have been conducted in monsoon-influenced humid subtropical climates (Cwa) and cold-summer Mediterranean climates (Csc) (Hashemi et al., 2024).

Research on microclimate and outdoor thermal comfort in New Zealand is gaining attention but remains significantly limited (Hashemi et al., 2024; Jalali et al., 2022). Classified in the Köppen Cfb climate zone, New Zealand experiences a temperate oceanic or maritime climate, typically characterised by mild, moist winters and relatively cool, pleasant summers (Mullan et al., 2012). Based on the climate conditions of these areas, the general perception seems to be that microclimate challenges and outdoor thermal discomfort are not critical issues that need to be addressed immediately (Baquero & Forcada, 2022). However, the outdoor thermal comfort requirements of the same outdoor space can vary significantly among users from different climatic backgrounds (Lam et al., 2021). Differences in thermal sensation, clothing and adaptive responses among populations from diverse climates further complicate comfort assessment (Niu et al., 2015).

Such knowledge is important to provide guidance for urban designers in developing context-responsive local design strategies (Fong et al., 2019).

A recent systematic review highlights a substantial lack of research in New Zealand on microclimate and thermal comfort. It identifies only six studies in three cities (Christchurch, Wellington and Auckland) (Hashemi et al., 2024). The study notes that relatively less attention has been given to outdoor urban places such as commercial areas, urban parks, squares and universities, though a reasonable number of studies focused on residential neighbourhoods and urban street environments.

The most common theme identified in the reviewed papers was the assessment of people's outdoor thermal perceptions (Hashemi et al., 2024). For example, one study of Christchurch urban streets examined the nature and social dimensions of urban comfort in a seasonally variable climate and a physical landscape experiencing rapid transformation following a series of major earthquakes. The study combined ethnographic approaches with on-site microclimate measurements across four case study locations in Christchurch, enabling the exploration of how individuals adapt their cultural practices, lifestyle values and expectations in response to the prevailing microclimatic conditions (Tavares et al., 2019). Another investigation in Christchurch urban parks examined the combined effects of solar exposure, wind and air temperature and human adaptive responses, concluded that standard physiological comfort models cannot be directly transferred across climatic contexts without accounting for local adaptation (Perera et al., 2021).

Overall, the review of previous studies reveals a clear gap in research examining the impacts of urban design elements such as geometry (e.g., aspect ratio, building orientations, sky view factor), surface materials (both buildings and land) and vegetation (trees, grass, green walls, green roofs) on microclimatic conditions and outdoor thermal comfort (Hashemi et al., 2024). No prior study has undertaken a comprehensive analysis of these factors in an urban context, indicating the need for integrated investigations to inform more accurate, context-specific design guidelines (Hashemi et al., 2024).

In New Zealand, current research and planning frameworks reveal a notable gap in addressing urban microclimate, the UHI effect, and outdoor thermal comfort in the context of future urban development and climate adaptation (Jalali et al., 2022). Inconsistencies in research parameters and methodologies, combined with limited validation of existing studies, reduce the robustness of current findings. The lack of attention to future urban development patterns and urban morphology further constrains understanding of how urban microclimatic conditions may evolve (Jalali et al., 2022).

Given New Zealand's distinct, unique climate characteristics, research conducted in other parts of the world may not be directly applicable. Together, the significant research gaps identified above collectively limit the clarity and reliability of scientific insights into both present and future urban microclimate dynamics in New Zealand, which indicates the need for country-specific research to ensure the relevance and accuracy of the outcomes. In the context of the growing impacts of climate change, microclimate and thermal comfort studies continuously call for evidence, presenting promising opportunities to advance evidence-based research and advance studies focused on child-specific microclimatic models. Such research would support the effective integration of bioclimatic design principles into the planning of children's outdoor environments, which is essential to reduce thermal exposure risks and promote healthier, safer outdoor conditions for children.

2.6 Landscape design for attractive play opportunities

2.6.1 Playground attractiveness: Definition

According to a dictionary, attractiveness refers to 'the quality of causing interest or making people want to do something' (Cambridge University Press & Assessment, 2022). In line with this, research on school playground design highlights that children's physical activity (play) is an important trigger for children's preference for and use of outdoor spaces (Anthamatten, Brink, et al., 2014; Lucas & Dymont, 2010). Increasing evidence suggests that children are naturally drawn to areas that offer adequate play opportunities (Boldemann et al., 2011), which often leads to greater use of some activity zones (Anthamatten, Brink, et al., 2014) in school playgrounds. Conversely, activity zones with fewer options and play opportunities are associated with increased boredom (Hyndman, 2017) and reduced use, which directly contributes to lower attractiveness to children (Lucas & Dymont, 2010). Based on this understanding, in this study, attractiveness is defined as the ability of activity zones to provide adequate play opportunities for children.

2.6.2 Factors influencing play opportunities

Research on children's outdoor environments consistently shows that play spaces must contain features or equipment that stimulate play or encourage physical activity (Dymont & O'Connell, 2013; Lucas & Dymont, 2010; Rutkauskaite et al., 2021). The relationship between playground characteristics, children's play opportunities and their play behaviour can be understood through the Theory of Affordances introduced by James J. Gibson in psychology. This theory explains how the physical environment can provide a context for human behaviour and learning. *Affordances* refer to the possibilities that the physical environment may afford for action or play that are inherently linked to the characteristics of the specific environment (Gibson, 2015).

According to the Theory of Affordances, the physical features of an environment offer *potential* and/or *actualised* affordances (Gibson, 2015). Potential affordances refer to all play possibilities that the environment offers. For example, rocks can afford climbing; sticks, branches and logs offer other diverse play opportunities. Actualised affordances are the possibilities that are used or actually needed in practice. For example, on a football field, ground markings and balls afford appropriate conditions to play the specific sport. In playground research using the theory, previous studies explain the correlation between outdoor design and children's play behaviour in a school environment (Rutkauskaite et al., 2021; Smith et al., 2016).

Activity zone types and spatial features influencing play affordances

The affordances for play and the presence of particular characteristics or design features are strongly shaped by the type of activity zone (Hyndman, 2015; Rutkauskaite et al., 2021). Playgrounds are commonly described in terms of activity zones. As noted previously, in this study an **activity zone (AZ)** is a designated space in a larger environment such as a playground, that is specifically designed for or supports a particular type of activity.

According to the definitions of Hyndman (2015) and Sener et al. (2008), AZs are generally categorised into **structured** and **unstructured** zones. **Structured zones** refer to areas that are organised or have a set purpose and location and are specifically designed by adults for a particular activity (Hyndman, 2015; Sener et al., 2008) e.g. a hard-court area designed for playing a specific sport. **Unstructured zones** refer to areas that are less organised, with no set purpose, location or design for a particular activity, but are often shaped by children's imagination (Hyndman, 2015; Sener et al., 2008) e.g., hard-paved areas or grassed areas that support more spontaneous or free play such as running, jumping or chasing.

Depending on the AZ type, specific playground spatial features or equipment play a pivotal role in promoting desired levels of physical activity and play among children (Anthamatten, Fiene, et al., 2014; Dymont et al., 2009; Hyndman, 2015) and directly contribute to its attractiveness. In this study, these features and equipment needed to promote play or physical activity are referred to as **attractors**. For instance, in structured zones, play is typically supported through actualised affordances, where defined markings and equipment create appropriate conditions for specific sports or organised games. Unstructured zones rely more on potential affordances, with natural elements and movable materials supporting a wider range of spontaneous, imaginative and self-directed play activities.

In general, these attractors can be grouped into three categories: (1) **play features** such as sand, multicolour paint markings, play markings (Cardon et al., 2012; Stratton & Mullan, 2005); (2) **loose or movable play equipment** such as balls, balance beams, bikes, hula-loops (Hyndman, 2017; Maxwell

et al., 2008; Ridgers et al., 2012); (3) **fixed play equipment** such as jungle gyms and slides (Ridgers et al., 2012); or (4) **loose or movable play parts** such as milk crates, tyres, rocks, boulders (Caldwell et al., 2023; Flannigan & Dietze, 2018; Pereira et al., 2023). Based on the literature, Table 2.9 summarises the attractors identified as supporting play opportunities across different AZ types commonly found in school playgrounds.

Table 2.9: A summary of activity zone types and the attractors identified in the literature as supporting play opportunities

Activity zone category	Activity type	Example(s)	Required Attractor(s)	Reference(s)
Structured	Field-based activity zones	Cricket pitch, soccer field	- Play features include play markings, goal post, hoops and - Loose play equipment such as balls, bats, racquets	Lucas and Dymont (2010) Zask et al., (2001)
	Court-based activity zones	Basketball court, tennis court	Loose play equipment such as balls, bats, racquets	Stratton and Mullan (2005)
	Painted surface-based activity zones	An area for hopscotch, four square	Play features such as multicoloured play markings	Stratton and Mullan (2005)
	Special surface-based activity zones	Sandpit	Play features such as sand	Stratton and Mullan (2005)
		Fixed play equipment	Fixed play equipment such as jungle gym, climber, swing, slide	Dymont and O'Connell (2013) Reimers and Knapp (2017) Zask et al. (2001)
	Seating-based activity zones	Designated lunch-eating area, covered outdoor learning area	- Loose, movable play equipment such as bikes, bicycles, skateboards, hula-hoops, and/or - Loose play parts such as tyres, milk crates, ropes, hoops	Farley et al. (2008)
Unstructured	Natural/soft surface zones	Grassed area, woodland	- Diverse assemblage of trees, shrubs, rocks, logs (i.e., allowing a variety of places to jump, climb, hide), and/or - Loose materials such as stones, leaves, flowers, sticks, twigs and/or - Loose, moveable parts such as tyres, milk crates, ropes, hoops	Lucas and Dymont (2010) Moore (1986) Aminpour and Bishop (2021) Farley et al. (2008)
	Artificial/hard surface zones	Hard-paved area, open asphalt area, classroom verandas	- Loose play parts such as tyres, milk crates, ropes, hoops and/or - Loose, movable play equipment such as bikes, bicycles, skateboards, hula-hoops	Farley et al. (2008)

Increasingly, school playground research indicates that the availability of these attractors is associated with higher levels of physical activity and the greater use of AZs (Colabianchi et al., 2011; Farley et al., 2008; Ridgers et al., 2012). Variation in the presence of attractors directly contributes to differences in how AZs are used, with some AZs being more popular and more frequently used, and others being less used (Anthamatten, Brink, et al., 2014; Sandseter et al., 2020), reflecting differences in their overall attractiveness.

Characteristics of most popular activity zones and contributing factors

Studies on school playgrounds and children's play behaviours consistently show that structured AZs with built-in attractors, such as sand pits (Dymont & O'Connell, 2013), fixed play equipment areas (Dymont & O'Connell, 2013; Sandseter et al., 2020), and paint marked areas (Dymont & O'Connell, 2013; Stratton, 2000) designed for organised games (e.g., hopscotch, or foursquare) tend to be the most popular AZs. Among them, sand pits are frequently reported as highly preferred AZs, because sand affords diverse forms of constructive, sensory and imaginative play (Dymont & O'Connell, 2013) which contributes to their widespread popularity across studies (Sandseter et al., 2020; Zamani, 2017). Similarly, paint-markings influence children's play choices by structuring games and social

interaction. The markings are a cost-effective, feasible option in outdoor play settings, by effectively influencing children's choice of play environment (Chancellor, 2013).

Fixed manufactured play equipment, such as climbers, swings and jungle gyms, is also widely recognised as a strong attractor. These structures support multiple play types, including functional, constructive and imaginative play (Dyment & O'Connell, 2013). However, studies highlight that high installation costs, maintenance demands and safety concerns often limit the provision of such equipment in school playgrounds (Chancellor, 2013; Dyment & O'Connell, 2013).

Natural green areas with diverse trees, shrubs and loose parts such as rocks, stones and sticks, are increasingly recognised as highly attractive play environments for children (Dyment & O'Connell, 2013). These environments provide flexible, diverse affordances that support imaginative, exploratory and social play (Dyment & O'Connell, 2013; Sandseter et al., 2020). Research indicates that expanding natural green areas not only increases use of school playground areas, but also provides numerous other benefits, including increased physical activity, enhanced social interaction and improved academic performance (Dyment & Bell, 2007; Lucas & Dyment, 2010). Despite these benefits, many school playgrounds around the world remain barren, hard and uninviting spaces lacking such natural elements (Dyment & O'Connell, 2013; Lucas & Dyment, 2010). Safety concerns, maintenance and surveillance are frequently identified as key barriers to the integration of more naturalised play areas in schools (Chancellor, 2013).

The characteristics of the least popular activity zones and the contributing factors

Research indicates that certain AZs in school playgrounds are consistently underused because of limited attractors and restricted play affordances. Unstructured zones, such as open grassed areas that are largely 'unprogrammed' and lack equipment or distinct play features, have been identified as some of the least used spaces in school playgrounds (Anthamatten, Brink, et al., 2014). Although these zones offer potential flexibility, the absence of identifiable play elements often results in low engagement.

In addition, some structured zones, particularly sports fields and hard-court areas designated for organised sports, are often reported as among the least preferred AZs during interval and lunch times (Anthamatten, Brink, et al., 2014; Dyment & O'Connell, 2013). When these zones lack appropriate sporting equipment (e.g., balls), they provide minimal external stimuli and limited affordances for spontaneous play, making them less attractive to children (Dyment & O'Connell, 2013). School playground policies are a key contributing factor, as schools may restrict the use of sporting equipment during free play in these zones (Chancellor, 2013). Under such conditions, the introduction of loose or movable play parts such as toys, bikes and scooters for riding has been suggested to stimulate play in these otherwise underused areas (Lucas & Dyment, 2010). Similarly,

other structured zones designated for resting or socialising, such as the canteen courtyards and classroom verandas, often without stimuli, restrict play affordances and lead to less use (Mackay, 2003b; Sandseter et al., 2020).

Research on school playgrounds indicates that they are primarily designed for more structured, organised sports, reflecting adults' priorities (Chancellor, 2013; Dymont & O'Connell, 2013) rather than children's play preferences. However, children interact with their environment in dynamic, unexpected ways, often differing from adults' expectations (Sandseter et al., 2020). Given the documented recent decline in children's free play opportunities (Rutkauskaite et al., 2021), researchers increasingly emphasise the need to rethink school playground design (Anthamatten, Fiene, et al., 2014; Dymont & O'Connell, 2013). There is growing evidence that more versatile school playgrounds that integrate natural elements and flexible design features can better cater to children's varied play behaviours while supporting traditional sports (Anthamatten, Brink, et al., 2014; Rutkauskaite et al., 2021).

2.6.3 Methodologies used in playground research

Playground research exploring children's play behaviour, physical activity levels and context factors uses a range of approaches, including systematic observation, behaviour mapping, objective measurements and qualitative methodologies. These methods are well-suited to capturing individual measures such as activity level, play type and pattern of use (Grady, 2018) and are often combined to provide a better understanding of playground dynamics.

Systematic observation and behaviour mapping are widely used to document children's play types, activity intensity and spatial use of playground zones (Hyndman, 2017; Ridgers et al., 2012). When used in combination, they provide rich, contextual detail on environmental variables such as availability of equipment, spatial layout and overall playground usability, making them valuable for informing environmental interventions and design decisions (Grady, 2018). However, these approaches are labour-intensive and time-consuming, particularly when applied across large sites or over extended observation periods.

Objective measurement tools, such as accelerometers and pedometers, are used to quantify physical activity levels through direct measurement (Engelen et al., 2013; Ridgers et al., 2007). Data from individual children can be aggregated to examine movement patterns at the group level. The method provides objective, precise activity data but may not fully capture the spontaneous physical activity of children in play (Ridgers et al., 2007). Time sampling methods, such as SOPLAY, record physical activity through momentary observations. Although trained observers can often classify activity intensity accurately, this method captures only brief snapshots in time and requires substantial

observer training to ensure reliability. A key advantage of SOPLAY, and similar tools, is their flexibility, because researchers can incorporate additional coding schemes to document behaviours beyond physical activity (Grady, 2018). GPS tracking complements these methods by identifying where activities occur, enabling the linkage of behaviour to specific environmental contexts (Grady, 2018). Despite their strengths in objectivity and spatial precision, direct observation methods can be costly, logistically challenging for large samples, and generally limited to a narrow set of measurable variables, so providing fewer insights into the qualitative and contextual dimensions of play (Grady, 2018).

Qualitative methodologies, such as surveys, questionnaires, focus groups and interviews, are used to explore children's preferences, perceptions and barriers to play. These methods provide rich contextual insights and help explain the social and environmental factors influencing playground use (Pawlowski et al., 2016). However, these methods are often limited by their complexity for translating the findings into measurable design parameters or practical environmental interventions (Grady, 2018).

When studies seek to explore context, particularly the characteristics of the playground environment, behavioural data are often complemented with environmental audits that document the presence of design features, facilities and play attractors (Grady, 2018). Geospatial and GIS-based analyses further support spatial evaluation of AZs and landscape characteristics (Grady, 2018).

2.6.4 Research gaps in existing attractiveness studies

Globally, studies on school playgrounds have largely prioritised examining children's play behaviour (Grady, 2018; Sandseter et al., 2020) and physical activity (Dyment et al., 2009; Reimers & Knapp, 2017; Ridgers et al., 2012). These direct, measurable indicators provide evidence on what children actually do in the playground, such as the type of play they engage in, which helps determine whether playground environments are meeting their intended role in promoting active play. More recently, greater attention has been given to understanding where children choose to play (Hyndman, 2015; Lucas & Dyment, 2010). This provides insights into social interactions and use patterns, including which areas are most or least used. However, though these approaches effectively quantify behavioural outcomes, they do not fully explain why children choose particular spaces or how environmental characteristics influence their choices. Studies show that research exploring these underlying factors remains limited (Anthamatten, Brink, et al., 2014) and highlight a significant knowledge gap for designers, managers and policy makers involved in school playground planning and designing (Anthamatten, Brink, et al., 2014; Dyment & O'Connell, 2013).

School playgrounds involve complex interactions among users, spatial features and social dynamics, necessitating a thorough, more comprehensive understanding of the multiple factors shaping play behaviour. As noted in previous studies, some dimensions are more widely studied than others, particularly because of methodological constraints and a lack of tools capable of capturing multidimensional, simultaneous data (Grady, 2018). This highlights the need for more integrated research approaches that combine methods to explore the less explored aspects of children's play environments.

Studies highlight significant limitations in generalising findings from existing school playground research largely because of methodological inconsistencies (Anthamatten, Brink, et al., 2014; Grady, 2018). A key challenge is the lack of standardised or consistent use of taxonomies (e.g., play, activity zones) that often vary according to the cultural and social context of children's behaviour and environmental design. In addition, although many studies examine children's play behaviours, the complexity of "play" as a construct results in varied interpretations and classifications across studies (Holmes, 2012). This variability makes it difficult to compare findings across studies or to reproduce the methodological approaches beyond the specific research context (Anthamatten, Brink, et al., 2014).

A further limitation of these studies concerns the unit of analysis adopted in playground research. Most studies examine the whole school playground as a single analytical unit (Cardon et al., 2012; Farley et al., 2008; Rutkauskaite et al., 2021). This approach may overlook important variations in different parts of the playground. Little work has focused on microgeographic analysis, which shifts the analysis scale to specific zones in school playgrounds (Anthamatten, Brink, et al., 2014; Anthamatten, Fiene, et al., 2014). This is significant in providing more detailed insights into how spatial features influence children's play behaviour. However, this approach presents methodological challenges, particularly when the zone boundaries are arbitrarily defined (Anthamatten, Brink, et al., 2014). As the demand for evidence-based playground design increases, there is growing recognition of the need for more consistent, carefully structured microgeographic analysis at smaller scales to generate findings that can provide more meaningful guidance for schools and playground designers (Anthamatten, Fiene, et al., 2014).

In addition to the methodological and research gaps identified in the literature, research in New Zealand mostly focuses on preschool and urban playgrounds, with primary schools receiving comparatively limited research attention (Okur-Berberoglu, 2025). Therefore, it is unclear whether New Zealand primary school playgrounds provide the spatial qualities necessary to support adequate play opportunities. There is also limited understanding of children's spatial play behaviour in primary schools, including patterns of use across playground areas, the extent to which all areas are

effectively used, and the popularity of different AZs, such as which zones are most frequently used and which ones remain underused.

In summary, it is evident that the qualities of school outdoor environments, particularly the spatial characteristics of specific AZs, significantly influence children's play behaviour and associated use patterns. Certain zones tend to promote higher activity levels and are more frequently used; others remain underused, indicating that spatial design affects both the distribution and diversity of play opportunities. Research highlights significant methodological limitations and, particularly in the New Zealand context, there is a clear lack of studies examining primary school playgrounds. Therefore, several key questions on the adequacy, distribution and effectiveness of play opportunities remain unclear. Addressing these gaps calls for more context-specific, primary school-focused research to better understand children's behavioural responses to optimise the performance of school outdoor environments.

2.7 Evidence-based design methodology for landscape design in support of sun protection behaviour

In the context of Global Climate Change (GCC), overexposure to extreme conditions poses significant health and well-being risks, particularly for vulnerable populations, such as young children. However, research indicates that simply increasing the amount of green space is not an adequate response (Vanos, 2015). Instead, well-designed, evidence-based interventions can effectively reduce the risks (Li et al., 2023; Lin et al., 2022; Vanos, 2015).

Evidence-based landscape architecture (EBLA), according to Brown and Corry (2011, p. 328) is defined as the "deliberate and explicit use of scholarly evidence in making decisions about the use and shaping of the land". Given the growing complexity of today's environmental challenges, EBLA provides an efficient, effective framework for creating adaptive solutions (Fagan, 2017). Brown and Corry (2011) stated that evidence-based landscape architecture can improve the health and well-being of humans as medicine to humanity. In fact, landscape architecture is uniquely poised to help solve problems where spatial design plays a key role, because it can lead to novel spatial solutions to problems based on the latest scientific knowledge, testing and evaluation (Nassauer & Opdam, 2008). Though the concept of EBLA is slowly emerging and gaining attention in the profession, its integration into landscape practice is still limited (Brown & Corry, 2011).

2.7.1 Evidence-based design process

Over the last 20 years, much has been accomplished with respect to advancing EBLA, but its potential has yet to be realised (Brown & Corry, 2011; Lenzholzer & Brown, 2013). Researchers commonly identify key barriers that hinder the effective integration of evidence into design (Cortese &

Lenzholzer, 2022; Lenzholzer et al., 2013; Lin et al., 2022). To address these barriers and advance evidence-based design (EBD), it is important to understand how evidence is integrated into design and the challenges that hinder effective integration.

Milburn and Brown (2003) have determined how evidence is commonly defined and used by designers during the three stages of design. In the evidence-based approach, evidence is accessed and evaluated before, during and after design implementation so that credible, defensible knowledge informs decision-making (Brown & Corry, 2011). The process of integrating evidence into design can be shown through a linear diagram (see Figure 2.3).

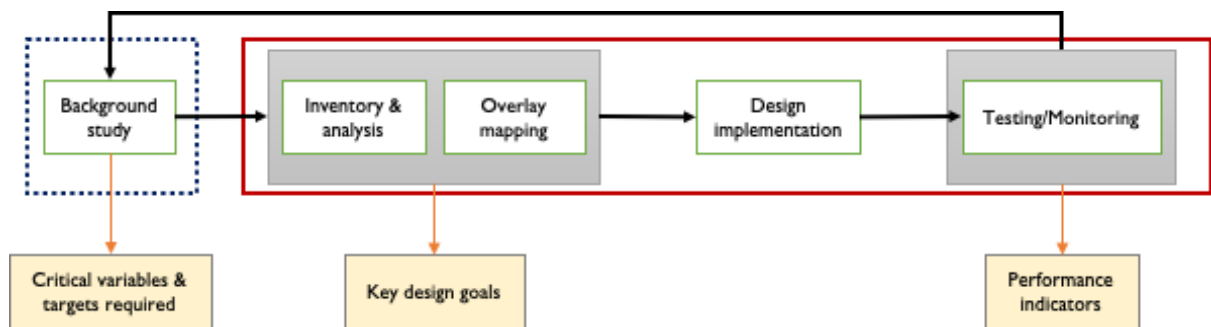


Figure 2.3: The integration of evidence-based landscape architecture into design

Source: Adapted from Brown and Corry (2020) and Lin and Brown (2021)

Incorporating evidence during research before the design stage

The research stage of design serves two primary purposes: (1) to understand the theoretical framework regarding a problem/solution applicable to other situations rather than just the specific site being designed (Li et al., 2023); and (2) to understand the implications of generalizable knowledge regarding a problem/solution (Cortese & Lenzholzer, 2022). During this stage, designers commonly incorporate two classes of evidence: indirect and direct (Milburn & Brown, 2003). Indirect evidence generally involves the broad collection of information that establishes the context of the design problem (Li et al., 2023). This includes the designer's understanding of factors influencing the issue (often termed intrinsic research), the review of current ideas, trends, theories, precedents and projects derived from literature review, and knowledge derived from comparable design situations, processes or solutions, commonly examined through case studies (Milburn & Brown, 2003). This process helps refine relevant information, narrow the inquiry's scope and form preliminary assumptions to guide subsequent design decisions (Li et al., 2023).

Direct evidence is the second class of evidence identified in academic research (Milburn & Brown, 2003). Often described as 'inventory and analysis', it primarily consists of collecting, evaluating and

editing site-specific information (Milburn & Brown, 2003). This process verifies context information and establishes the foundational knowledge necessary for EBD (Lin & Brown, 2021).

Some key challenges constrain the integration of evidence during this design stage. First, there is a persistent need for more rigorous, practice-relevant scholarship (Lenzholzer et al., 2018). Site-specific information is often collected in an unsystematic and haphazard manner, and is largely criticised for its inconsistent quality and lack of methodological rigour (Milburn & Brown, 2003). Moreover, the profession often relies heavily on anecdotal knowledge and not incrementally developed systematic evidence (Milburn & Brown, 2003), which further weakens the reliability and applicability of research in supporting design decisions.

Second, many designers are generalists and may lack the specialised knowledge required to address complex or technical issues (Eliasson, 2000). Additionally, practical constraints, particularly limited time, and the nature of assignments can make it hard for design professionals to locate and apply relevant evidence to inform designs (Lenzholzer et al., 2018; Milburn & Brown, 2003). This lack of evidence makes it difficult to assess design outcomes in a consistent, reliable manner (Lenzholzer et al., 2018).

Third, the strength of the evidence base in all areas of landscape architecture is uneven (Milburn & Brown, 2003). Strong empirical evidence exists in some domains such as soil drainage, transplanting of trees, microclimate modification, materials engineering and visual preferences (Milburn & Brown, 2003). In contrast, areas related to social and cultural components and aesthetics are less readily supported by conventional forms of evidence and may not align easily with standard evidence paradigms. Moreover, knowledge across all disciplines remains provisional, and gaps persist, yet design decisions are frequently made despite incomplete or evolving evidence (Lenzholzer et al., 2018).

There is therefore a need to generate knowledge that extends beyond site-specific application towards more transferable insights. Concurrently, practitioners often encounter difficulties in translating evidence from other disciplines into practical application, especially when the knowledge is very abstract (Eliasson, 2000; Nassauer & Opdam, 2008).

Incorporating evidence during the design stage

The purpose is to give form, explore alternatives and determine spatial solutions that show the extent to which effective solutions are achieved based on evidence (Milburn & Brown, 2003). This involves the application and synthesis of evidence, translating it into a set of design strategies and subsequently applying them to the site (Li et al., 2023). Iteration between the verification of

information and the application of evidence supports optimisation, enabling continuous refinement and improvement of the design outcome (Li et al., 2023).

In this stage, the predominant use of modelling, simulations and/or mapping tools is often noted (Li et al., 2023). However, research suggests that many practitioners continue to perceive design primarily as a creative process intrinsic to design and less a scholarly process, which is partly evident from the limited use of accurate testing of design alternatives at this stage (Cortezão & Lenzholzer, 2022). Several challenges were noted by practitioners limiting the use of such tools or techniques. Relevant modelling hardware/software can be expensive and therefore inaccessible, and their effective use often requires specialised technical skills. Many tools are designed to model only certain types of evidence, limiting their capacity to accommodate the full range of knowledge needed to support comprehensive designs (Lin et al., 2022).

Incorporating evidence after the design or monitoring stage

Following implementation, evidence plays a critical role in both justifying and evaluating design outcomes (Milburn & Brown, 2003). At this stage, evidence is used to substantiate design decisions, respond to criticism and communicate the rationale behind the proposed or implemented solutions (Milburn & Brown, 2003). In effect, evidence therefore functions as a means of defending design ideas, supporting persuasion and stakeholder acceptance (Milburn & Brown, 2003).

Evidence is central to identifying the implications for advancing future interventions (Li et al., 2023). This involves openly reported and replicable procedures for measuring outcomes (Li et al., 2023). The outcomes of design intervention are systematically documented, objectively assessed and clearly described. These findings are then archived in a broader knowledge base where they contribute to the existing knowledge pool and can be critically applied to future projects. In this way, design becomes embedded in a systematic framework in which effectiveness is documented, shared and continuously re-evaluated, supporting ongoing learning and advances in practice (Li et al., 2023).

Post-occupancy evaluation (POE) is one of the most commonly used approaches at this stage (Deming & Swaffield, 2011; Lin et al., 2022). Modelling and projection during earlier phases are insufficient here because they are not effective in determining the real-world effectiveness of a specific design solution (Deming & Swaffield, 2011). Research indicates that evaluations are not consistently disseminated, limiting opportunities for shared learning (Lenzholzer et al., 2018; Milburn & Brown, 2003). Ideally, implemented projects should be monitored and, where possible, examined through rigorous research so that findings can inform refinement of the original design hypothesis in subsequent design cycles.

Several barriers constrain implementation of the POE. Practitioners may lack motivation to undertake monitoring because clients are often unwilling to fund it, planning policies rarely mandate it, and there may be concerns about revealing shortcomings or potential legal liability (Chen et al., 2021). In addition, some practitioners are unfamiliar with available monitoring methods, and others face barriers related to accessibility, methods can be costly, time-intensive (particularly for long-term assessment) and may require specialised skills or equipment.

Overall, considering the three stages through which evidence can be integrated into design, the benefits of integrating evidence can thus be summarised as: 1) a means of collecting valid, reliable data (Canfield et al., 2018; Lin & Brown, 2021); 2) results can be used to better future practice (Kato & Ahern, 2008); 3) it provides feasible design options (Lin & Brown, 2021); and 4) it helps expand professional knowledge (Canfield et al., 2018).

Despite these advantages and as discussed above, some frequently identified barriers to designers' slow adoption of evidence in practice can be summarised as follows: 1) availability of time, resources, and technical expertise (Canfield et al., 2018; McCoy, 2018); 2) a lack of easily accessible information and tools (Eliasson, 2000); 3) unfamiliarity with rigorous evaluation tools and techniques (e.g., computer-based simulation tools) (Lin et al., 2022); and 4) a lack of understanding and guidance in systematic theoretical methods (Lin et al., 2022).

Given the barriers and enablers associated with integrating evidence into design, there is a clear need for an effective evidence-based design methodology capable of identifying and refining best design solutions in support of critical issues while addressing some of the key barriers to EBLA implementation among landscape architecture scholars and practitioners. Such a methodology would be a valuable tool for practitioners and other stakeholders involved in the design and planning of children's outdoor environments, by supporting more informed decision-making and leading to more effective health-related outcomes (Anthamatten, Fiene, et al., 2014; Boldemann et al., 2011).

2.7.2 The attributes of an effective evidence-based design methodology

In landscape architecture, a range of methodologies can be used by both practitioners and researchers for the testing, evaluation and design of landscapes (Deming & Swaffield, 2011). The requirements or attributes of a scholarly design methodology differ from those of a practice-based design methodology. Research-based methodologies are characterised by being rigorous, leading to evidence that satisfies the requirements of scholarly research, such as accuracy/precision, reliability, transparency and validity (Cortese & Lenzholzer, 2022). Commonly used methods include field or direct observation, computer-based modelling and simulation and overlay or mapping techniques. Among these, field observations (such as on-site measurements, systematic observation and

recording) are widely used across studies and are valued for their capacity to generate robust data that support valid, reliable, accurate results.

In contrast, landscape design practice has traditionally relied on site inventory and analysis that involve on-site observations and mapping to gather site-specific information (Cortese & Lenzholzer, 2022; Fagan, 2017). Although computer-based modelling and simulations are increasingly used, their adoption in practice remains comparatively limited (Lin et al., 2022). The processes of collecting, synthesising and analysing information in practice are often criticised as being non-methodical, haphazard, inconsistent and lacking rigour (Milburn & Brown, 2003). As a result, the knowledge generated is considered less scholarly in terms of accuracy, reliability and validity (Cortese & Lenzholzer, 2022; Fagan, 2017) and tends to be more subjective and casual in nature (Fagan, 2017). Nevertheless, for practitioners working under time and resource constraints, and where rigorous evaluation methods may not be feasible (Fagan, 2017; McCoy, 2018), site inventory and analysis remain pragmatically and contextually appropriate.

Overcoming the barriers to implementing EBD requires a methodology that bridges the gap between research and practice (Bherwani et al., 2020; Lin et al., 2022) and is capable of meeting the needs of practitioners (Lin et al., 2022) while fulfilling the norms of scholarly evidence (Fagan, 2017; Lin et al., 2022). Accordingly, as identified in the literature, some key attributes of an effective methodology are as follows:

Systematic, reliable and valid: Evidence used in design should be credible, defensible and capable of informing design decisions in a transparent manner (Chong et al., 2010). EBD literature emphasises the importance of organised, systematic data collection (Fagan, 2017), with results assessed on a reliable basis (Cortese & Lenzholzer, 2022) leading to more scholarly evidence that is credible and defensible in decision-making.

Cost-effective, accessible and nimble: Studies emphasising the practical constraints in terms of time, cost and resources, call for methodologies that are economically feasible and supported by readily accessible tools and techniques (Eliasson, 2000). Approaches that can be applied and tested quickly support iterative design and are particularly beneficial for practitioners (Cortese & Lenzholzer, 2022). Such cost-effective, adaptable methods also support clients by enabling broader and more consistent application in real-world projects (Fagan, 2017).

Simple, user-friendly: Evidence points to the need for more simplified, user-friendly tools that are not too complicated for non-expert users (Bherwani et al., 2020; Eliasson, 2000; Lin et al., 2022). Over-complex methods reduce usability and limit adoption. A practical methodology should

therefore balance technical robustness with ease of use, ensuring that integrating evidence does not itself become a barrier to achieving the intended objectives.

Flexible and integrative: Contemporary design challenges, such as UVR protection, are often complex and multi-factorial, involving multiple interdependent variables that require simultaneous evaluation. Microclimate, for example, is shaped by critical parameters like wind speed, relative humidity, albedo, solar insolation, urban canyon effect and street canyon effect, all of which interact dynamically. However, these relationships and their dependencies or impacts on each other remain only partially understood because they have had limited examination and are often in isolation (Bherwani et al., 2020). Certain parameters are being explored more than others, creating knowledge imbalance. This gap reflects the lack of simultaneous assessment approaches that integrate multiple factors in a single framework (Bherwani et al., 2020). Such integration improves understanding of the interactions among factors and supports the optimisation of design responses. Integrated assessment, combined with enhanced visualisation, supports effective decision-making by enabling designers to evaluate trade-offs and synergies across different performance criteria (Bherwani et al., 2020).

Transparent and iterative frameworks: Landscape architects frequently use 3D modelling programs to visualise their design concepts (Lin & Brown, 2021). However, many landscape design variables, such as microclimatic elements, are invisible and intangible, making them challenging to integrate into conventional 3D modelling tools (Lin & Brown, 2021). Additionally, research highlights the lack of frameworks or methodologies that combine mapping, modelling and evaluation tools in an iterative process to support testing and refinement and inform decision-making throughout design development and detailing (Lin & Brown, 2021; Lin et al., 2022).

Effective visual representation of results: Communication is a central component of design (Eliasson, 2000). The results/findings must be presented in a clear, spatially explicit manner that facilitates easy interpretation (Lin & Brown, 2021; Lin et al., 2022). Strong visual outputs such as maps, overlays, diagrams and performance indicators enhance understanding (Eliasson, 2000) and support stakeholder engagement through effective communication, thereby enabling more informed decisions (Bherwani et al., 2020).

Building on the key attributes outlined above, an effective EBD methodology to evaluate and design school playgrounds in support of SPB must therefore meet the following criteria: (1) integrate multiple interdependent variables for evaluating SPB design; (2) support a transparent, flexible iterative process, enabling EBD decision-making; (3) facilitate clear, effective communication across disciplines and with stakeholders to enhance decision-making for optimal SPB among children; and

(4) incorporate user-friendly tools and techniques for data collection, synthesis and analysis, leading to improved outcomes.

2.7.3 A critical evaluation of existing methodologies

Existing methodologies commonly used in landscape architecture practice and research can be broadly grouped into five categories: (1) field monitoring and analysis; (2) modelling and simulation; (3) conventional observational site analysis; (4) gestalt assessment; and (5) overlay or suitability analysis. Each approach has its strengths and limitations. However, it was significant to determine their suitability for this study purpose – specifically, the evaluation and design of school playgrounds to promote SPB. Therefore, these five methodologies were evaluated against the criteria for an effective methodology outlined above and summarised in Table 2.10.

Table 2.10: Evaluation of existing design methodologies against the established criteria for an effective evidence-based design methodology

Existing Methodology	Methods/tools used	Integrated assessment			Presentation of spatially explicit findings	Incorporating user-friendly tools and techniques			Producing substantial evidence	Suitability at site-scale application
		Obj 1	Obj 2	Obj 3		Time-efficient	Cost-effective	Simple		
Field monitoring and analysis	Shade assessment methods such as: shade audits, UV meters, etc.	✓			×	×	×	×	✓	✓
	Microclimate assessment methods such as: monitoring stations, Thermal comfort indices, etc.		✓		×	×	×	×	✓	✓
	Direct observation			✓	✓	×	✓	✓	✓	✓
	Combined		✓		×		×		✓	✓
Modelling and simulation	Shade modelling	✓			✓	✓	✓	✓	✓	✓
	Thermal comfort modelling		✓		✓	×	×	×	✓	✓
	Combined		×		✓		×		✓	✓
Gestalt assessment					✓	×	×	×	✓	✓
Site observation analysis			✓		✓	✓	✓	✓	×	✓
Overlay/suitability analysis	Landscape-unit method, Resource-pattern method, McHarg's overlay method		✓		✓	✓	✓	×	✓	×

In the table:

Obj 1 – UVR protection

Obj 2 – Microclimatic comfort

Obj 3 – Attractiveness

✓ – meets the methodological requirement

× – does not meet the methodological requirement

The field monitoring and analysis approach relies on direct measurements such as shade audits and meteorological data, and the modelling and simulation-based approach. Though the former supports the integration of multiple interdependent variable assessments, its outputs are not always spatially explicit. In contrast, the latter is effective in generating spatially explicit outputs (Lin et al., 2022) but is less effective for integrated assessment. In both cases, the results are not always transparent or adaptable for iterative processes. These approaches are often not user-friendly because they require

specialised expertise, substantial time commitment and significant financial resources (Bherwani et al., 2020; Cortesão & Lenzholzer, 2022; Lin et al., 2022).

Conventional observational site analysis methods record and evaluate site-specific information. This method relies on personal experience and is largely descriptive (Lin et al., 2022). As a result, the knowledge generated is often insufficient to justify complex design decisions and interdisciplinary challenges (Li et al., 2023). The Gestalt assessment method, on the other hand, is a more sophisticated field observation method that uses tools, such as aerial photographs or topographic maps to support holistic judgements about the suitability of different regions. Grounded in Gestalt principles of perceiving environments as integrated wholes, this method relies on the designer's professional knowledge and experience to interpret spatial patterns, relationships and landscape character (Ndubisi, 2014a). Suitability is therefore inferred through expert judgement and is typically translated into a series of maps depicting descriptive suitability across regions. A key limitation of this method is its substantial reliance on the designer's expertise to guide decision-making. Because these judgments are largely implicit, they can be difficult to scrutinise, replicate or verify (Ndubisi, 2014a), making it challenging to communicate and convincingly justify findings to other stakeholders in the decision-making process.

Finally, the overlay or suitability analysis approach integrates large-scale GIS and other spatial datasets to map resource-specific land information. Though it effectively integrates multiple interdependent variables (Ndubisi, 2014a), its application has largely been limited to broad-scale landscape planning and assessment. This limitation highlights the need for a framework that is applicable across diverse scales including finer, site-specific contexts and capable of addressing a wider range of landscape challenges. It is still unclear whether the above approaches are effective across different design stages (Lin et al., 2022). There is a gap in current evaluation methodologies (Li et al., 2023) and a need for *implementation-oriented research* (Bherwani et al., 2020) that integrates diverse factors, generates transparent, verifiable outcomes and communicates results convincingly across disciplines.

2.8 Summary

Chapter 2 comprehensively reviews the literature on the theory of sun protection behaviour (SPB) and the planning and design of school playgrounds for improved sun protection for primary school children. It describes the impacts of overexposure to solar UVR and the factors that increase children's vulnerability in outdoor environments. It also reviews existing school-based sun protection initiatives and measures and highlights their contribution and limitations in adequately protecting children from overexposure to UVR.

The review also evaluated current landscape architecture approaches to sun protection, identifying their limitations and emphasising the potential of landscape design to promote spontaneous SPB. Three key factors were established as essential: sufficient UVR protection (both direct and indirect), microclimatic comfort (including thermal and wind comfort), and attractiveness (adequate play opportunities). The literature, assessment methods, and research gaps associated with each of these factors were examined separately.

Furthermore, the chapter emphasises the need for an evidence-based design methodology that meets the needs of both practitioners and researchers. It defines the key criteria for an effective evidence-based design methodology and critically reviews existing methodologies, identifying their limitations and thereby establishing the need for the development of a novel approach.

Chapter 3 presents the research strategies and methods used to address the research questions, the site selection criteria and gives a detailed description of the study sites.

Chapter 3

Methods and Study Sites

Chapter 2 presented a critical review of the literature on the theory of sun protection behaviour (SPB) in the planning and design of school playgrounds and established the need for the development of a novel approach and the evaluation of existing school playgrounds. This chapter introduces the research framework, strategies, research design and methods that guided the purpose, scope and process of this study. Section 3.1 presents the research framework and details the strategies adopted to address the research questions and objectives. Section 3.2 describes the theoretical framework – the Landscape Units approach – that guided the selection of multiple methods and the development of the methodology. Section 3.3 discusses the study context – Christchurch – and provides an overview of its geographical location, climate and key microclimatic variables relevant to the study. Section 3.4 outlines the research design, based on a case-study approach, and the site selection criteria used. Section 3.5 details the protocols and multiple methods used in the methodology. Section 3.6 outlines the study sites and their spatial characteristics in relation to sun protection behaviour (SPB) design. Finally, Section 3.7 outlines the ethical considerations addressed in this study.

3.1 Research framework

This study was conducted in two stages using a combination of research strategies and methods to address the research objectives (Figure 3.1 and Table 1.1). Stage 1 focused on developing an improved evidence-based SPB-D methodology, which addresses research objectives 1 to 4. Evidence-based landscape architecture (EBLA) “uses knowledge – generally from methodically studied experiments or experience – as the principal information source for design” (Brown & Corry, 2011, p. 328). Knowledge production in landscape architecture, as in other disciplines, draws on multiple, and sometimes conflicting, epistemologies, ontologies, research paradigms, theories and methods. Swaffield (2002) argues that in landscape architecture “knowledge is always *situated*” (Swaffield, 2002, p. 3); place-specific circumstances may resist attempts of generalisation.

Research strategies in landscape architecture vary in relation to underlying ontological assumptions ranging from “objectivist” through “constructionist” to “subjectivist” paradigms, using inductive, deductive and abductive research strategies (Deming & Swaffield, 2011, p. 7). Research paradigms are normative social constructs, “philosophical worldviews” (Creswell, 2011) that promote a particular understanding of knowledge and how it is developed. Such worldviews have been subject to discourse and debate; they have changed and evolved over time. Lenzholzer et al. (2013) conclude

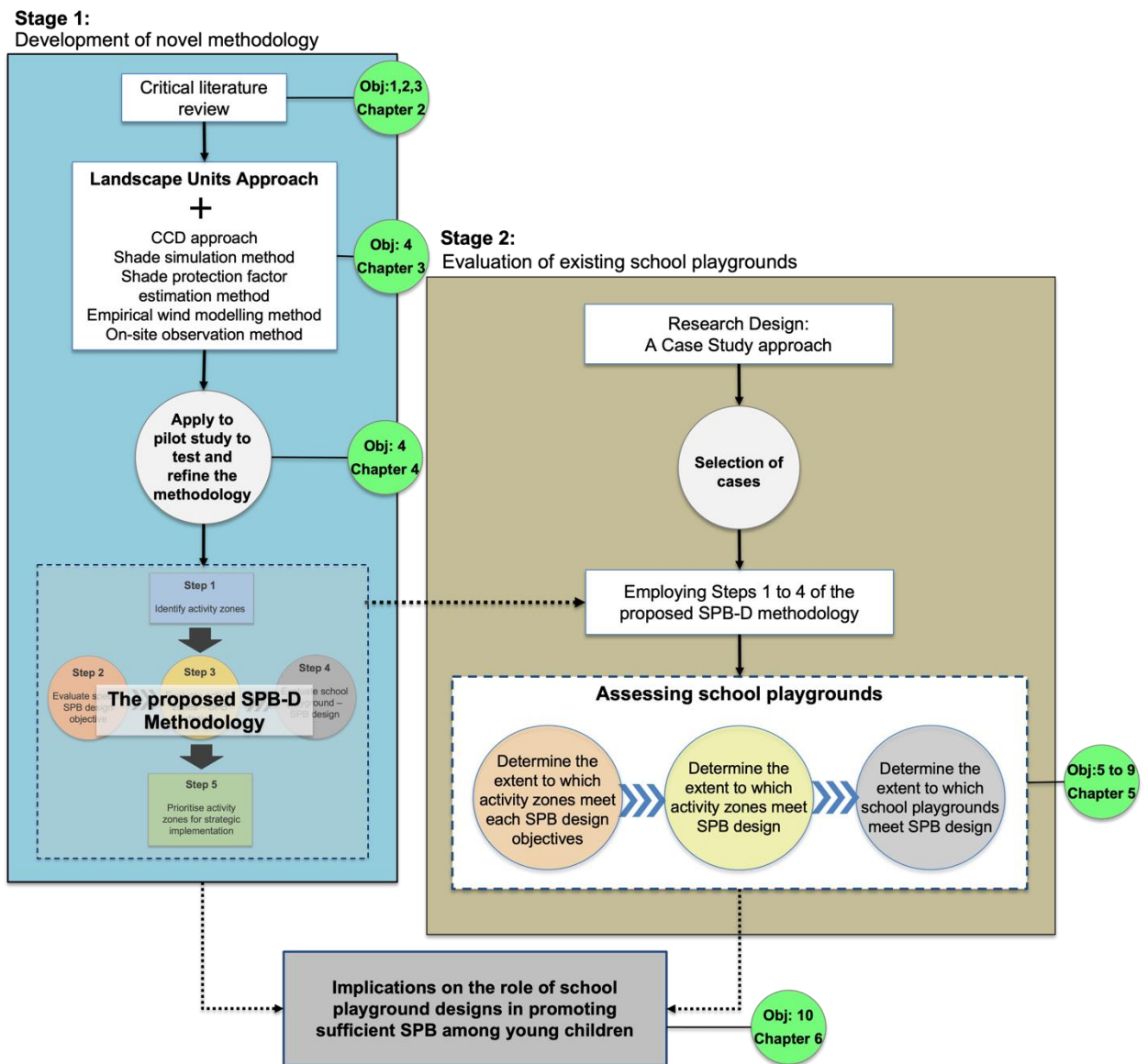


Figure 3.1: Research framework indicating the methodology and methods applied in two research stages

Note. The two key findings of this study are presented in the dashed rectangles

that landscape architecture researchers need to be aware of the contextual diversity of knowledge production and the applicability with regard to specific research questions and research methods. For example, widespread criticism of positivist research and associated ideas, e.g., related to claims of absolute truth and ‘value-free’ science, resulted in the revised notion of ‘postpositivism’ (Creswell, 2011, p. 6; Phillips et al., 2000, p. 6; Robson, 2011, p. 20). Like its positivist parent, the postpositivist research paradigm is based on “careful observation and measurement of the objective reality that exists ‘out there’ in the world” (Creswell, 2011, p. 7). However, it also acknowledges that even the best (evidence-based) research may be imperfect and potentially fallible. Though research methods may follow a general postpositivist approach, they may include types of data that do not fully meet postpositivist criteria such as universal validity.

Within this philosophical and methodological context, Stage 1 of the study adopted the Landscape units' approach as its theoretical foundation. This approach provides a structured spatial framework for integrating the multiple methods, data collection techniques and analytical processes that are discussed in this chapter. Guided by the landscape units' approach, a novel evidence-based SPB-D methodology was developed to evaluate and improve school playground designs in support of SPB among young children. The methodology was tested and refined through applying it to a pilot study – a school playground in Christchurch, New Zealand - to spatially 'situate' knowledge production. The detailed step-by-step process is discussed in Chapter 4.

Stage 2 focused on evaluating the potential of existing school playground designs to promote sufficient SPB among children, thereby meeting research objectives 5 to 9. In this stage, the developed SPB-D methodology (Steps 1 to 4) was applied to purposefully selected case study school playgrounds in Christchurch to evaluate the extent to which: (i) activity zones meet individual SPB design objectives; (ii) activity zones meet SPB design; and (iii) school playgrounds meet SPB design criteria. The findings from this evaluation are discussed in Chapter 5.

Finally, integrating the two key findings from Stages 1 and 2 addressed the final research objective, Objective 10 (Figure 3.1). Its implications are discussed in Chapter 6. The combined use of multiple methods positions this study in an integrative and interpretive research strategy. The integrative strategy supports the development of the evidence-based SPB-D methodology by bringing together multiple methods that help determine the strengths and limitations of the methods used and the knowledge gaps that remain. This understanding is important to inform future applications and bridges the gap between research and practice. The interpretive strategy, on the other hand, seeks to "make sense of the phenomena" (Deming & Swaffield, 2011, p. 152) by deepening the "understanding of meaning and context" (Deming & Swaffield, 2011, p. 30). This strategy allows the researcher to move reflexively between observed data and the theoretical concepts that are brought to the investigation, thus helping to make sense of emerging patterns (Deming & Swaffield, 2011). In this study, it was particularly helpful in examining the relationship between school playground design and its potential role in supporting SPB, through the investigation of three key SPB objectives. This approach acknowledges that school playgrounds are shaped by broader cultural, climatic and urban contexts, and that these contexts influence both design decisions and children's use patterns. Understanding these contextual barriers and enablers was therefore fundamental not only for explaining why playgrounds are designed in particular ways, but also for identifying opportunities to strengthen SPB outcomes.

3.2 The theoretical framework – The landscape units' approach

The landscape units, or physiographic-unit approach, was proposed in 1961 by Canadian forester G. Angus Hills (Lyle, 1999). The approach begins by dividing the landscape into physiographically homogeneous units referred to as 'landscape units' (LUs), which are then reaggregated for planning purposes (Lyle, 1999). LUs are relatively homogeneous areas sharing a common set of attributes or specific landscape characteristics (Lyle, 1999). Once individual LUs have been classified, each is analysed to define its limitations and potential, thus forming the basis for assessing suitable landscape uses (Lyle, 1999; Ndubisi, 2014b). Fundamentally, the LU approach aligns with the principles of overlay or suitability methods, extensively described in *'Design with Nature'* (McHarg, 1994) and is most widely used in landscape planning to date. However, it differs in one key aspect: rather than beginning with problems and potential, it starts with the inherent biophysical characteristics of the land, which allows the integration of multiple interdependent factors in the landscape (Lyle, 1999).

Hill's approach focused on using soil associations to determine land capabilities. Over time, it developed to using landforms and vegetation associations that contributed to the development of the Canadian Land Inventory system (Lyle, 1999). It is regarded as a simple, direct and highly effective approach widely applied in land use planning and resource management (Lyle, 1999) at coarser spatial scales such as district, territory or region (Deming & Swaffield, 2011). The approach was later promoted by Brown (2008) in his book *'Landscape Assessment for Planning and Design'*, where he refined and systematised the process.

In this study's context, the landscape units' approach is particularly suitable because it provides a structured, spatially coherent framework for integrating the three key SPB design objectives: UVR protection, microclimatic comfort, and attractive play opportunities. This approach allows the environment to be analysed as a series of discrete yet interrelated units (Ndubisi, 2014b), facilitating the integration of diverse spatial and environmental data. The spatially explicit framework is especially well suited to this study because LUs are concise, mappable entities that effectively convey a wide range of information (Brown, 2008). When displayed on a single map, LUs synthesise specific landscape characteristics into clearly distinguishable units, offering a simplified yet robust foundation for developing targeted design strategies (Brown, 2008). Their visual clarity enhances the ability to differentiate between landscape types, thus enabling users to interpret information quickly (Lyle, 1999) and make well-informed, evidence-based design decisions.

Brown (2008) outlines a five-step process that begins by gathering site-specific resource characteristics such as landforms, soils and microclimate and represents them on a series of maps. These resource maps are overlaid one by one to divide the site into homogeneous physiographic

units, referred to as landscape units (LUs). After identifying the LUs, a matrix is developed to assess the characteristics and land requirements of the proposed land uses. Each LU is subsequently evaluated and rated for its ability, suitability and feasibility to support potential land use. Based on these ratings, the LUs are categorised from 'best' to 'worst', enabling the identification of the most appropriate locations for each land use, which then form the basis for land-use allocation and the development of alternative land-use strategies.

According to the LU approach, each unit, defined by its specific landscape characteristics, is capable of supporting a particular land use or function (Brown, 2008; Lyle, 1999). In this study's context, each LU with particular characteristics corresponds to a particular SPB objective and mapping them spatially helps identify areas that are most likely to achieve the objective. It also indicates areas that do not meet objectives, enabling the development of alternative design strategies to improve outcomes, thereby supporting an iterative, evidence-based design.

Overall, the adoption of the LU approach guided the selection of appropriate methods for data collection, synthesis and analysis. As noted by Ndubisi (2014b), the framework helped address several key questions central to landscape design and planning, particularly in support of SPB design. They include: (1) How can the time and resources required to collect detailed site inventories be minimised without compromising accuracy? (2) What is the most effective way of differentiating landscapes for multiple design objectives and management purposes? (3) What are the relative advantages of maintaining or enhancing their capacities under current or projected social or economic conditions? (4) What design or management strategies are needed to effectively improve and sustain these benefits over time?

3.3 The study context: Christchurch

The primary aim of this study is to investigate the potential role of existing school playground designs in promoting sufficient SPB through the integration of three key SPB design objectives: UVR protection, microclimatic comfort and attractive play opportunities. The geographical context of the study is particularly important because it strongly influences the evaluation of both UVR protection and microclimatic comfort and, therefore, the overall SPB potential of school playgrounds. Given the study's context, Christchurch, New Zealand, was chosen as the study region because it presents distinct environmental conditions: a combination of high UVR levels (NIWA, 2022), moderate temperate climate, and highly variable microclimatic conditions (Mullan et al., 2012) that, together, pose a challenge in promoting effective SPB among children. The following sections describe Christchurch's geographical setting and outline the UVR levels and microclimatic conditions relevant to this study.

3.3.1 The geographical location and climate overview

Christchurch is located on the east coast of New Zealand's South Island, situated inland on the low-lying Canterbury Plains (Figure 3.2). It is the largest urban centre in the South Island and the second largest in New Zealand (Environment Canterbury, 2022). New Zealand spans latitudes 34° to 47° south, and lies in the Southern Hemisphere temperate zone, with a wide range of regional and local (micro) climates (Macara, 2016). According to the Köppen-Geiger climate classification system, New Zealand experiences a Cfb or marine climate, where the ocean's proximity significantly influences its climate (Mullan et al., 2012). The configuration of the mountainous regions across both islands, especially the Southern Alps, together with the prevailing westerly airflow, produces substantial climatic variability (Macara, 2016). New Zealand's climate is classified into 10 broad zones; Christchurch belongs to the Eastern South Island climate zone (Greenwood et al., 2000).



Figure 3.2: Map of the mainland of New Zealand showing the location of the study region – Christchurch

Source: Canterbury Maps (2024)

Christchurch's distinct climate is strongly influenced by its surrounding geographical features, the Southern Alps, Port Hills, Banks Peninsula and the Pacific Ocean. The Southern Alps act as a massive barrier to the prevailing westerly winds. This has a profound effect in shaping the region's microclimate (Mullan et al., 2012). Summers are generally warm, with temperatures typically ranging from 18°C to 26°C, but may exceed 30°C, often when hot, dry foehn northwesterlies blow over the

Alps and plains (Greenwood et al., 2000). Abrupt temperature changes can occur when cold fronts pass over the region, followed by cold southwesterly winds (Greenwood et al., 2000). Winters are cold with frequent frosts and temperatures ranging from 7°C to 14°C (Greenwood et al., 2000). Christchurch receives relatively low annual rainfall and frequently experiences long dry periods, particularly during summer (Mullan et al., 2012). The average relative humidity ranges from 71.5% in December to 87.3% in July (Macara, 2016), suggesting that humidity is not a significant concern in terms of local microclimatic conditions. The city is moderately windy in the warmer months (Mullan et al., 2012) and local climate perception is strongly shaped by prevailing wind patterns (Tavares, 2015). The combination of high solar radiation, frequent winds and relatively low humidity can cause uncomfortable outdoor conditions, even in summer (Tavares, 2015). In summary, UVR levels, air temperature and the local wind patterns are the three most important microclimatic variables to consider when designing school playgrounds in support of SPB.

3.3.2 Christchurch's ultraviolet levels

Located at 43.5320°S and 172.6366°E in the Southern Hemisphere, Christchurch experiences very high UVI levels during summer months, with high UVI levels also occurring in early autumn and late spring (Greenwood et al., 2000). Between November and February, UV levels typically range from UVI 7 to 9 but may exceed UVI 10 in December and January (NIWA, 2022) indicating an extreme risk of UV exposure. During late spring and early autumn (i.e., March–April and September–October), UVI values commonly range between UVI 3 and 6 (NIWA, 2022), which still necessitates regular sun protection (WHO, 2002a). The lowest UVI levels, between 1 and 2, occur in winter (NIWA, 2022). Figure 3.3 shows the mean monthly maximum UVI levels recorded for Christchurch from 2016 to 2020.

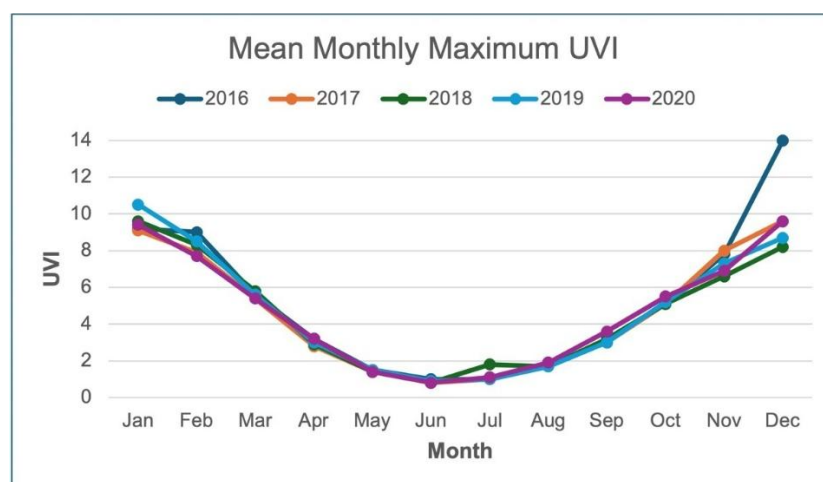


Figure 3.3: The average monthly maximum ultraviolet index (UVI) levels recorded for Christchurch from 2016 to 2020

Source: NIWA (2025)

The Christchurch primary school year runs from late January to early December, overlapping with periods of peak UV intensity, during which children, when outdoors, are exposed to the highest UVI levels. Especially during the summer, when UVI values exceed 8, children, when left unprotected, can achieve an erythemal dose in 13 to 15 minutes of full sun exposure (Gies & Mackay, 2004), placing them at significant risk of overexposure. McKenzie and Lucas (2018) show that on a single summer day there is sufficient sunburning UV radiation to accumulate 30 erythemal doses (30 MEDs) for fair skin. For fair-skinned individuals, 1 MED is the threshold for visible sunburn, and 30 MEDs in a single day means that the available UV radiation is 30 times the amount required to cause erythema (McKenzie & Lucas, 2018), highlighting the urgent need for sun protection measures. **Figure 3.4** shows a typical UV forecast for Christchurch on a summer day and indicates the UV levels and times of the day when sun protection is required. UVI values above 3, which require protective measures, are seen from approximately 9.00 a.m. to 5.00 p.m. In line with WHO (2002a) recommendations, this pattern indicates that comprehensive, all-day sun protection is essential during the summer.

On a typical school day, primary school children in New Zealand spend an average of 2.3 hours outdoors (Wright et al., 2007), including a one-hour lunch break centred around local solar noon (12:30–1:30 p.m.), when UV intensity peaks, particularly during summer (Figure 3.4). Even during other periods (i.e., March–April and September–October) when UV levels frequently range from UVI 3 to 6 (Figure 3.3), evidence from a New Zealand study at Lauder (~45°S) indicates that, on clear-sky days with a peak UVI of 3, the mean daily erythemal dose ranges from 12.5 to 14.3 SED (McKenzie & Lucas, 2018). When the maximum daily dose exceeds 10 SED, visible skin damage can occur in little more than one hour in fair-skinned individuals (McKenzie & Lucas, 2018).

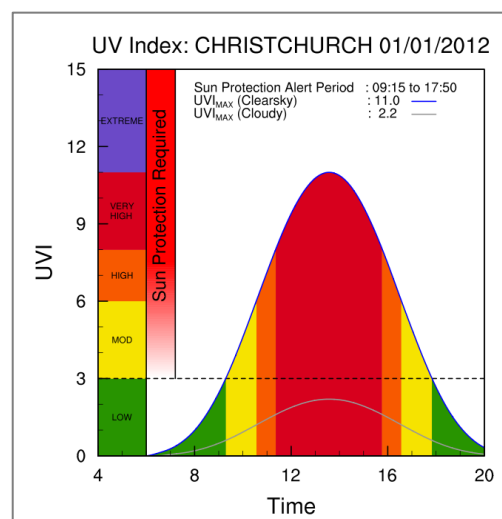


Figure 3.4: Hourly ultraviolet index (UVI) levels recorded on a typical summer day in Christchurch

Source: NIWA (2025)

As skin damage is determined by both UV intensity and exposure duration (Gies & Mackay, 2004), primary school children are at potential risk of significant UV overexposure for a substantial portion of the school year.

3.3.3 Air temperature

Christchurch’s coastal setting, with its proximity to the Pacific Ocean and the presence of the Southern Alps, creates highly variable temperatures (Mullan et al., 2012). As noted above, in Christchurch, the mean summer air temperature typically ranges from 18°C to 26°C, but may exceed 30°C, often when hot, dry foehn northwesterlies blow over the Alps and plains (Greenwood et al., 2000), increasing the risk of heat stress in children. The average observed high heat-related mortality is 9.1 deaths per day during the summer in the Canterbury region (Haenfling et al., 2023). Climate change projections for New Zealand predict an increase in mean temperatures, maximum temperatures and hot days in coming decades (Ministry for the Environment, 2018). Specifically, the number of hot days (maximum temperature above 25°C) is projected to increase 40-100% by 2040 (Ministry for the Environment, 2018). Extreme temperatures are expected to occur more frequently and persist for longer, increasing the risk of heatwaves (Ministry for the Environment, 2018) and, potentially, associated health impacts, particularly among vulnerable groups such as young children. Figure 3.5 presents the mean air temperature data for 2020 (NIWA, 2025). In 2020, the mean monthly maximum air temperatures ranged from 24.5°C in February to 12.5°C in July and the mean monthly minimum temperatures ranged from 13.1°C to 2.8°C. In the same period, the mean air temperature ranged from 18.8°C to 7.5°C.

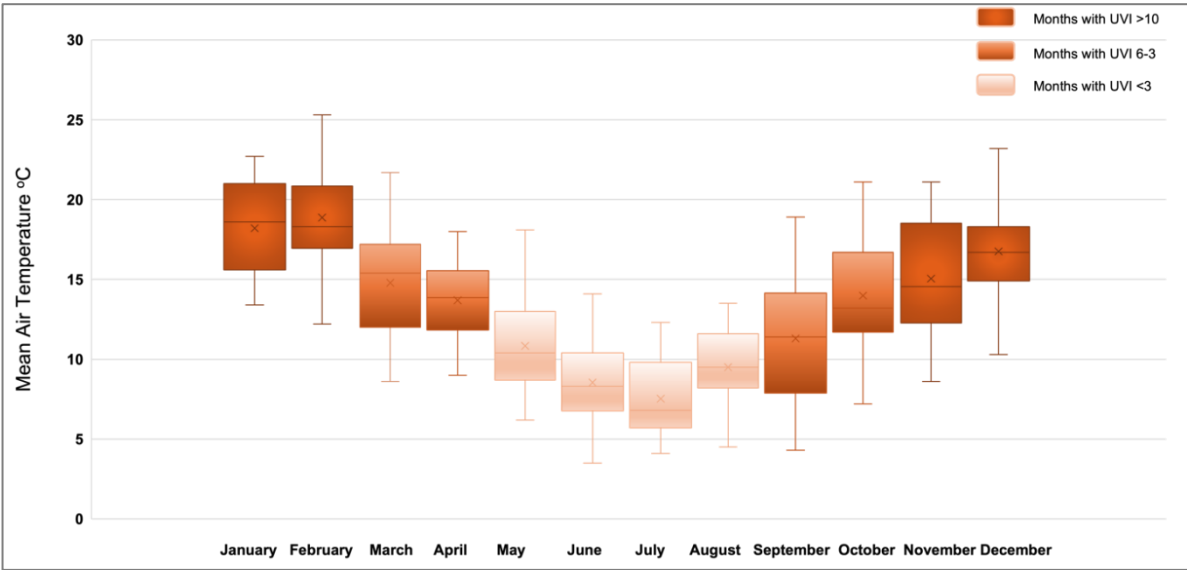


Figure 3.5: Mean air temperature data for Christchurch, indicating mean monthly maximum, mean monthly minimum, and mean air temperatures for 2020

Source: NIWA (2025)

On the other hand, when the mean air temperature is 18°C or less, frequent sea breezes lower the perceived temperature, encouraging individuals to seek direct sun for warmth even when UV levels remain high (Mackay, 2003a). These two contrasting microclimatic conditions in Christchurch strongly influence children’s SPB and, consequently, have significant implications for the design of school playgrounds.

Heatwaves and hot conditions:

In 2020, the Ministry for the Environment and Stats NZ (2020) provided the following definition: “heatwaves are defined as three or more consecutive days with a maximum temperature or more than 5 degrees Celsius above the monthly average for 1981–2010”. Based on this definition, a study in the Canterbury region estimated 39 heatwave days between 2015 and 2018, with the 2015-16 summer recording the highest number, 20 days, followed by the 2017-18 summer with 16 days (Haenfling et al., 2023). Most heatwave days occurred in January and February, coinciding with the start of the school year and, therefore, indicating a potential risk of children’s exposure to heat stress.

To estimate hot days, the Ministry for the Environment applies a daily maximum temperature threshold of 25°C (Ministry for the Environment, 2018). Using this threshold, the number of hot days (daily maximum temperature above 25°C) in Christchurch was estimated using daily air temperature data from NIWA (2025) from 2016 to 2020 (see Table 3.1). Over the five-year period, 2016 had the highest number of hot days (exceeded 25°C). January and February experienced the greatest number of hot days, 10 to 15 days per year, followed by March, November and December with 6 to 10 days. Early autumn and late spring (i.e., April and October) recorded 3 or 4 hot days per year.

Table 3.1: The number of hot days estimated for Christchurch from 2016 to 2020

Month	No. of days per month with daily maximum air temperature > 25°C from 2016 to 2020				
	2016	2017	2018	2019	2020
Jan	8	16	15	15	10
Feb	16	11	11	13	13
Mar	8	6	10	8	4
Apr	4	3	2	3	1
May	3	0	0	0	1
Jun	0	0	0	0	0
Jul	0	0	0	0	0
Aug	0	0	0	0	0
Sep	1	3	0	1	1
Oct	5	2	2	0	6
Nov	6	2	4	10	7
Dec	9	15	4	8	7
Total in a year	60	58	48	58	50

Maximum recorded hot days

Minimum recorded hot days

Source: NIWA (2025)

From the table, the high number of hot days in January, February and parts of March, November and December coincide with school terms when schools are open. During these times, children are frequently outdoors during the school day and are exposed to increasing heat, raising the risk of heat-related illness. The data also demonstrate that hot days are becoming more frequent during school months, suggesting that children's exposure to uncomfortable or hazardous heat conditions is now increasing.

Cool and mild conditions:

In the absence of direct solar radiation, the ASHRAE thermal comfort standard estimates that a minimum air temperature of 18.1°C creates a cool but comfortable environment (ASHRAE, 2020). Accordingly, it can be assumed that people positioned out of direct sun are likely to feel uncomfortably cool when the dry bulb temperature is less than 18.1°C (Mackay, 2003a). Using this threshold, the average number of cool days for Christchurch from 2016 to 2020 is summarised in Table 3.2. The data are sourced from NIWA (2025). According to the table, the high UVI periods, November and December, recorded a higher number of cool days with roughly 3 to 8 days per year with notable peaks of 23 days in 2018 and 22 days in 2020. In early autumn and late spring, when UVI levels still exceed 3, the average number of cool days increased; September and October recorded the most cool days, from 16 to 24 days per year.

Table 3.2: The number of cold days estimated for Christchurch from 2016 to 2020

Month	No. of days per month with daily maximum air temperature < 18.1°C from 2016-2020				
	2016	2017	2018	2019	2020
Jan	4	1	2	0	0
Feb	1	2	3	3	2
Mar	4	9	4	4	15
Apr	8	13	15	23	9
May	13	29	22	21	24
Jun	26	25	30	29	27
Jul	26	31	27	29	30
Aug	27	19	29	28	27
Sep	23	16	24	21	16
Oct	17	13	20	20	16
Nov	7	4	15	6	16
Dec	3	2	8	3	6
Total in a year	159	164	199	187	188

Maximum recorded cool days

Minimum recorded cool days

Source: NIWA (2025)

Mackay et al. (2014) report that during summer in Christchurch, when the UV levels exceed UVI 2 for up to eight hours a day, air temperatures were below 18.1°C for 30% of the time (light blue in Figure

3.6), making conditions too cool for comfort, which encourages users to seek warmth in the full sun, even though UV levels were high (Mackay, 2003a).

In summary, during periods when the UVI exceeded 3, cool and mild conditions occurred as frequently as hot days, indicating a consistent need for UVR protection regardless of the temperature. This implies that Christchurch schools cannot rely on air temperature alone to ensure children’s sun safety. The combination of high UVI levels and fluctuating hot and cool days makes children vulnerable throughout the year. Notably, cooler temperatures may create a false sense of safety, encouraging longer periods of outdoor play without consideration of UVI levels, which heightens the risk of sunburn. This situation further highlights the need for school playgrounds to be designed and managed to minimise both heat stress and UV-related risk.



Figure 3.6: The chart showing the requirement for ‘warm shade’ in Christchurch

Source: Mackay et al. (2014)

3.3.4 Wind and ultraviolet levels

In coastal cities like Christchurch, where winds are frequent and air temperature frequently fluctuates (between hot and cool conditions), wind is a key climate variable influencing both thermal

comfort (Mackay, 2003a; Tavares, 2015) and sun-seeking behaviour (Mackay, 2003a). Christchurch’s wind patterns can make a summer day cold or a winter day warm (Tavares, 2015). Cool northeasterly winds from the sea are common for much of the year (Mullan et al., 2012). Hot, dry northwesterly winds, an important factor of Christchurch’s climate, give the highest temperatures in all seasons (Mullan et al., 2012). This is particularly significant in summer because temperatures can rise by 10-15°C in an hour (Mullan et al., 2012).

Table 3.3 shows the seasonal distribution and frequency of strong winds (a daily mean wind speed greater than 30 km/hr). Of all strong winds recorded in Christchurch, 35% (around seven days) occur in spring and 28% (six days) in summer (Macara, 2016). Though strong winds in summer benefit convective cooling, they can also contribute to thermal discomfort when the daily maximum air temperature falls below 18.1°C. This is particularly noticeable in spring and becomes more significant when UVI levels exceed 3.

Table 3.3: The seasonal distribution and frequency of strong winds for Christchurch

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Source: Adapted from Macara (2016)

3.4 The study’s design: A case study approach

A study’s design is “the glue” that holds the components of a research project together by connecting data collection to the research questions and, ultimately, to the conclusions (Trochim & Donnelly, 2006; Yin, 2018). It refers to the structural framework of the investigation, guiding how an inquiry selects and processes relevant data sources, such as the sampling and analytical techniques (Deming & Swaffield, 2011). A research design outlines what types of data will be collected for the specified variables or parameters and explains how the data will be accessed in a manner most appropriate to the study’s aims (Deming & Swaffield, 2011). This study is based on multiple embedded case studies (Yin, 2018) and multiple methods of data collection. The study was focused on exploring the relationship between the physical characteristics of school environments and children’s predicted patterns of use based upon UVR protection, microclimate and attractive play opportunities. Consequently, the design had to capture both environmental data related to UVR and microclimate and spatial data related to play opportunities in various Christchurch school playgrounds.

A case study approach is well-suited to an empirical inquiry that investigates a contemporary phenomenon in its real-life context (Yin, 2018). As noted by Gerring (2007, p. 37), it involves “an

intensive study of a single unit or a small number of units (the cases), for the purpose of understanding a larger class of similar units (a population of cases)”. In this study, the objective is not just to explore a specific school playground, but to gain an in-depth understanding of how school playground design more broadly influences children’s use patterns across schools. A case study approach was, therefore, appropriate because it enables detailed exploration of the design-behaviour relationship. The insights gained through this approach helped the development of strategies and informed design guidelines for wider applications relevant to similar school environments. Evidence from multiple cases is often considered more compelling and robust because it allows comparisons (Deming & Swaffield, 2011; George & Bennett, 2005; Yin, 2018).

3.4.1 Multiple embedded case study design

A multiple embedded case study design was used to evaluate the potential of existing school playground designs to support SPB among children. A multiple embedded case study design means there are multiple cases (different school playgrounds in this study), and each case has embedded analysis units, including different activity zones in school playgrounds (Figure 3.7). The concept of within-case (George & Bennett, 2005) and embedded cases (Yin, 2014) was applied to explore how different AZ types and their spatial arrangement in a school playground influence overall SPB design outcomes. Focusing on the embedded units enabled detailed comparisons both within each school (across activity zones) and between schools. This approach provides a deeper, more nuanced understanding of trends, patterns and relationships (van den Brink et al., 2016) in a relatively underexplored area of school playground design in support of SPB. Figure 3.7 presents the relationships between the context, case studies and units that constitute the case study design of this study.

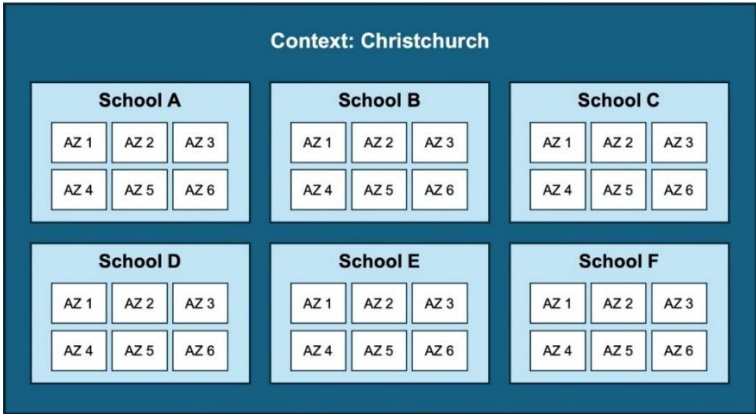


Figure 3.7: The multiple embedded case study design used in this study

Source: Adapted from Yin (2014)

Note. AZ in the boxes refers to activity zones in each school

Selecting cases that serve as *paradigmatic* examples, i.e., those that ‘typically’ represent the general characteristics of primary school playgrounds, supports the potential for generalising the findings (Yin, 2014) in the study context. According to Yin (2014), two or three literal replications (i.e., predict similar results) are sufficient when the underlying theory is straightforward, whereas five or more cases are recommended for more nuanced theoretical propositions. In this study, six school playgrounds provided stronger grounds for inquiry, producing more compelling evidence and allowing more rigorous cross-case comparisons to be made (van den Brink et al., 2016). Christchurch is the study context with six primary school playgrounds functioning as the case studies used to understand the complex phenomena of school playground design and SPB outcomes. Each case study has embedded units (i.e., activity zones) that elucidate how children use and experience these spaces in the school playground environment and help illustrate how the three related objectives collectively contribute to overall SPB design.

3.4.2 Site Selection Criteria

Christchurch primary schools serve a growing and increasingly diverse student population. Approximately 64, 000 students are enrolled across nearly 100 public primary schools, including full primary, contributing and intermediate schools, located throughout urban areas and the rural Banks Peninsula (Education Counts, 2025). Christchurch’s primary school sector has also undergone significant change over the past decade, following the post-earthquake reconfiguration, including school closures, mergers, and rebuilding programmes. Accordingly, for the case study design, six primary school playgrounds were selected using established site selection criteria. This process involved a combination of literature review, consultation with the Cancer Society and viewing potential study sites. The criteria used in selecting the schools were: (1) school type and authority; (2) accreditation status; (3) school roll size and decile rating; and (4) school playground characteristics. These criteria are now discussed.

School type and authority

In New Zealand, children aged 5 to 12 years typically attend either a full primary school or a contributing school (Ministry of Education, 2014). A full primary school covers Years 1 to 8, whereas a contributing school type covers Years 1 to 6, after which the children attend an intermediate school for Years 7 to 8 (Ministry of Education, 2014). Most primary schools, where 85% of children attend, are either state schools, which are owned and funded by the government or state-integrated schools, which receive funding from the government but operate under a ‘special character’ (Ministry of Education, 2014). A small proportion of children attend private schools that are primarily funded by charging parents school fees.

Given that state and state-integrated schools comprise the largest share of primary schools and enrol most children, they were appropriate for this study to explore the general characteristics of a primary school playground. The first site selection criterion was that the schools be either full primary or contributing schools belonging to the state or state-integrated authority type.

Accreditation status

Every state and state-integrated school in New Zealand is governed independently under individual Boards of Trustees (BOTs), funded by the government and overseen by the Ministry of Education (Education Counts, 2024). The board is responsible for setting strategic directions and targets for the school, developing policies and procedures, consulting with the community to make decisions, overseeing the curriculum, finance and property, employing staff and ensuring the health and safety of both staff and students (Ministry of Education, 2024).

As noted previously, the SunSmart Accreditation Programme (SSAP) is a voluntary programme that schools may choose to adopt. This voluntary nature of the sun protection programme and the autonomy in school governance have resulted in considerable variability in how schools approach sun protection, particularly in the accreditation and implementation of the SSAP (Collins et al., 2006). This variation may influence playground design, especially in relation to implementing sun protection measures such as installing shade structures or increasing tree cover. In consultation with the Cancer Society, it was therefore decided that only schools that had been accredited under the SSAP for at least five years would be included in this study. This criterion ensured that the selected schools had sufficient time and resources to implement effective sun protection measures.

School roll size and decile rating

The third criterion for site selection was the school roll size and decile rating. The school roll refers to the total number of pupils enrolled at a school (Education Counts, 2025). The decile rating is an indication of the economic status of the area from which a school draws its students (Ministry of Education, 2023). Decile 1 schools, about 10% of schools, draw their highest proportion of pupils from a low socio-economic community, and Decile 10 schools represent the 10% of schools with the lowest proportion of pupils from a low socio-economic community (Ministry of Education, 2023).

Both roll size and decile rating are key factors that determine the level of funding a school receives, which, in turn, directly affects a school's capacity to adopt and implement sun protection measures in the school (Watts & Meikle, 2008). Schools with larger rolls receive more funding than those with smaller rolls. Similarly, schools with a low decile rating receive additional funding compared with higher decile schools for additional support (Education Counts, 2025). To determine whether the funding level influences the SPB design of playgrounds, school roll size and decile ratings were therefore included as site selection criteria. This approach also facilitates cross-case analysis (Yin,

2018), enabling comparisons of playground design between lower and higher decile schools. Finally, it is important to note that, as of January 2023, the New Zealand Ministry of Education replaced school decile ratings with an Equity Index for determining funding. This study uses school decile rating as a selection criterion, because the fieldwork for site selection began in 2019, before the policy change.

3.4.3 Study sites selection

Initially, a 3 X 2 site selection matrix was developed based on school roll size and decile rating. State and state-integrated primary schools in Christchurch, based on their roll size, were categorised into three groups: high (> 400 pupils), medium (200 - 400 pupils) and low (< 200 pupils). Schools were categorised on their decile rating into two groups: low (deciles 1 - 5) and high (deciles 6 - 10). Using the developed matrix (Table 3.4) and in consultation with the Cancer Society, potential study sites were shortlisted.

Pilot testing of the proposed SPB-D methodology (see Chapter 4) revealed the importance of specific playground characteristics (i.e., analysis units) that were critical for both the evaluation and comparison of findings. Following the methodology, school playgrounds were divided into activity zones classified as structured and unstructured types. These were the analysis units. Among the potential schools shortlisted for the study, fieldwork was then conducted to purposefully select six

Table 3.4: The site selection matrix developed to select case study schools for this study

School Roll Size	School Decile Rating	
	Low (< 5)	High (> 5)
Low (< 200)	School A	School B
Medium (200 to 400)	School C	School D
High (> 400)	School E	School F

schools that aligned with the specified playground characteristics (i.e., the presence of both structured and unstructured AZs) as outlined in the methodology. Table 3.4 presents the matrix used to identify potential case study schools and the placement of the six selected schools that met the specified requirements. Figure 3.8 shows the geographical location of these six selected schools in Christchurch.

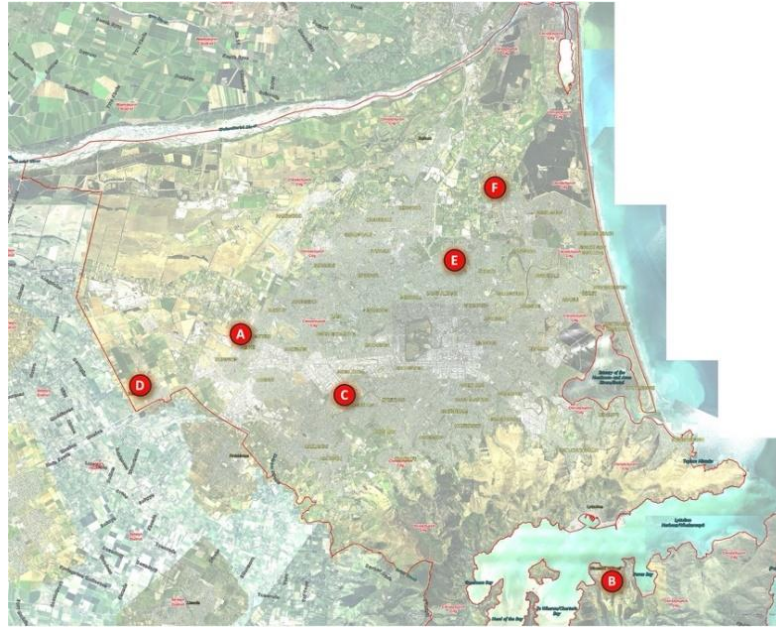


Figure 3.8: The location of the six study schools in Christchurch

Source: Canterbury Maps (2024)

3.5 Research methods

In this study, the LU approach provided the structural framework for data collection and analysis. The brief process was described in Section 3.2. Adopting this framework necessitated incorporating multiple methods: i) the critical component design (CCD) approach; ii) the shade simulation method; iii) the shade protection factor (PF) estimation method; iv) the empirical wind modelling method; and v) field observations. Together, they led to the development of a novel SPB-D methodology. A detailed, step-by-step application of the SPB-D method is presented in Chapter 5. The following sections outline the five methods integrated in the process and explain the study's relevance. Figure 3.9 illustrates the five methods integrated at two stages of the SPB-D methodology and indicates the purpose of their application.

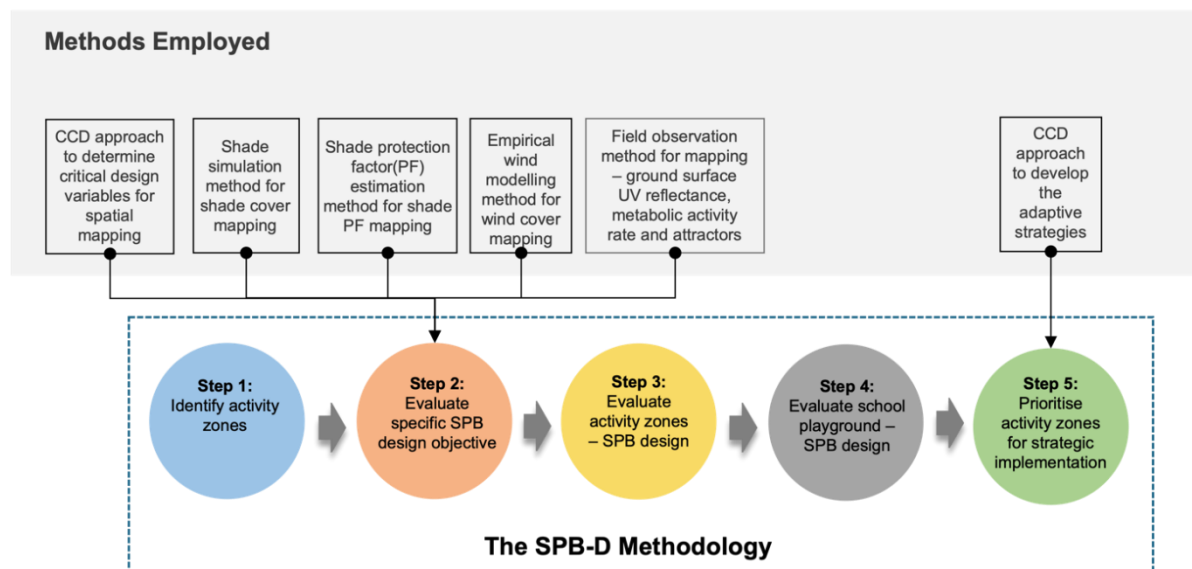


Figure 3.9: The five key methods used at various stages of the 5-step sun protection behaviour design method

3.5.1 The critical component design (CCD) approach

The critical component design (CCD) approach was developed by Brown (2010) is outlined in his book *'Design with Microclimate'*. People often make a wide range of decisions about their environment, but those choices may not always align with a designer's preference (Brown, 2010) or the project's expectations. Such divergence can introduce uncertainty for designers and/or complicate the design process. To address the problem, the CCD approach helps to identify only the essential characteristics that should be included to create a landscape or environment that will achieve positive outcomes (Brown, 2010).

As outlined by Brown (2010), the CCD approach groups design components into three categories: (i) which components of the design *"must"* be incorporated for achieving optimal functionality; (ii) which ones are desirable but not crucial and *"should"* follow; and (iii) which have minimal influence and are considered *"optional"*. From this, a designer can choose and prioritise the design components that best serve the expectations. In essence, the CCD concept isolates the key characteristics or elements in order of their priority that need to be included to achieve the intended outcomes. In this study, the CCD approach was used at two key stages in the development of the SPB-D methodology (Figure 3.9).

First, using the LUs approach involves identifying and mapping important site-specific components of the landscape (e.g., topography, soil, water) that influence a particular landscape function (Brown, 2008). In this study, it involved identifying the landscape components relevant to specific SPB design objectives. Combining the three SPB design objectives resulted in a large number of landscape components. Measuring and mapping all of them would result in an extensive, complex dataset,

complicating the inventory and spatial mapping process. To streamline the process, the CCD approach was used to identify the key landscape components, referred to as the *Critical Design Variables (CDVs)* that must be incorporated for effective evaluation and mapping. Table 3.5 presents the SPB design objectives with their associated CDVs determined for further inventorying and spatial mapping in the study. Sections 2.4, 2.5 and 2.6 provide more detailed discussion on CDVs influencing each SPB design objective.

It is important to note that, in assessing microclimatic comfort, only thermal comfort was considered. This decision was made to ensure the universal applicability of the methodology because thermal comfort is a fundamental parameter that requires consideration across all climatic zones. Although wind conditions can significantly influence outdoor comfort, particularly in the New Zealand context, wind comfort assessment was beyond the scope of the present methodology and requires further study to integrate these factors.

Table 3.5: Sun protection behaviour design objectives and associated critical design variables determined for the study

SPB design objective	Influencing factors	Critical design variables (CDVs)
UVR protection	Direct UV radiation	Shade cover
		Shade protection factor
	Indirect UV radiation	Ground surface UV reflectivity
Microclimate comfort	Thermal comfort	Shade cover
		Wind cover
		Metabolic activity rate
Attractiveness	Play opportunities	Attractors

In the methodology, once the overall SPB design had been evaluated, a key consideration was to identify ‘*where*’ interventions were most needed and ‘*what*’ strategies could be applied to achieve optimal SPB design outcomes. For this purpose, the CCD approach was used. Building on the principles of the CCD approach, three adaptive approaches referred to as the “three R’s”: Retrofit, Redesign and Remove/Relocate, were developed to inform the SPB design strategies. These strategies help determine the extent of modification required and provide a structured framework for prioritising AZs for implementation over time based on users’ specific needs and the time and resources available. The three adaptive strategies and their detailed application are discussed further in [Chapter 5](#).

3.5.2 The shade simulation method

The shade simulation method was used to generate shade cover maps for the studied schools. This is a widely used method in shade assessment studies (Cherian & Subasinghe, 2023; van Vliet et al., 2021) and was adopted here for its efficiency; it requires substantially less time and is less labour-intensive than other shade assessment methods. Its ability to model shade for specific times and dates, while being spatially explicit, aligns well with the criteria outlined for an effective, evidence-based methodology: it incorporates user-friendly tools and supports a flexible iterative process that enables evidence-based design decisions.

The method involved generating digital 3D models of the study schools. An accurately scaled aerial map of each school was sourced via the LINZ data service (Canterbury Maps, 2024). This map served as a base map of the study school to identify the location and horizontal dimensions of existing site features (e.g., tree canopy width, building width). To verify the accuracy of these features and gather necessary details, fieldwork was conducted from late November 2019 to February 2020. This was summer in Christchurch, and it provided ideal conditions for documenting vegetation characteristics, including identifying tree species, estimating canopy height, canopy density and other relevant attributes.

A site-audit tool adapted from Greenwood et al. (2000) and refined through pilot testing was used to collect and document all existing landscape elements influencing shade availability in each study school. These elements were categorised into: (i) natural elements, such as trees, shrubs or other vegetation; (ii) built elements such as buildings and classrooms; and (iii) purpose-built structures such as covered outdoor shade structures or trellis. For natural elements, tree canopy density was classified as being heavy or medium based on the canopy density guide of Greenwood et al. (2000). Trees with light-density foliage were excluded because they do not sufficiently block UVR (Greenwood et al., 2000). As established in previous studies, trees with a canopy width less than 2 m were not considered because they do not provide adequate UVR protection (Gage et al., 2019). For built shade and/or purpose-built structures, the roofing material was classified as wood, metal, plastic, glass, fabric or 'other'. Horizontal and vertical dimensions (height, width and depth) of all landscape elements were recorded and collated into tables for subsequent modelling and analysis.

The digital 3D models of the study schools were developed via SketchUp Pro 2023 (Trimble Inc.) software and geolocated using Christchurch coordinates (Latitude 43.4876 S, Longitude 172.5374 E). Shadows in the study schools were then generated using SketchUp's Shadow feature for the critical protection time (CPT) set for the study. CPT refers to the time of the day and year when UVR protection is most needed (Greenwood et al., 2000). For this study, the CPT was set for 1 February at 1.30 p.m. This date was chosen because primary schools in Christchurch are open then and UV levels

are typically at their highest level, ranging from UVI 8 to 10 (NIWA, 2022). The selected time aligns with the lunch break (12.30 – 1.30 p.m.) in Christchurch’s primary schools, which is near solar noon, when children typically spend prolonged time outdoors. Figure 3.10-**A** presents an example of a digital 3D model, and **B** the shade pattern generated for the pilot study school.

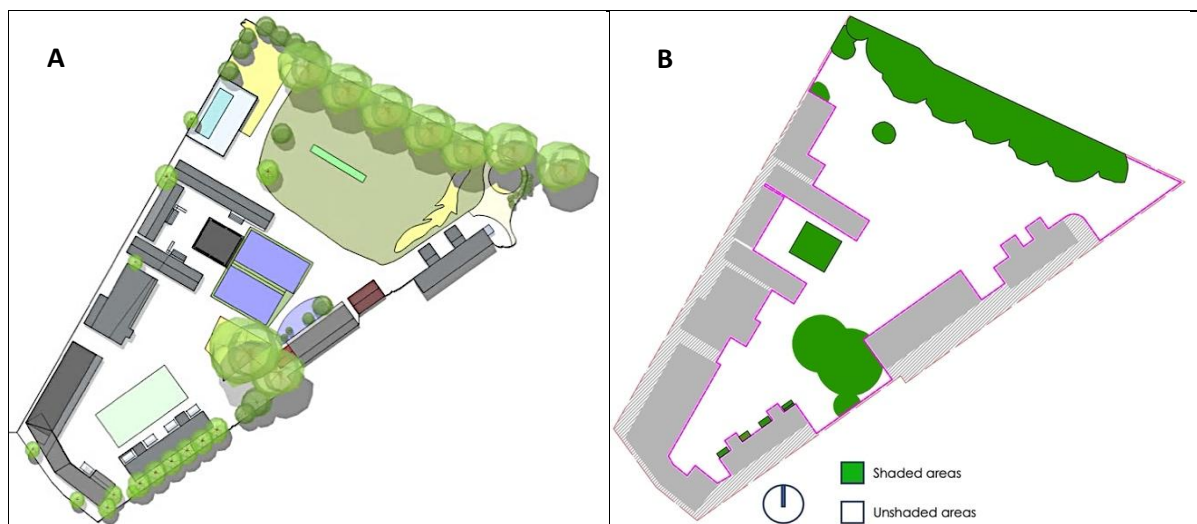


Figure 3.10: An example of a shade simulation output developed for the study school. (A): a 3D model with shadow generated for the critical protection time; (B): the shade pattern manually mapped

The generated shade pattern imported into AutoCAD had shaded and unshaded areas manually delineated. Figure 3.10-**B** is an example of a shade cover map with shaded areas and unshaded areas.

3.5.3 The shade protection factor estimation method

The shade protection factor estimation method described by Mackay (2009) was used to calculate the approximate protection factor (PF) of the shade. This calculation method is straightforward and does not require specialised skills or technical expertise, while offering a robust evaluation. It provides clear, measurable PF ratings for the shaded areas that are evidence-based and easy to interpret. As outlined by Mackay (2009), an approximate PF of shade was estimated by the following formula:

$$\text{PF (estimated)} = \frac{1}{\text{UV transmittance X 0.5} + \text{sky factor* X 0.5}} \\ \text{(of shading material)}$$

*Sky factor is the proportion of the hemisphere of the open sky that can be seen at a specified point under a shade canopy.

In the formula, the UV transmittance of a shading material refers to the percentage of UVR that passes directly through the shade material or canopy. They were approximated using literature generalisations (Table 3.6).

Table 3.6: Ultraviolet transmittance values for built and natural shade types

Shade type	Shading material (roof type/canopy density)	Approximate UV transmittance (%)
Built	Solid (timber, polycarbonate sheets)	10
	shade cloth (fabric)	15
Natural	Dense/medium canopy density	10
	Light canopy density	70

The sky factor, defined as the proportion of the open sky hemisphere visible from a given point under a shade canopy (Mackay, 2009) is a measure commonly referred to as sky view factor (SVF). The SVF was estimated via SketchUp's - Sky View Analysis plug-in tool. The SVF under the canopy was estimated for a central point (at 1 m above the ground) under the canopy and collated for subsequent analysis.

Using the two values in the formula, the PF rating under the shade at the study schools was estimated (Table 3.7).

Table 3.7: Examples of shade protection factor estimated from the data gathered

Shade structure	Shade type	Shading material	UV transmittance ratio	SVF ratio	Estimated shade PF
V2	Built	Solid timber	0.1	0.28	5.3
V3	Built	Solid timber	0.1	0.25	5.7
S1	Built	Shade cloth	0.15	0.28	4.7
S2	Built	Shade cloth	0.15	0.24	5.1
T1	Natural	Medium canopy	0.1	0.39	4.1
T7	Natural	Medium canopy	0.1	0.15	8.0

3.5.4 Empirical wind modelling method

The empirical wind modelling method was used to develop wind cover maps for the study schools. This method is a simple, efficient method commonly used to estimate wind patterns empirically at a site (Brown & Gillespie, 1995). In essence, it involves modelling wind conditions based on measurements taken from generalised situations and extending these data to other landscapes (Brown & Gillespie, 1995). However, because site conditions are rarely the same, the method requires some assumptions, which can limit its accuracy (Brown & Gillespie, 1995). Compared with

advanced computational methods such as Computational Fluid Dynamics (CFD), empirical wind modelling is less resource-intensive and ideal for small-scale or preliminary studies. The spatially explicit outputs it produces are clear, easily interpreted, and offer valuable insights into local wind behaviour, supporting informed decision-making. In this study, the decision to use empirical wind modelling aligned with the criteria for an effective evidence-based design methodology that allows the use of user-friendly tools, and supports flexible, iterative evidence-based design (see [Chapter 2, Section 2.7.4](#)).

Employing empirical wind modelling involves the collection of long-term meteorological data, such as average wind speed and prevailing wind directions, including frequency at the study location, to consolidate existing wind statistics (Ebrahimabadi et al., 2018). Five year wind data is considered ideal to provide a general picture of the wind conditions of any location (Brown & Gillespie, 1995). Given this, wind data from 2016 to 2020 were gathered from NIWA’s Kyle’s Street Weather Station, which is located close to the study sites. NIWA was a government organisation that, in 2025, became part of what is now known as ‘Earth Sciences New Zealand’. It operates hundreds of monitoring stations across New Zealand (NIWA, 2025). The wind data for this study were obtained from the National Climate Database via the NIWA DataHub web portal, which provides registered access to raw and summary climate station data. Access to DataHub is free for non-commercial use but requires online registration (NIWA, 2025). The consolidated wind data corresponding to the quarter from December to February aligns with the CPT – set as 1 February (see [Section 3.5.2](#)).

Table 3.8: Five-year wind frequency data (percent of time) for all wind directions, and quarterly data (December, January and February) for Christchurch

	N	NE	E	SE	S	SW	W	NW
Yearly Average	5	9	3	5	2	7	2	3
Quarterly Average	3	9	9	3	2	5	5	2

Source: NIWA (2025)

TTable 3.8 summarises consolidated wind data for the five years from 2016 to 2020, with the yearly average frequency of winds occurring in all directions, and the quarterly data for December, January and February. In both datasets, the northeast and southwest (highlighted) emerge as the prevailing wind directions. Figure 3.11 presents a wind rose diagram developed through an online application Blom (2021), using data from NIWA (2025). It illustrates the percentage of time the wind blew from each direction in 2020, confirming the prevailing wind directions.

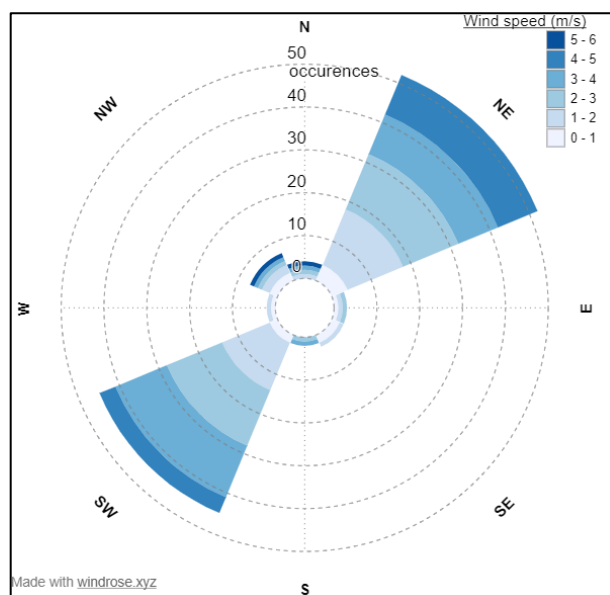


Figure 3.11: A wind rose diagram for Christchurch for 2020 to indicate the prevailing wind directions

Source: Data sourced from NIWA (2025) and developed using Blom (2021)

The Table 3.9 shows the monthly and annual mean wind speed data for Christchurch from 2016 to 2020. The average wind speed observed for the study quarter (highlighted in the table) was around 3.1 m/s.

Table 3.9: The consolidated mean and annual wind speed data for Christchurch from 2016 to 2020

Year/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2016	2.8	2.8	2.7	2.1	2.7	2	2.1	2.3	3	3	3	3	2.6
2017	3.5	2.9	2.4	2.2	2	1.9	2.2	2.2	2.9	2.7	2.7	3.2	2.6
2018	3	3	2.6	2.5	2.1	1.9	2	2.1	2.3	2.4	2.8	2.8	2.5
2019	3.1	3	2.6	2.4	1.9	2.1	2.1	2.2	2.6	2.6	2.9	3.4	2.6
2020	3.1	3	3	2.5	2.1	2.3	2.2	2.3	2.6	2.8	2.9	3	2.6
Average wind speed	3.1	2.9	2.7	2.3	2.2	2.0	2.1	2.2	2.7	2.7	2.9	3.1	2.6

Source: NIWA (2025)

From the consolidated wind data, the mean wind speed used in the study for the quarter from December to February was 3.1 m/s (measured at 6 m high, at the Kyle St weather station), with prevailing winds from the northeast and southwest directions. Based on these identified wind directions, separate wind patterns for the study schools were modelled as outlined by DeKay and Brown (2014), Brown and Gillespie (1995) and Chiesa and Grosso (2017).

Wind pattern modelling requires: (1) mapping the landscape elements of the site that modify wind (Brown & Gillespie, 1995) and (2) analysing the site to determine wind-protected areas (i.e., lee side of wind barriers with at least a 50% reduced wind speed) and wind-exposed areas (i.e., lee side of wind barriers with uninterrupted wind flow) for the prevailing wind directions. The site-audit tool described previously (see [Section 3.5.2](#)) was used to record all relevant features: (i) natural elements such as trees, shrubs or other vegetation; (ii) built elements such as buildings and classrooms; and (iii) purpose-built elements, such as covered outdoor shade structures, trellises, fences or other. Wind barriers were visually estimated and classified into solid barriers with porosity from 0-50% (Burke, 1998; Straight & Brandle, 2007) and porous wind barriers with porosity greater than 60% (Burke, 1998; Straight & Brandle, 2007). Porous barriers were excluded because they do not sufficiently affect wind flow (DeKay & Brown, 2014). The inventoried landscape elements were then mapped in the study schools using AutoCAD software. Other relevant details were collated in tables.

The identified prevailing wind directions, northeast and southwest, were overlaid on the developed base map, and each direction was analysed separately to determine wind-protected areas and wind-exposed areas across each study site. For this purpose, two key generalisations derived from a critical literature review were applied as follows:

- (1) For built or solid barriers such as buildings, walls, solid fences, the wind speeds in the lee of barriers drop by at least 50% at various distances, depending on the height and orientation of the barrier, as illustrated in Figure 3.12-A. The equation for estimating the wind-protected area around a built or solid wind barrier (DeKay & Brown, 2014) is given by:

$$D = 3 \times H$$

where: D is the depth of the wind-protected area, and H is the height of the wind barrier.

- (2) For natural barriers such as trees and vegetation, the modified wind speed area depends on their height and orientation, as shown in Figure 3.12-B. The equation for estimating the wind-protected area around a natural wind barrier (DeKay & Brown, 2014) is:

$$D = 5 \times H$$

where: D is the depth of the wind-protected area, and H is the height of the wind barrier.

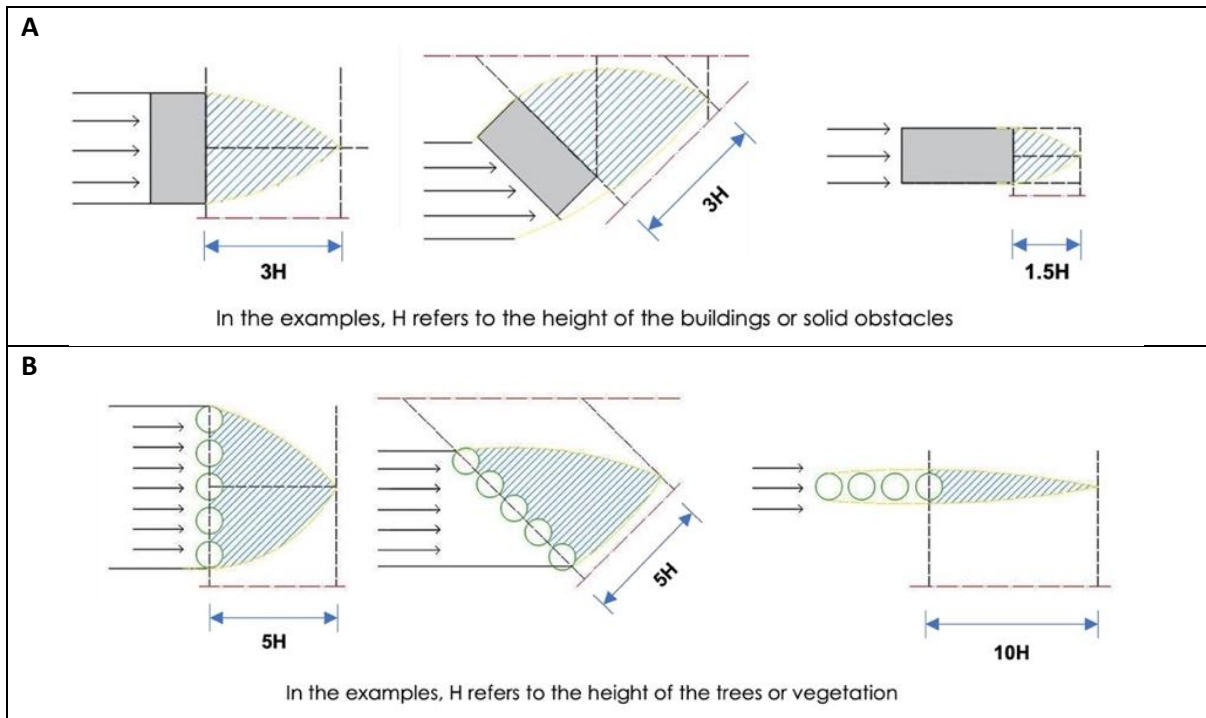


Figure 3.12: The wind pattern modelled around wind barriers. (A): wind patterns modelled around buildings or solid obstacles; (B): wind patterns modelled around natural barriers

Source: Adapted from Brown and DeKay (2001)

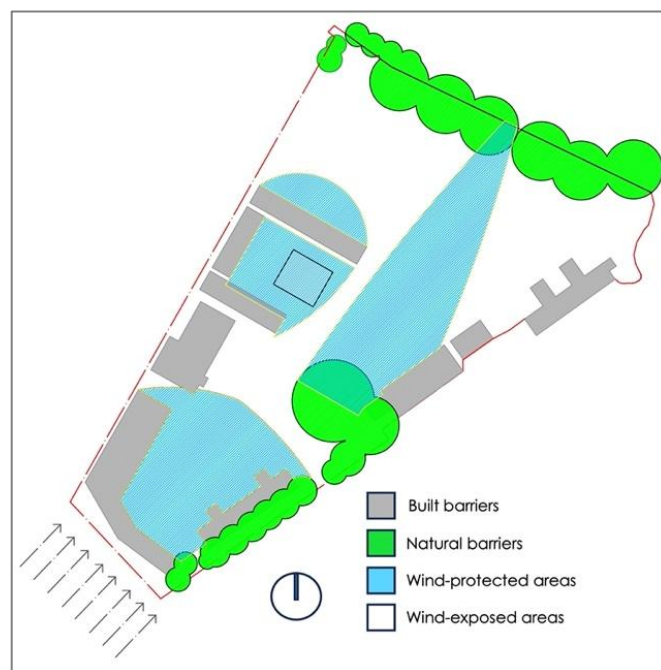


Figure 3.13: An example of a wind cover map developed for the southwest wind direction for the pilot study school

Applying two generalisations, wind patterns – wind-protected areas and wind-exposed areas were modelled and subsequently mapped for each prevailing wind direction in the study schools. Figure

3.13 illustrates an example of the resulting wind cover map, indicating the wind-protected areas and wind-exposed areas generated for the pilot study school for the southwesterly winds.

3.5.5 Field observation method

Field observation is one of the oldest and most fundamental methods of scientific inquiry commonly used across both scientific and social research. Field observation and site inventory are an integral part of landscape architecture, providing rich contextual data (Deming & Swaffield, 2011), while offering a simple, efficient means of recording and mapping appropriate biophysical attributes of a landscape. It is widely used to describe the nature and location of activity or phenomena (Deming & Swaffield, 2011) to document specific landscape attributes such as soil or vegetation patterns (Deming & Swaffield, 2011) or to learn about their uses (Marcus & Francis, 1997). In this study, field observation was used to systematically gather and spatially map all relevant site-specific data for each SPB design objective.

Data collection was grouped into four categories: (i) shade-related data, (ii) wind-related data, (iii) ground surface UV reflectance data, and (iv) play-related data. A site-audit tool previously tested and refined during the pilot study was used to systematically collect and record all relevant information. The fieldwork was conducted from late November 2019 to February 2020. This is summer in Christchurch, and it provided ideal conditions for documenting vegetation characteristics, including identifying tree species, estimating canopy height, canopy density and other relevant attributes. Details of the shade- and wind-related data collection were provided previously (see [Sections 3.5.2, 3.5.3, 3.5.4](#)).

For ground surface UV reflectance, all existing ground surface materials in the study schools were recorded and mapped. Ground surfaces in and adjacent to the school playground areas were categorised as grass, asphalt, concrete, sand, rubber, wood chips or other and were mapped.

For play-related data, existing play features and play equipment that influence play opportunities in the playgrounds were recorded. Play features were categorised as field markings, cricket pitches, court markings, play/paint markings, goal posts, basketball hoops or other. Play equipment was categorised as fixed play structures, balls, scooters, skateboards, hula hoops, bicycles, loose equipment, loose parts or other. All recorded play information was spatially referenced and mapped.

All collected data were consolidated and mapped on a base map via AutoCAD software. Figure 3.14 gives an example of a base map that incorporates all inventoried and mapped landscape elements for the study school.



Figure 3.14: An example of a base map indicating the integrated landscape elements relevant for sun protection behaviour design evaluation

3.6 The study schools and their characteristics

The six purposefully selected study schools are located across Christchurch (Figure 3.8) and range in size from approximately 1.7 to 3.9 hectares. Table 3.10 summarises the key details of the six schools, including school type, authority, SSAP accreditation status, roll size and decile rating.

Table 3.10: Details of the study schools including type and authority, SunSmart Accreditation Programme status, roll size, decile rating and total school ground area

Study school	School type & authority	Accreditation status (as in 2020) Years	School roll size (as in 2020)	School decile rating (as in 2020)	School area (ha)
School A	Contributing - State	10	165	2	2.82
School B	Full Primary - State	14	133	10	1.79
School C	Full Primary - State	9	314	3	2.35
School D	Full Primary - State	11	353	8	1.75
School E	Full Primary - State	9	447	6	2.83
School F	Full Primary - State	10	470	9	3.99

All six study schools had 'open-plan' layouts, with small rows of semi-detached classrooms that open to large vacant sports fields. The classrooms were typically oriented towards north to maximise

exposure to the winter sun, and most buildings were single-storey, with a few having overhanging canopies and/or verandas.

School A, located in the outer suburbs, is surrounded by large open areas with sparse vegetation along its boundaries. School B, located on the slopes of Banks Peninsula, is characterised by tall, dense evergreen trees shaped by its hilly terrain and coastal proximity. In contrast, School C, close to the city centre, is surrounded by major commercial hubs, high-density neighbourhoods and medium-density trees along its boundaries. School E, nestled in a suburban area, is surrounded by medium-density residential buildings and high-density boundary vegetation. Schools D and F are on the rural-urban fringe and are bordered by expansive flatlands primarily used for agriculture. They have minimal boundary vegetation.

3.6.1 School playground characteristics

Application of the SPB-D methodology informed the selection of six study schools with specific school playground characteristics, including defined activity zones (AZ) and types. First, in each study school, the potential school playground area was determined. This includes all the outdoor areas the school used for play and other outdoor recreational activities and excludes buildings, parking areas and other out-of-bounds areas. Over the six study schools, playground areas ranged from 12,716.8 to 25,461.19 m² (Table 3.11).

Table 3.11: A summary of the playground characteristics of the six study schools

Study school	School playground area (m ²)	Total no. of activity zones	Structured			Unstructured		
			No. of activity zones	Total area (m ²)	Mean % cover	No. of activity zones	Total area (m ²)	Mean % cover
School - A	21662.28	14	8	8981.42	41.46	6	12680.86	58.54
School - B	12716.8	12	6	4182.21	32.89	6	8534.59	67.11
School - C	14576.15	19	8	3096.5	21.24	11	11479.65	78.76
School - D	13874.95	14	8	6106.39	44.01	6	7768.56	55.99
School - E	19816.01	16	6	7003.74	39.14	10	12812.27	64.66
School - F	25461.19	16	14	9735.08	38.23	2	15726.11	61.77
Total (of all six schools)		91	50			41		

The identified potential school playground areas were delineated into AZs (using Step 1 of the SPB-D methodology) and classified into one of two types: structured and unstructured. Table 3.11 summarises the playground characteristics of the six study schools, including the potential school playground area, number of AZs categorised into structured and unstructured zone types, and the corresponding mean cover area for each school. Across the six study schools, 91 AZs were identified. AZ areas ranged from 20 m² to 25,000 m² (see [Appendix D](#)). Among them, roughly 54% (n=50) were

structured zones (for definition, refer [Appendix A](#)) and 45% (n=41) were unstructured zones (for definition, refer [Appendix A](#)).

Structured activity zones

In the study schools, structured AZs typically covered 21% to 44% of the school playground area (Table 3.11). Across the six study schools, in this category, eight types of AZ were observed. The details are summarised in Table 3.12. The table shows that structured AZs were determined for the six schools and indicates the different AZ types in the category and the total counts and mean coverage for each school.

Table 3.12: A summary of structured activity zone categories of the six study schools with activity type and total count

Activity zone type	Total no. of activity zones (in all six schools)	School A		School B		School C		School D		School E		School F	
		# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover
Sports pitch	5	1	26.93	1	20.07	0	0	1	23.47	1	19.11	1	16.31
Hard court area	11	2	5.55	1	3.98	2	12.49	2	7.27	1	9.74	3	5.9
Fixed equipment area	18	2	3.84	2	7.88	4	6.67	3	11.28	3	6.02	4	5.64
Sand pit area	9	1	0.66	1	0.56	1	0.74	2	2	1	0.47	3	1.35
Paint marking area	3	0	0	0	0	1	1.34	0	0	0	0	2	0.9
BMX – Track area	2	1	2.64	0	0	0	0	0	0	0	0	1	9.02
Outdoor amphitheatre	1	1	1.84	0	0	0	0	0	0	0	0	0	0
Covered Outdoor Learning Area (COLA)	1	0	0	1	0.4	0	0	0	0	0	0	0	0
Total	50	8	41.46	6	32.89	8	21.24	8	44.02	6	35.34	14	39.12

In the structured AZ category, the most commonly identified types across all study schools were sports pitches (n=5), hard court areas (n=11), sand pit areas (n=9) and fixed play equipment areas (n=18). Less frequently observed zones included paint marked areas (n=3), bicycle motor cross (BMX) track areas (n=2), an outdoor amphitheatre (n=1), and a covered outdoor learning area (COLA, n=1).

Sports pitches were the predominant structured AZ type, ranging from 2,552.28 m² to 5,833.8 m² and occupying approximately 16% to 26% of the total playground area (Table 3.12), except for School C, which lacked a sports pitch area. Other AZs occupied relatively smaller areas in school playgrounds.

Hard court areas were present in all six schools and ranged from 100 m² to 1,500 m² and covered 5% to 10% of the playground area. Fixed play equipment areas were also common, with most schools featuring two to four zones. They ranged from 150 m² to 600 m² and accounted for 2% to 4% of the total area (Table 3.12).

Sand pit areas were widely observed, with four schools (A, B, C and E) having at least one; Schools D and E had two and four zones, respectively. The zones ranged from approximately 50 m² to 150 m² and covered less than 1% of the total school playground area.

In contrast, paint marked areas (n=3) designated for games like hopscotch and four square were found in only two schools, one zone in School C and two in School F. The area involved ranged from 100 to 200 m². BMX tracks designated for bike riding were observed in Schools A and F and measured 571.8 m² and 2062.76 m², respectively. An outdoor amphitheatre in School A (398.53 m²) and a COLA in School B (50.32 m²) were common spaces used for lunch breaks and outdoor gatherings.

Unstructured activity zones

In four schools (A, D, E and F), the unstructured AZ category typically occupied 50 to 60% of the school playground area (Table 3.11). In Schools B and C, it comprised a larger portion, approximately 68% and 79% of the playground area, respectively. Across all six study schools, four common types of AZ were observed within this category (for details see Table 3.13). The table summarises the unstructured AZs for the six schools. It indicates the different AZ types in this category and their total counts and mean coverage for each school.

Table 3.13: A summary of unstructured activity zone categories of the six study schools, showing activity type and total count

Activity zone type	# of activity zones in all schools (n)	School A		School B		School C		School D		School E		School F	
		# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover	# of activity zones	Mean % cover
Hard paved area	6	1	12.27	1	9.84	1	15.1	1	24.05	1	21.18	1	13.25
Grassed area	7	1	38.43	1	37.56	2	58.61	1	25.17	1	29.2	1	48.52
Green area	19	2	5.82	2	18.74	4	3.18	4	6.78	7	13.34	0	0
Classroom verandas	9	2	2.01	2	0.98	4	1.86	0	0	1	0.94	0	0
Total (unstructured zones)	41	6	58.53	6	67.12	11	78.75	6	56	10	64.66	2	61.77

In the unstructured category, the most commonly observed AZs were hard paved areas (n=6), grassed areas (i.e., area adjoining the sports pitch, n=7) and green or landscaped areas (n=19). Classroom verandas (n=9) were found in four schools (A, B, C and E).

Hard paved areas (n=6), designated for unstructured play such as running and jumping, were the predominant zone type, occupying 10% to 15% of the playground area in most schools. In Schools D and E, this zone occupied a significantly higher proportion, 24 and 21% of their total area, respectively. Grassed areas adjoining the sports field were commonly used for unstructured activity, such as socialising, observing and running. They covered 25% to 40% of the total area in four schools (Schools A, B, D and E). They occupied a significantly larger area in Schools C and F, approximately 58% and 48% of the total area, respectively. The hard paved and grassed areas together covered a significant proportion of the school playgrounds of all schools.

Green or landscaped areas occupied very small areas in the playgrounds of most schools. The exception was School F. Classroom verandas were seen in four schools. They ranged from 80 m² to 150 m² and were predominantly used for unstructured activities.

3.7 Ethical concerns

The study presented in this thesis was conducted in accordance with the ethical guidelines of the Lincoln University Human Ethics Committee (HEC), 2019 ([Appendix B](#)). Key ethical considerations included obtaining informed consent from the authorities of the participating schools, ensuring the anonymity and confidentiality of the participating schools, and minimising any potential risks associated with data collection.

3.8 Summary

This study adopted a wide range of strategies and integrated multiple methods to develop a novel methodology usable by both designers and researchers. Chapter 3 outlined the case study, research design and the approach used in the two stages of the study. It presents the methods used in the proposed SPB-D methodology, including data collection, the protocols adopted and the analytical techniques. This study involved a detailed exploration of a complex socio-environmental phenomenon, with activity zones functioning as embedded units of analysis in the broader school playground environment. The chapter also outlined the characteristics of the case study schools and presented the different activity zone types considered in the study.

Chapter 4 presents a pilot study used to test and refine the application of the proposed SPB-D methodology, and its step-by-step process.

Chapter 4

The Application and Testing of the Proposed Sun Protection

Behaviour-Design Methodology: A Pilot Study

Chapter 3 presented the two stages of this study and the research framework adopted. It described the theoretical framework - the landscape units' approach adopted for this study and detailed the multiple methods integrated to support the development of the new SPB-D methodology. This chapter applies the newly developed SPB-D methodology to a pilot study school for testing and further refinement. Section 4.1 provides an overview of the purpose and significance of the methodology, the criteria for an effective methodology and its benefits to both design practice and research. Section 4.2 describes the proposed SPB-D methodology and details the step-by-step process for a Christchurch pilot study school.

4.1 Overview

In response to the identified methodological gaps, this study advances evidence-based landscape architecture (EBLA) by introducing a novel, implementation-oriented methodology: the Sun Protection Behaviour – Design (SPB-D) methodology. The proposed SPB-D methodology was developed to evaluate and design school playgrounds to promote sufficient SPB among children in the context of long-term protection from the dangers of excessive sun exposure.

The methodology aims to: (1) meet the criteria outlined for an effective evidence-based design methodology applicable to both practitioners and scholars; (2) identify the contribution of specific SPB objectives in achieving optimal SPB designs; and (3) facilitate comparisons of SPB design performance based on a landscape's distinct biophysical characteristics. By doing so, the methodology moves beyond abstract calls for evidence-based practice by offering a pragmatic, transferable approach to enhance spatial design as a tool for solving design challenges.

By integrating the strengths of existing methods, the methodology supports the identification of *where* and *what* is causing the problem and, more importantly, facilitates comparisons to prioritise activity zones for strategic design implementation. Central to the methodology is the adoption of the landscape units (LUs) approach that provides a structured, spatially coherent framework for integrating the three key SPB design objectives: UVR protection, microclimatic comfort and attractive play opportunities as described in [Chapter 3](#).

The methodology's outputs can help designers and planners understand how various landscape characteristics influence SPB design outcomes across three spatial scales: (1) the **landscape units**

(**LUs**) scale, which identifies the combined characteristics of critical variables that influence specific SPB design objectives and determines which factors contribute to meeting/not meeting each SPB design objective; (2) the **activity zones (AZs)** scale, which informs the potential of individual zones to meet specific SPB design objectives and contribute to SPB designs and identifies which objectives enable or hinder AZs meet the criteria for a SPB design; and (3) **whole school playground scale**, which integrates the results of individual AZs and informs the overall effectiveness of a school playground in promoting SPB by indicating which AZs meet the required SPB design.

In this chapter, the SPB-D methodology was applied and tested in a pilot study, an existing primary school playground in St. Albans, a northern suburb of central Christchurch, New Zealand. The following sections describe the process.

4.2 The Sun Protection Behaviour – Design (SPB-D) Methodology

In the proposed SPB-D methodology, the following definitions and terms are used. **Sun protection behaviour (SPB)** is the action of protecting oneself from overexposure to solar UVR, such as by sunscreen and protective clothing. In landscape design, it is occupying or conducting activities in spaces that are designed to protect people from overexposure. Accordingly, the design of school playgrounds that supports the intended SPB is **SPB design**. A **school playground** comprises all outdoor areas, also called '**activity zones**', that are potential play and outdoor recreational areas in a school. An **activity zone (AZ)** is a designated space in a school playground that is designed for or supports a particular activity type. A typical playground usually consists of multiple activity zones. **Landscape units (LUs)** are distinct, homogeneous areas that share similar biophysical characteristics in support of a particular land use (Lyle, 1999). In this study, they refer to landscape characteristics for a specific SPB design objective. **Critical design variables (CDVs)** are key variables that directly influence specific SPB design objectives. For example, UVR protection is determined by CDVs such as shade cover, shade protection factors and ground surface UV reflectivity.

The SPB-D methodology comprises five steps (Figure 4.1). In Step 1, the school playground is spatially delineated into individual AZs. These serve as the primary analysis units because children's spatial choices are based on available activity options (Hyndman, 2017; Lucas & Dymont, 2010). In Step 2, each AZ is individually evaluated against the three SPB design objectives (UVR protection, microclimatic comfort and attractiveness). The evaluation is conducted at two spatial scales: LUs within AZs and AZs scale. The goal is to identify where and what design improvements are needed in each AZ. In Step 3, the results from the three evaluations are integrated for each AZ to assess its overall SPB design effectiveness. Step 4 integrates the evaluation of all AZs to assess the overall effectiveness of the school playground in promoting SPB. Finally, Step 5 applies the findings from Step 3 to suggest an adequate adaptive SPB design strategy that enables designers to prioritise

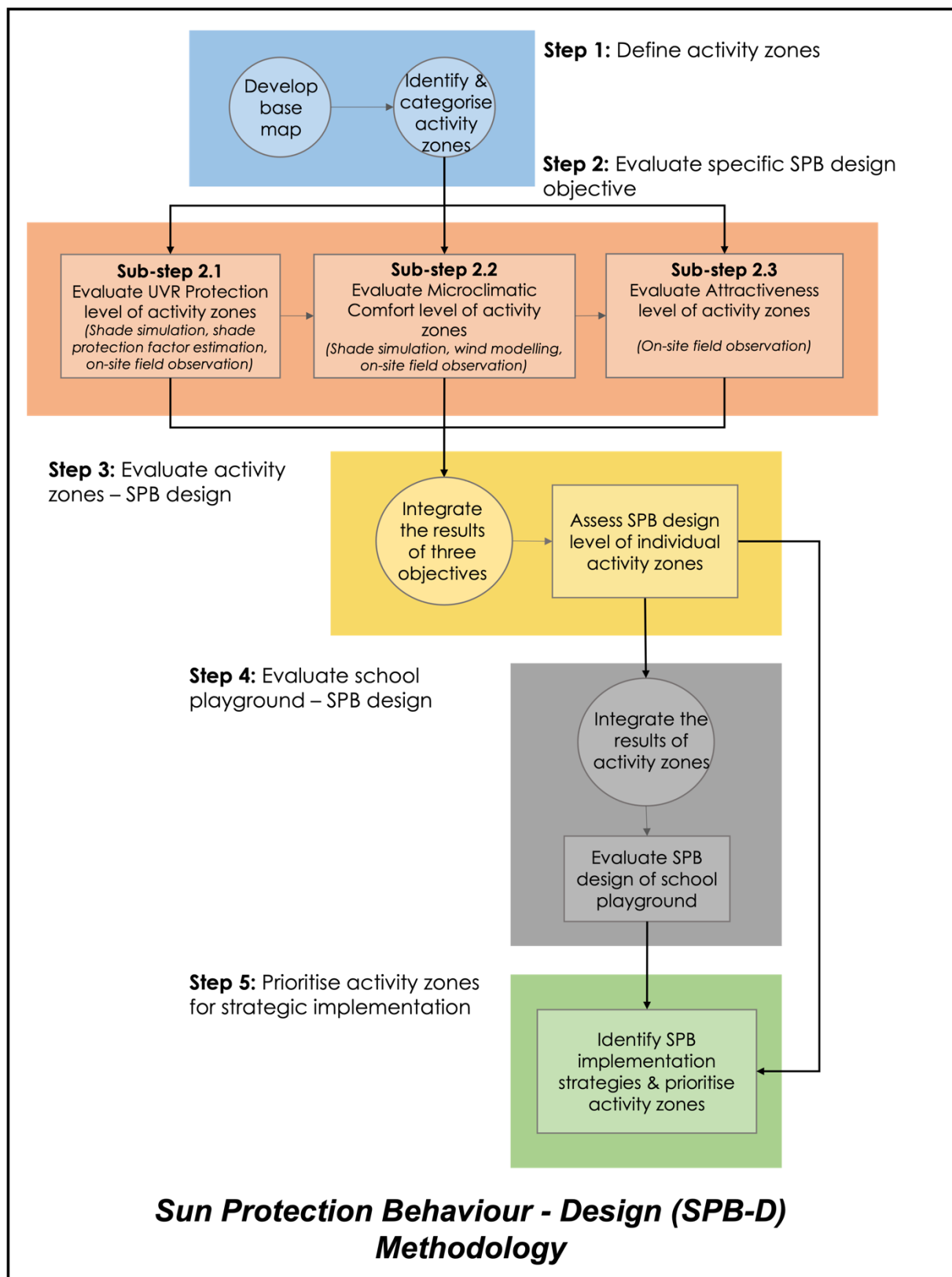


Figure 4.1: The sun protection behaviour design (SPB-D) methodology, with the five steps to design, evaluate and prioritise activity zones in school playgrounds to promote sun protection behaviour in school children

AZs to implement and achieve optimal SPB design over time. The methodology suggests three different design strategies for school playgrounds (the three R's): retrofit, redesign and relocate/remove.

4.2.1 Identifying and classifying activity zones (Step 1)

This step involves two sub-steps: spatially mapping the area to be evaluated, and inventorying and mapping all elements that determine the three SPB design objectives (Step 1.1), identifying the types of AZ and categorising them into structured and unstructured zones (Step 1.2).

Base map development (Step 1.1)

An accurately scaled base map of the site is prepared to define the evaluation area and identify the elements critical to SPB design. First, the boundaries of all potential areas for play and other outdoor activities in the school playground during interval and lunch are marked. This area (Figure 4.2-A, in yellow) extends up to the abutting building edges, excludes school buildings and outdoor areas with restricted access for children, such as roads and parking areas (in grey).

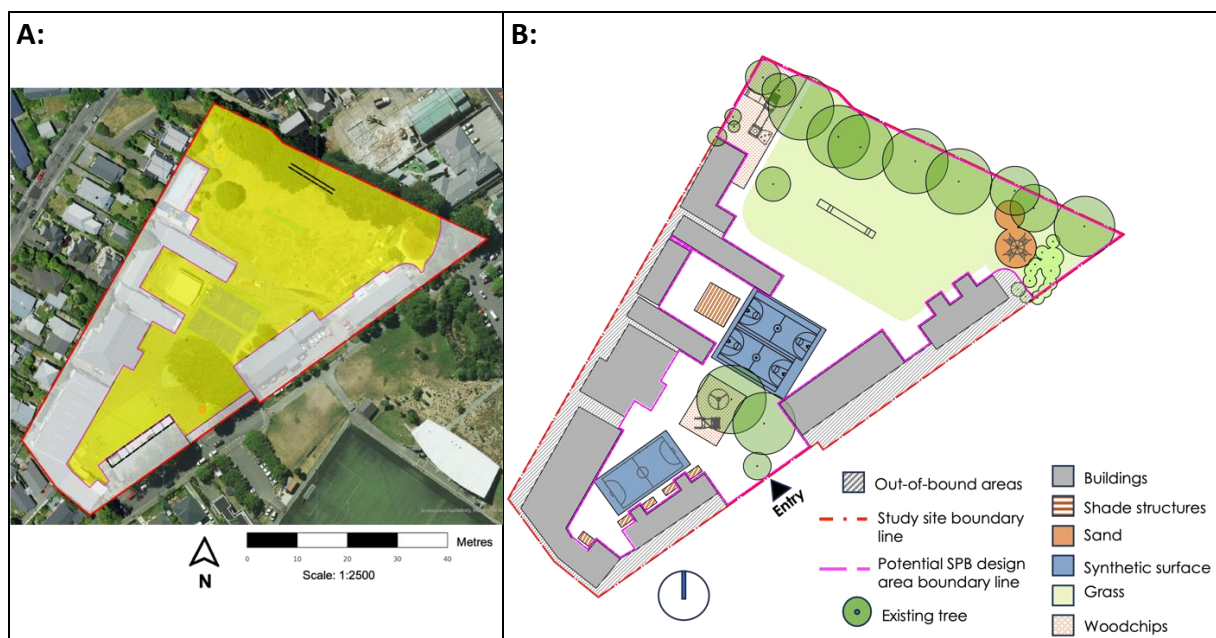


Figure 4.2: An example of a base map developed for the pilot study school. (A): potential sun protection behaviour design area; (B): the base map showing the site elements influencing the design

Source: Canterbury Maps (2024)

Next, site elements relevant to the three SPB design objectives are inventoried (Table 4.1) and mapped (Figure 4.2-B). Elements outside the playground that influence SPB on the site are included, e.g., a large tree on a neighbouring property or a tall adjacent building providing shade.

Identifying and categorising activity zones (Step 1.2)

Activity zones (AZs) are first identified by their primary play type and then categorised as ‘structured’ or ‘unstructured’ zones. The primary play type is determined by the main intended activity, e.g., a basketball court may be used sometimes for socialising, but its primary function is basketball.

Table 4.1: A summary of the critical design variables influencing specific sun protection behaviour design objectives and the relevant site elements

SPB Design Objective	Influencing Factors	Critical Design Variables (CDVs)	Site elements
UVR Protection	Direct UV radiation	Shade cover	- Natural elements such as trees, shrubs or other vegetation - Built elements such as buildings, classrooms - Purpose-built structures such as covered outdoor shade structures and trellises
		Shade protection factor	- Tree canopy density - dense, medium and light - Roofing material type such as solid, transparent, shade cloth
	Indirect UV radiation	Ground surface UV reflectivity	Ground surface such as grass, asphalt, concrete, sand, rubber, wood chips
Microclimate Comfort	Thermal comfort	Shade cover	- Natural elements such as trees, shrubs or other vegetation - Built elements such as buildings, classrooms - Purpose-built structures such as covered outdoor shade structures and trellises
		Wind cover	- Natural elements such as trees, shrubs or other vegetation - Built elements such as buildings, classrooms - Purpose-built wind barriers such as fences, and walls
		Metabolic activity rate	n/a (see Table 4.7)
Attractiveness	Play opportunities	Attractors	- Play features such as field markings, cricket pitches, court markings, play/paint markings, goal posts, basketball hoops - Play equipment such as fixed play structures, balls, scooters, skateboards, hula-hoops, bicycles - Loose equipment - Loose parts such as egg craters, tyres, rocks, boulders.

Structured AZs have a set purpose or location to support a particular activity (Hyndman, 2015; Sener et al., 2008), e.g., basketball courts, sandpits, areas for sitting or eating typically support specific activities and are spatially defined by them (a basketball court is defined by its play boundary).

Unstructured AZs without a set purpose or location support a variety of activities. These are often determined by the children at the time of play and result from stimulation of a child's imagination (Hyndman, 2015; Sener et al., 2008). For example, open areas of asphalt or grass can support free play, such as running, jumping, chasing (Salmon et al., 2003) or engaging in imaginative and creative play (Bundy et al., 2009). For the SPB-D methodology, any area that lacks distinct play features or equipment is categorised as an unstructured AZ.

Once activity types have been identified, their outer spatial boundaries are determined. For structured AZs, the boundary includes the active play area (where children perform the intended activity), plus a two-metre buffer to allow for associated activities, such as children waiting to play or observing play. This buffer is consistent with recommendations for non-player space in sports (Harris & Dines, 1988). For example, in a court-based AZ such as a basketball court, the active play area is

determined by the marked boundary lines of play. Similarly, in a field-based AZ such as cricket or football (soccer), the active play area is determined by the outermost extent of the boundary lines. If visible boundary lines are missing, the play area is determined according to official dimensions. (e.g., the standard size of a football field). Table 4.2 summarises the various structured activity zone types commonly observed in school playgrounds and the spatial boundary rules applied to define the active play areas associated with each zone type.

Table 4.2: The spatial boundary rules to define active play areas for various structured activity zone types

Activity zone type	Example	Rule for boundary definition of active play area
Field-based activity	A cricket field, soccer field, football field	Determined by the furthest extent of the boundary lines of play. If there are no boundary lines, then the boundary is determined by official published boundary lines for the sport/activity. If there is not enough room for official dimensions of the activity (often true in school playgrounds), then the boundary is determined by the maximum size of play that can fit into the field area
Court-based activity	Basketball court, tennis court	Determined by the marked boundary lines of play
Painted surface-based activity	An area for hopscotch, four square	Determined by the outer boundaries of painted lines
Special surface-based activity	Sandpit, fixed play equipment area	Determined by the furthest extent of the frame (e.g., wooden timber edging) or the surface (e.g., rubber matting)
Seating-based activity*	Designated lunch-eating areas, covered outdoor learning areas	Often these are confined by walls, fences, or other structural members

* Seating-based activity zones do not include a buffer area

The outer spatial boundary of unstructured AZs is determined by surface type and the location of the abutting building edges, structures designating property lines (e.g., fences and walls) and/or the outer boundaries of structured AZs. Applying these rules to the pilot study school playground helped identify seven structured AZs and two unstructured ones (Figure 4.3). Table 4.3 lists the AZs defined for the pilot study school playground categorised as structured and unstructured zones.



Figure 4.3: An activity zone map of the pilot study school with structured and unstructured activity zones delineated and marked

Table 4.3: Activity zones categorised into structured and unstructured zones for the pilot study school

Activity zone ID	Activity zone category	Activity Zone
AZ-1S	Structured zones	Fixed play equipment area -I
AZ-2S		Sports field
AZ-3S		Sandpit
AZ-4S		Covered outdoor learning area (COLA)
AZ-5S		Tennis court
AZ-6S		Fixed play equipment-II
AZ-7S		Basketball court
AZ-8US	Unstructured zones	Grassed area
AZ-9US		Hard-paved area

4.2.2 Evaluating each sun protection behaviour design objective within activity zones (Step 2)

In this step, the three SPB design objectives, UVR protection, microclimatic comfort and attractive play opportunities, are evaluated individually for each AZ. This involves three sub-steps (Figure 4.1). Step 2.1 assesses the potential of individual AZs for UVR protection. Step 2.2 assesses the microclimatic comfort in the individual AZs, and Step 2.3 assesses the attractive play opportunities in each AZ.

The LUs approach begins by identifying and mapping important site-specific landscape components (e.g., topography, soil, water) that influence a specific landscape function (Brown, 2008). In this methodology, it involves measuring and mapping CDVs that influence each SPB design objective, e.g., for shade cover, the shade protection factors influencing the UVR protection level. Table 4.4 summarises the CDVs determined for each SPB design objective and the methods used to measure and map them.

The mapped CDVs are systematically overlaid to delineate discrete, homogeneous landscape units (LUs) that represent combinations of key landscape characteristics across the entire school playground. These LUs are then overlaid with the AZs map to determine LUs contained within each AZ, forming the basis for assessing how effectively each AZ meets the intended SPB design objectives. Finally, each AZ is evaluated to determine where and to what extent AZs within the school playground meet the respective objective.

Table 4.4: A summary of critical design variables (CDV) associated with each sun protection behaviour design objective and the methods used

SPB Design Objective	Influencing factors	Critical design variable (CDV)	Method used
UVR Protection	Direct UV radiation	Shade cover	Shade simulation method (SketchUp 3D modelling software)
		Shade protection factor	Shade protection factor estimation method (SVF plug-in tool)
	Indirect UV radiation	Ground surface UV reflectivity	On-site observation method
Microclimate Comfort	Thermal comfort	Shade cover	Shade simulation method (SketchUp 3D modelling software)
		Wind cover	Empirical wind modelling method
		Metabolic activity rate	On-site observation method
Attractiveness	Play opportunities	Attractors	On-site observation method

Assessing the ultraviolet radiation protection level of individual activity zones (Step 2.1)

The effectiveness of UVR protection can be assessed by the level of protection against direct and indirect UVR exposure, based on three CDVs: shade cover, shade protection factor (PF) and ground surface UV reflectivity. Various methods may be used to develop CDV maps. In this methodology, a combination of methods (i.e., shade simulation, shade protection factor estimation and on-site observation) was used to measure and map the CDVs (Table 4.4).

Developing a shade cover map

Shade simulation was used to generate the shade patterns of the study school (see [Chapter 3, Section 3.5.2](#)). For this, the critical protection time (CPT), defined as the time of the day and year when UVR protection is most needed (Greenwood et al., 2000) was set at 1.30 p.m., 1 February. This date was chosen because primary schools in Christchurch are open then and UV levels are typically at their highest, often ranging from UVI 8 to 10 (NIWA, 2022). The selected time aligns with the end of the lunch break (12.30 – 1.30 p.m.) in Christchurch’s primary schools, and is near solar noon, when children typically spend a prolonged time outdoors. Providing protection then is assumed to ensure adequate protection at other times when the exposure risk is lower.

The shade pattern for the CPT was generated using SketchUp 3D modelling software (Trimble Inc), and then was imported into AutoCAD, where shaded and unshaded areas were manually delineated. Figure 4.4 is an example of a shade cover map for the study school, shaded areas are in green and unshaded areas in white.



Figure 4.4: A shade cover map of the study school

Developing shade protection factor map

The shade protection factor estimation method was used to estimate the shade’s approximate protection factor (PF) (see [Chapter 3, Section 3.5.3](#)). As noted by Mackay (2009), the PF needs to be appropriate for the proposed use period, the UVI levels of the geographic location and the users’ skin type. For example, in most mid-latitude locations (such as Australia and New Zealand), the maximum amount of solar UVR during a 1 hour period around midday in summer will generally be between 8

and 10 SED (McKenzie et al., 2006). Under these conditions, shade structures with a PF rating of 4 to 6 is considered to provide sufficient protection for fair-skinned individuals for 1 hour (max) by keeping exposure to less than 2 SED (i.e., $UVI < 2$) (Gies & Mackay, 2004). In equatorial regions with an extreme UVI of 14, a brown-skinned person achieves adequate protection simply by shielding from direct UVR (i.e., $UVI < 5$) (Mackay, 2009).

A shade PF of 6 was adopted for the study school as appropriate for outdoor activity of up to one hour (Gies & Mackay, 2004). Based on this and the estimated shade PF values, shaded areas were categorised into those with $PF \geq 6$ and those with $PF < 6$. In addition, shaded areas outside the canopy cover were identified and delineated (Figure 4.5). This step is critical because shaded areas outside the canopy cover provide very low protection (i.e., $PF < 3$) (Cheng, 2020; Mackay, 2006).

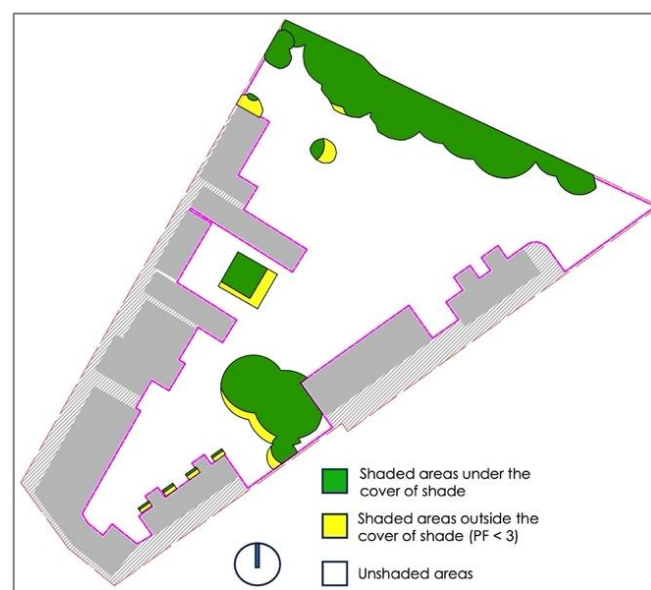


Figure 4.5: A shade cover map showing the shaded areas in and outside the canopy cover of the study school

Finally, a shade protection factor map (Figure 4.6) showing the shaded areas with and without the required PF (for the study school, areas with $PF \geq 6$ and $PF < 6$) was produced. Figure 4.6 is an example of a shade protection factor map for the study school with areas with the required PF in green, shaded areas without the required PF in yellow and unshaded areas in white.

Developing ground surface ultraviolet reflectance map

On-site observation was used to inventory and map the existing ground surfaces to develop a ground surface UV reflectance map, indicating areas with low and high UV reflectivity. Surface UV reflectivity is determined by the surface material (Turner & Parisi, 2018) and its UV albedo. Materials with a UV albedo $\leq 5\%$ are considered to have low UV reflectivity (Cherian & Subasinghe, 2023; Parisi & Turnbull, 2014), whereas those with $> 5\%$ have moderate to high UV reflectivity (Cherian &

Subasinghe, 2023). The inventoried and mapped ground surfaces of the study school were categorised into those with low UV reflective materials (i.e., UV albedo $\leq 5\%$) and high UV reflective materials (i.e., UV albedo $> 5\%$), based on UV albedo values from the literature database. Figure 4.7 shows an example of a ground surface UV reflectance map indicating areas with high UV reflectivity (orange) and low UV reflectivity (mustard).



Figure 4.6: A shade protection factor map of the study school, showing the shaded areas with and without the required protection factor rating

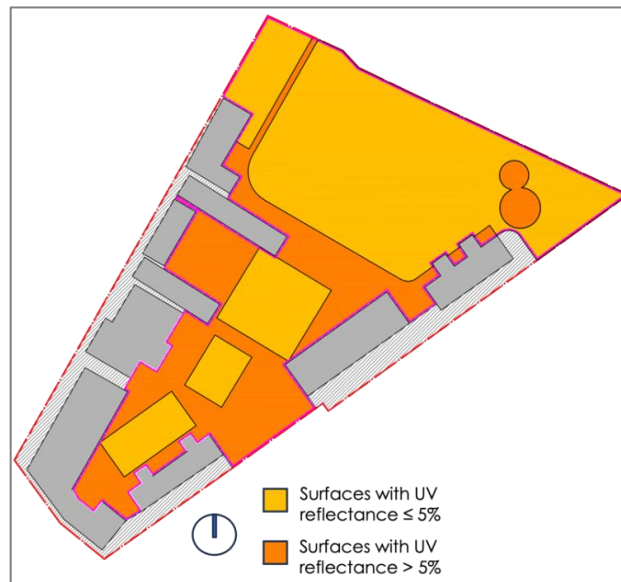


Figure 4.7: A surface ultraviolet reflectance map of the study school showing areas with high and low ultraviolet reflectivity

Generating landscape units (LUs) and evaluating ultraviolet radiation protection levels

The three CDV maps were combined to generate an LUs map showing the combined UVR protection characteristics of the site. Overlaying the three CDV maps (Figure 4.4, Figure 4.6 and Figure 4.7) generated for the school produced four distinct LUs (Figure 4.8-A): shaded areas with appropriate shade protection factor (green), shaded areas lacking the required protection factor (yellow), unshaded areas with low UV reflectivity (orange) and unshaded areas with high UV reflectivity (brown).

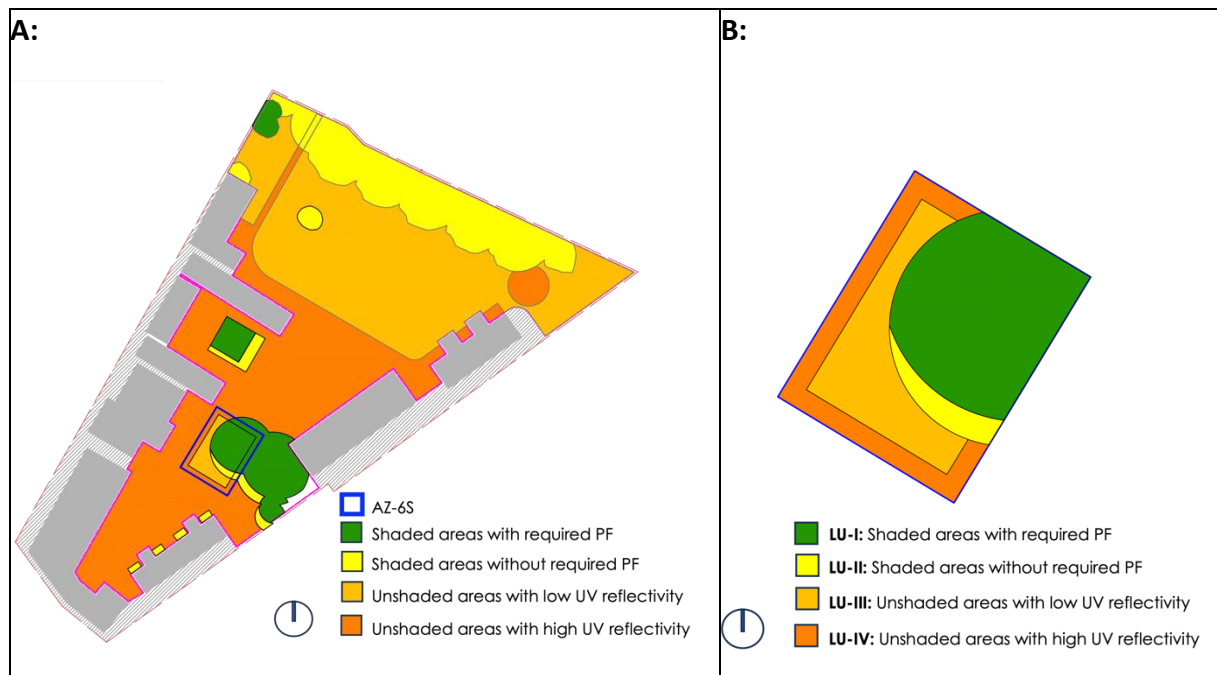


Figure 4.8: Landscape units maps showing the combined ultraviolet radiation protection characteristics. (A): landscape units map of ultraviolet radiation protection for the entire study school; (B): landscape units map of ultraviolet radiation protection in a specific activity zone (AZ-6S)

The LUs map can then be overlaid with the AZs map (Figure 4.3) to develop a detailed representation of UVR protection characteristics in individual AZs. This helps identify the LUs in each AZ and forms the basis for evaluating the UVR protection levels of each AZ. For example, overlaying “AZ-6S” from Figure 4.3/ Table 4.3 and the same area in Figure 4.8-A results in a detailed LUs map of AZ-6S (Figure 4.8-B) with four LUs (LU-I to LU-IV). The LUs in each AZ (e.g., LU-I to LU-IV) were analysed against literature-based UVR protection recommendations (Table 4.5) which allows a designer to identify areas lacking adequate protection and the factors that contribute to such inadequacy.

For example, based on Table 4.5, for the AZ in Figure 4.8-B, LU-I (green) are shaded areas with an appropriate shade protection factor providing adequate UVR protection, LU-II (yellow) are shaded areas with a low protection factor offering good UVR protection. LU-III (orange) are unshaded areas

with low UV reflectivity, and LU-IV (red) are unshaded areas with high UV reflectivity, which together provide no UVR protection.

Finally, UVR protection levels for each AZ are assessed according to the relative area occupied by different LUs in the AZ. As shown in Table 4.5, the following rules determine the level of UVR protection provided by an AZ:

Table 4.5: Landscape units and combined landscape characteristics with their corresponding ultraviolet radiation protection levels

Landscape Unit (LU)	Landscape characteristics	UVR protection levels	Remarks	Authors
LU-I	Shaded areas with required shade PF ratings	Adequate	Offer adequate protection from both direct and indirect UVR exposure	Cherian and Subasinghe (2023) Gies and Mackay (2004) Greenwood et al. (2000) Parisi and Turnbull (2014) Parsons et al. (1998)
LU-II	Shaded areas without required shade PF ratings	Good	Offer good protection from direct UVR but are exposed to high indirect UVR exposure	
LU-III	Unshaded areas with low UV reflective ground surfaces (i.e., UV albedo $\leq 5\%$)	No	Subject to both direct and indirect UVR exposure, offering no protection	
LU-IV	Unshaded areas with high UV reflective ground surfaces (i.e., UV albedo $> 5\%$)	No	Exposed to both direct and indirect UVR, providing no protection . These areas are particularly critical as they experience high levels of reflected UV radiation.	

- **‘adequate’ UVR protection** is achieved if $\geq 80\%$ of the AZ is shaded with the required shade PF ratings (i.e., LU-I type)
- **‘moderate’ UVR protection** is achieved if $< 80\%$ to $\geq 25\%$ of the AZ is shaded with varying levels of PF (i.e., LU-I & II types)
- **‘low’ UVR protection** is achieved if $< 25\%$ of the AZ is shaded with varying levels of PF (i.e., comprising LU-I & II types)

Table 4.6 presents the relative areas of each LU in AZ-6S, as in Figure 4.8-B. Since LU-I and LU-II together account for 53% of the AZ, this AZ is classified as providing ‘moderate’ UVR protection.

Table 4.6: Ultraviolet radiation protection evaluation table presented for an activity zone within the study school

Activity zone ID	Landscape Unit (LU)	% area covered	UVR protection evaluation outcome
AZ-6S	LU-I	48	Moderate
	LU-II	5	
	LU-III	25	
	LU-IV	22	

Repeating this process across all AZs of the study school identifies one activity zone (AZ-4S) as meeting adequate UVR protection (in green) and four AZs meeting ‘moderate’ UVR protection levels (in mustard). Four activity zones achieve ‘low’ UVR protection (orange), as illustrated in Figure 4.9.



Figure 4.9: Ultraviolet radiation protection level map of the study school's playground

Assessing the microclimatic comfort level of individual activity zones (Step 2.2)

Microclimatic comfort refers to outdoor microclimatic conditions that are perceived as comfortable for most individuals (Brown & Gillespie, 1995) and encompasses thermal comfort (the effect of the thermal environment on an individual's energy balance) (ASHRAE, 1989; Brown & Gillespie, 1995) and wind comfort (the mechanical impact of wind on individuals) (Ebrahimabadi, 2015). Thermal comfort is universally relevant and requires assessment regardless of site or climate (Brown & Gillespie, 1995). Wind comfort is context-specific and is considered only when wind exposure significantly affects outdoor use. As the proposed methodology is intended for universal application, microclimatic comfort was assessed in terms of thermal comfort, defined by three CDVs: shade cover, wind cover and the metabolic rate associated with AZs (Table 4.1).

As noted previously, a combination of methods can be used to measure and develop CDV maps from which the user can choose the best to meet particular circumstances. In this methodology, a combination of methods (i.e., shade simulation, empirical wind modelling and on-site field observation) has been used to measure and map the CDV. See section on dDeveloping a shade cover map for detailed description of the procedures used to generate the shade cover

Developing a wind cover map

Empirical wind modelling was used to generate wind patterns for the study school (refer [Chapter 3, Section 3.5.3](#)). The site was subsequently delineated into ‘*wind-protected*’ areas – defined by 50% reduced wind speed and ‘*wind-exposed*’ areas – defined by uninterrupted wind flow. For the pilot study school in Christchurch, the two wind pattern maps generated for the northeast and southwest wind directions (Figure 4.10-A and B) were overlaid, and the areas were categorised into: *wind-protected* areas delineated in one or both maps (in blue) and *wind-exposed* areas (all areas outside them) (in yellow) (Figure 4.10-C).

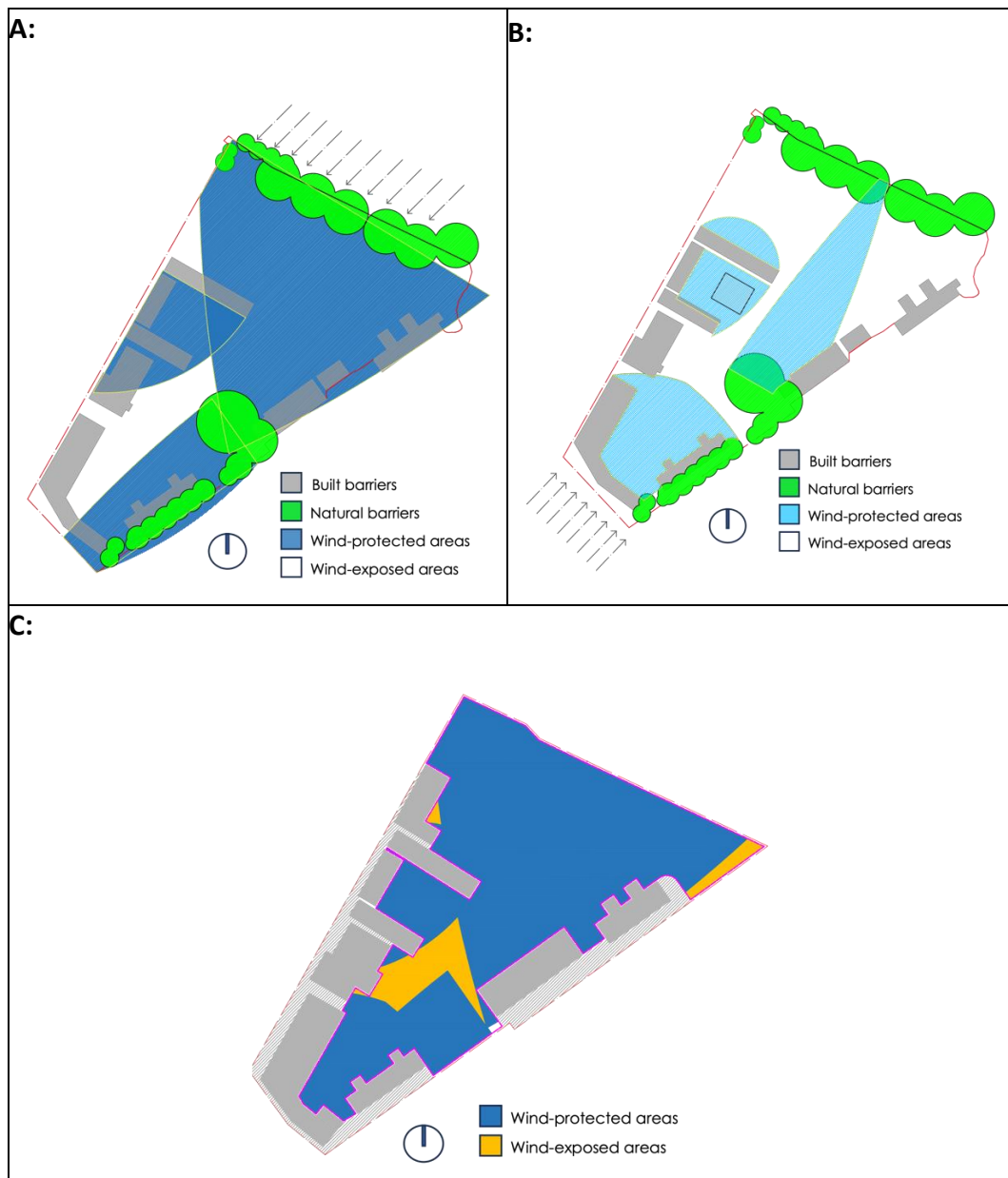


Figure 4.10: Wind cover maps of the study school. (A): the wind pattern for the northeast wind direction; (B): the wind pattern for the southwest wind direction; (C): a composite wind pattern developed for both directions

Determining the metabolic activity rate of activity zones

Metabolic rate is a measure of energy expenditure associated with a particular activity expressed in METS (Ainsworth et al., 2000). It is a key factor in determining the total metabolic heat generated by a person and directly impacts energy balance and their overall thermal comfort level (Brown & Gillespie, 1995). The metabolic rate is a function of the intensity of activity and can be divided into MET levels as summarised in Table 4.7.

Table 4.7: Activity types grouped into three metabolic rate levels

Metabolic rate (MET) level	Outdoor activity	Activity areas
Vigorous activity (> 6 MET)	Jogging/running; jumping rope; jumping jacks; competitive games (basketball, tennis, soccer, football, kickball, swimming); hopscotch; catch and throw balls; ball games	Sports fields, courts, paved areas, areas with play markings
Moderate activity (3 to 6 MET)	Brisk walking; skating; cycling; riding scooters; playing on school playground equipment; free play (swings, slides, ropes, hoops, climb, ladders); 4-square; dodgeball; low impact aerobics	Areas with play equipment, natural green areas, classroom verandas
Light activity (< 3 MET)	Casual walking; stretching; sitting; reading; writing; talking with friends; playing with toys, bricks or loose parts; board games; video games; arts and crafts	Sand pit, lunch-eating areas, gathering/outdoor learning areas

Source: Adapted from Butte et al. (2018)

As indicated in Table 4.7, nine activity zones within the study schools were categorised into: vigorous activity zones – four zones; moderate activity zones – two zones; and light activity zones – three zones, as summarised in Table 4.8.

Table 4.8: Activity zones in the study school grouped into three levels of metabolic rate

Activity zone ID	Activity area type	Zone category	Metabolic activity level (METS)
AZ-2S	Field sports area	Structured	Vigorous (> 6 MET)
AZ-5S, AZ-7S	Court-based activity area	Structured	
AZ-9US	Hard paved areas	Unstructured	
AZ-1S, AZ-6S	Fixed play equipment area	Structured	Moderate (3 to 6 MET)
AZ-3S	Sand-based activity area	Structured	Light (< 3 MET)
AZ-4S	Seating-based activity area	Structured	
AZ-8US	Natural green areas	Unstructured	

Generating landscape units (LUs) and evaluating the microclimatic comfort level

Combining the developed CDV maps generates an LUs map representing the combined microclimatic comfort (MCC) characteristics for the site. For example, overlaying the two CDV maps (Figure 4.4 and Figure 4.10-C) for the study school produced four distinct LUs (Figure 4.11-A): shaded and wind-

protected areas (in green), shaded and wind-exposed areas (in yellow), unshaded and wind-protected areas (blue), and unshaded and wind-exposed areas (mustard).

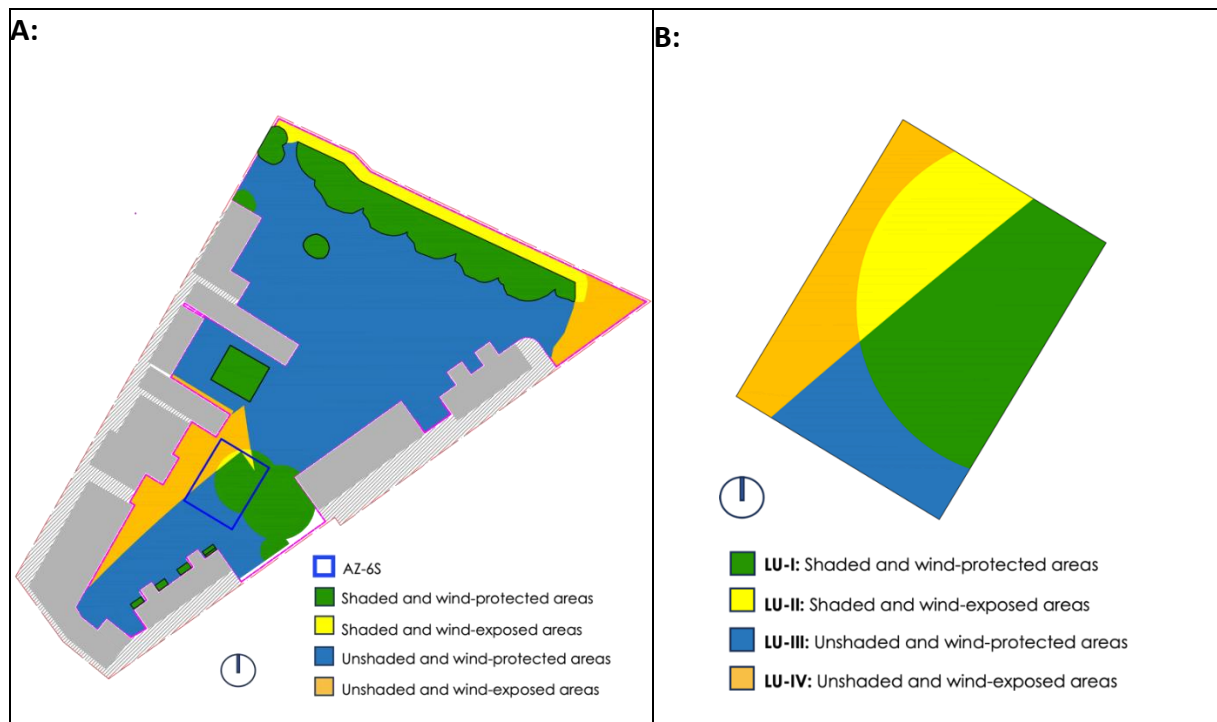


Figure 4.11: A landscape units map showing combined microclimatic comfort conditions: (A): microclimatic comfort conditions for the entire school; (B): microclimatic comfort conditions in a specific activity zone (AZ-6S)

The LUs map is then overlaid with the AZs map from Step 1 to develop a detailed representation of MCC characteristics for individual AZs. For example, overlaying “AZ-6S” from Figure 4.3/ Table 4.3 and the same area in Figure 4.11-A results in a LUs map of AZ-6S, Figure 4.11-B.

The LUs in each AZ are analysed using a standard measurement, as summarised in Table 4.9. The LUs analysis allows designers to identify areas where adequate microclimatic comfort is lacking and to determine which comfort factors are missing or inadequate (i.e., assessing whether the required wind-shade quantity available is adequate or is required in wind-exposed areas). The relationship between landscape characteristics and their microclimatic comfort levels indicated in Table 4.9 is specific to the temperate climate zone of Christchurch, New Zealand. It can be adapted for other climate zones by modifying the climate-specific factors for the particular case study. This requires careful assessment of the relevant local microclimatic comfort factors (see Chapter 3, Section 3.3) in relation to associated literature and specific landscape characteristics. It is beyond the scope of this study to discuss that process in detail.

Table 4.9: Landscape units and their combined landscape characteristics and corresponding microclimatic comfort levels

Landscape Unit (LU)	Landscape characteristic	Metabolic activity level (METS) of the activity zone	Microclimatic comfort level	Remarks	Authors
LU-I	Shaded areas with wind-protected areas	Low	Adequate	Good protection from solar radiation and wind, reducing heat loss and significantly providing adequate thermal comfort	Brown and Gillespie (1995) Brown et al. (2015) DeKay and Brown (2014) Chiesa and Grosso (2017)
		Vigorous / Moderate	Low	Good protection from solar radiation and wind, reducing heat loss and lowering thermal comfort	
LU-II	Shaded areas with wind-exposed areas	Low	Low	Good protection from solar radiation, while wind promotes heat loss and lowers thermal comfort	
		Vigorous / Moderate	Adequate	Good protection from solar radiation, while wind promotes heat loss, providing adequate thermal comfort	
LU-III	Unshaded areas with wind-protected areas	Vigorous / Moderate / Low	Very Low	Inadequate protection from solar radiation significantly lowers thermal comfort regardless of wind availability	
LU-IV	Unshaded areas with wind-exposed areas	Vigorous / Moderate / Low	Very Low		

After the LUs analysis, individual AZs are evaluated based on the area occupied by LUs in the zone.

The classification rules are:

‘adequate’ MCC is achieved if:

- an AZ for vigorous – moderate activity levels has $\geq 80\%$ of the zone shaded and wind-exposed areas (i.e., LU-II type); and
- AZs classified for light activity have $\geq 80\%$ of the zone shaded and wind-shaded areas (i.e., LU-I type);

‘moderate’ MCC is achieved if:

- an AZ (belonging to vigorous, moderate or light activity level) has $< 80\%$ to $\geq 25\%$ of the zone shaded from varying levels of wind exposure (i.e., LU-I and II types); and

‘low’ MCC is achieved if:

- an AZ (belonging to vigorous, moderate or light activity level) has $< 25\%$ of the zone shaded from varying levels of wind exposure (i.e., LU-I and II types).

Table 4.10 presents the proportional areas of each LU in the AZ-6S illustrated in Figure 4.11-B, along with the corresponding MCC evaluation outcomes. Since LU-I and II together account for 54% of the AZ, the zone is classified as providing a ‘moderate’ MCC level.

Table 4.10: Microclimatic comfort evaluation table presented for an activity zone within the study school

Activity zone ID	Metabolic activity level (Table 4.8)	Landscape Units (LU)	% area covered	MCC evaluation outcome
AZ-6S	Moderate	LU-I	49	Moderate
		LU-II	5	
		LU-III	30	
		LU-IV	16	

Applying this process across the AZs in the study school resulted in identifying one AZ (AZ-4S) as meeting the adequate MCC level (in green) and four AZs meeting ‘moderate’ MCC levels (in mustard). The remaining four AZs achieved no MCC level (in orange) (Figure 4.12).



Figure 4.12: A microclimatic comfort level map of the study school's playground

Assessing the attractiveness levels of individual activity zones (Step 2.3)

Attractiveness in this methodology is defined as the extent to which AZs provide engaging play opportunities. This is based on the assumption that children naturally gravitate to zones that stimulate play (Anthamatten, Fiene, et al., 2014). If zones are not designed to achieve this objective, children will likely not spend time in them (Boldemann et al., 2006; Mackay, 2003b). The attractiveness of an AZ is determined by the presence of features or equipment ('attractors') that promote play, as summarised in Table 4.11.

Table 4.11: A summary of activity zone types categorised as structured and unstructured with the corresponding attractors identified from the literature

Activity zone category	Activity type	Examples	Required Attractors	References
Structured	Field-based activity zones	Cricket field, soccer field	- Play features include play markings, goal posts, hoops - Loose play equipment such as balls, bats	Lucas and Dymont (2010) Zask et al. (2001)
	Court-based activity zones	Basketball court, tennis court		
	Painted surface-based activity zones	An area for hopscotch, four square	Play features such as multicolour play markings	Stratton and Mullan (2005)
	Special surface-based activity zones	Sandpit	Play features such as sand	Stratton and Mullan (2005)

		Fixed play equipment	Fixed play equipment such as jungle gym, climber, swing, and slide.	Dyment and O'Connell (2013) Reimers and Knapp (2017) Zask et al. (2001)
	Seating-based activity zones	Designated lunch-eating area, covered outdoor learning area	- Loose, movable play equipment such as bikes, bicycles, skateboards, hula-hoops and/or - Loose play parts such as tyres, milk crates, ropes, hoops.	Farley et al. (2008)
Unstructured	Natural/soft surface zones	Grassed area, a woodland	- Diverse assemblage of trees, shrubs, rocks, logs (i.e., allowing variety of places to jump, climb, hide), and/or - Loose materials such as stones, leaves, flowers, sticks, twigs and/or - Loose, moveable parts such as tyres, milk crates, ropes, hoops	Lucas and Dyment (2010) Moore (1986) Aminpour (2021) Farley et al. (2008)
	Artificial/hard surface zones	Hard-paved area, open asphalt, classroom verandas	- Loose play parts such as tyres, milk crates, ropes, hoops and/or - Loose, movable play equipment such as bikes, bicycles, skateboards, hula-hoops.	Farley et al. (2008)

In this step, a site auditing tool is used to identify and record the attractors available in each AZ.

Depending on the attractors present (see Table 4.11), AZs are categorised as:

- **'adequate'** attractiveness – if one or more attractors are present, or
- **'low'** attractiveness – if one or more attractors are absent.

For example, in the study school, four of seven structured AZs (AZ-1S, AZ-3S, AZ-4S, AZ-6S) were equipped with attractors, such as climbers, a jungle gym, loose objects and sand for play, and were therefore classified as zones with 'adequate' attractiveness. Three structured zones (AZ-2S, AZ-5S, AZ-7S) lacked the recommended attractors like balls for play (because school policy restricted the use of balls during breaks) and were therefore classified as having 'low' attractiveness. One of two unstructured AZs (AZ-8US) was classified as 'low' attractiveness because of the lack of required attractors. Figure 4.13 illustrates the zones meeting adequate attractiveness (in green) and those of low attractiveness (in orange).



Figure 4.13: An attractiveness level map of activity zones in the study school

4.2.3 Evaluating the effectiveness of activity zones in meeting sun protection behaviour design (Step 3)

In this step, findings from the AZ evaluation for each SPB design objective in Step 2 (Steps 2.1 to 2.3, Figure 4.1) are integrated to evaluate the overall SPB design capability of the AZs. The criteria for determining the effectiveness of AZs in meeting SPB design levels were developed with supporting rationale and relevant literature as presented in Table 4.12.

Applying the criteria summarised in Table 4.12 to the pilot study school resulted in a classification of AZs according to their SPB design capability (Figure 4.14). Of the nine AZs evaluated, only one (AZ-4S) achieved a 'high' SPB design rating by meeting all three objectives. Four zones were rated 'low' and the remaining four achieved no SPB design objective.

4.2.4 Evaluating the effectiveness of the school playground in meeting sun protection behaviour design (Step 4)

The final step integrates the results of individual AZs evaluations (from Step 3, Figure 4.1) to assess the overall effectiveness of the school playground. This step shows the extent to which the playground design meets the intended SPB among the children, i.e., ensuring adequate protection while promoting the use of all activity areas in the playground. In this methodology, a school

playground is considered to effectively meet SPB design criteria only if all AZs in the given playground attain a 'high' SPB design rating. This criterion ensures that all children and associated adults using the playground are sufficiently protected from solar UVR overexposure and experience thermally comfortable conditions.

Table 4.12: Evaluation criteria developed to assess the effectiveness of activity zones in meeting sun protection behaviour design

Effectiveness of activity zones in supporting SPB Design	Target	Rationale	References
Considered as 'high' SPB design when...	A zone achieves 'adequate' in 'all three' SPB design objectives	The zone is considered to adequately promote SPB among children because 100% of users are UVR protected and is frequently used because of sufficient microclimate and play opportunities	Mackay (2002) Boldeman et al. (2004) Cheng (2020) Lucas and Dymont (2010) Hyndman (2015) Mårtensson et al. (2009) Vanos et al. (2017) Holman et al. (2018) Gage et al. (2017)
Considered as 'moderate' SPB design when....	A zone achieves 'adequate' in 'any two' SPB design objectives	The zone is considered to moderately promote SPB among children because either the users are not adequately UVR protected, or the zone is only moderately used because of lack of play opportunities or poor microclimate.	
Considered as 'low' SPB design when...	A zone achieves 'adequate' in 'at least one' SPB design objective	The zone promotes only low SPB among children because users are not adequately UVR protected, and/or the zone is only moderately used because of lack of play opportunities and/or poor microclimate.	
Considered as 'no' SPB design when...	A zone achieves 'adequate' in 'none' of the SPB design objectives	The zone does not promote SPB among children because the users are not adequately UVR protected, and the zone is less frequently used because of poor microclimate and play opportunities.	

In the pilot study school, integrating the AZ results reveals that a dominant proportion of the school playground consists of AZs meeting 'no' to 'low' SPB design standards (orange and mustard, respectively, Figure 4.14); only one AZ met 'high' SPB design standards (green, Figure 4.14).

4.2.5 Identifying adaptive sun protection behaviour design strategies and prioritising activity zones (Step 5)

The final step identifies adaptive SPB design strategies that suggest which AZs should be prioritised for improvement. The evaluation of SPB design capability across AZs helps designers and stakeholders decide where intervention is most needed and what strategies could be applied to achieve optimal SPB outcomes.

The methodology adopts principles of the 'Critical Component Design (CCD)' approach (Brown, 2010), which outlines three key design moves: 'must do,' 'should do,' and 'can do' to guide decision-making and support the achievement of desired outcomes. Building on these principles, three adaptive approaches referred to as the "three R's" were developed to inform SPB design strategies: Retrofit, Redesign and Remove/Relocate. These approaches help determine the extent of the modification

required and provide a framework for prioritising AZs over time based on users' specific needs and the time and resources available.



Figure 4.14: A sun protection behaviour design capability map of the study school to show the proportion of playground meeting various levels of the design

A 'retrofit' approach involves implementing SPB design strategies without making substantial modifications to the existing design components. It applies primarily to AZs with *moderate* SPB capability, where relatively simple or cost-effective modifications can significantly enhance performance. It is appropriate to prioritise these zones when there is a need for immediate improvement to maximise the number of zones in a playground meeting optimal SPB.

The 'redesign' approach involves making substantial design modifications to improve zones' potential to meet SPB design objectives. This approach primarily applies to AZs classified as having 'low' SPB capability because they demand significant changes to key design components to achieve optimal SPB design. The redesign approach is most appropriate for mid- to long-term implementation, when larger-scale intervention can be strategically planned and resourced.

The 'relocate or remove' approach applies to AZs meeting 'no' SPB design objective. These zones lack adequate UVR protection, do not provide thermal comfort and are seldom used by children. In such cases, relocating the AZ to a more suitable location or repurposing the zone for alternative uses may be appropriate. Additionally, adopting alternative sun protection strategies, such as rescheduling

activities to safer times of day or promoting personal sun protection measures, can also be considered.

Following the identification of appropriate adaptive approaches, stakeholders can prioritise zones by considering their needs and the availability of resources (cost and time) while aiming to maximise the number of zones that achieve a 'high' SPB design. This process ultimately supports the optimisation of SPB for all playground users.

4.3 Summary

This chapter applied the proposed five-step SPB-D methodology. The detailed step-by-step process was tested in a pilot study school in Christchurch, New Zealand. The chapter outlines the integration of the multiple methods that were used to evaluate specific SPB design objectives: UVR protection, microclimatic comfort and attractiveness, while also assessing the overall SPB design and informing adaptive SPB design strategies for prioritising AZs. The next chapter presents the findings of SPB design assessments of six school playgrounds in Christchurch using the SPB-D methodology.

Chapter 5

The Evaluation of Playground Designs in Support of Sun Protection Behaviour among Children

Chapter 4 demonstrated the application of the developed Sun Protection Behaviour–Design (SPB-D) methodology through a step-by-step process using a pilot study school. Chapter 5 presents the results of applying the novel SPB-D methodology to Christchurch primary school playgrounds to evaluate the SPB design’s potential in individual AZs and the whole playground environment in supporting sun protection behaviour among children. Section 5.1 gives an overview of the methodology used in the evaluation of the study schools. Section 5.2 answers the question: To what extent do individual activity zones meet specific SPB design objectives? Section 5.2.1 addresses UVR protection evaluation, Section 5.2.2 covers microclimatic comfort evaluation and Section 5.2.3 covers attractiveness evaluation. Section 5.3 answers the question: To what extent do individual AZs meet SPB design levels? Finally, Section 5.4 answers the question: To what extent do school playgrounds meet the SPB design criteria?

5.1 Overview

As indicated in Chapter 3, Stage 2 of this study focuses on evaluating the potential of existing primary school playground designs to support sun protection behaviour (SPB) among children. For this purpose, a case study approach was adopted and six primary schools located in Christchurch, New Zealand, were selected (see [Chapter 3, Section 3.6](#) for details). The proposed SPB-D methodology (Steps 1 to 4) was applied to the study schools’ playgrounds to evaluate the extent to which (i) AZs meet individual SPB design objectives; (ii) AZs meet SPB design; and (iii) school playgrounds meet SPB design criteria.

A multiple embedded case study approach was used. Each school playground was subdivided into AZs that function as embedded analysis units in the school playground. Step 1 of the SPB-D methodology (see [Chapter 4](#) for the step-by-step process) was applied to determine the potential school playground areas and categorise AZs into structured and unstructured zones (for definitions see [Appendix A](#)). Across the six schools, the potential playground area ranged from 12,716.8 m² to 25,461.19 m². The general characteristics of the playgrounds of the six study schools are discussed in Chapter 3, and site-specific details are provided in [Appendix D](#).

Across the six schools, 91 AZs were identified, with size averages ranging from 20 m² to 25,000 m² (see [Appendix D](#)). Among them, 54% (n=50) were structured zones and 45% (n=41) were

unstructured zones. Structured zones typically occupied 21% to 44% of a school's playground area and comprised eight AZ types: sports pitches (n=5), hard court areas (n=11), sand pit areas (n=9), and fixed play equipment areas (n=18). Less frequently observed types were paint marked areas (n=3), bicycle motor cross (BMX) track areas (n=2), an outdoor amphitheatre (n=1), and a covered outdoor learning area (COLA, n=1) (for details see [Table 3.12](#)). Unstructured zones generally occupied 50 to 60% of the school playground area and comprised hard paved areas (n=6), grassed areas (i.e., areas adjoining sports fields, n=7), green or landscaped areas (n=19), and classroom verandas (n=9) in four schools (School A, B, C and E) (see [Table 3.13](#)).

Step 2 of the methodology was used to assess the specific SPB design objectives: UVR protection, microclimatic comfort and attractiveness in the individual AZs. Step 3 integrated the results to assess the effectiveness of individual AZs in meeting the SPB design criteria. Step 4 integrated the AZ level outcomes (from Step 3) to determine the overall effectiveness of each school playground in achieving the intended SPB design.

The analysis was done for the study schools for the critical protection time (CPT), 1 February at 1.30 p.m. (see [Chapter 3](#)). The following sections present the findings of the evaluation at three analysis levels: (1) the effectiveness of individual AZs in meeting the SPB design objectives; (2) the effectiveness of individual AZs in meeting SPB design criteria; and (3) the effectiveness of school playgrounds in meeting the SPB design criteria.

5.2 Activity zones and sun protection behaviour design objectives

Step 2 of the SPB-D methodology (sub-steps 2.1 to 2.3) was used to assess the potential of individual AZs to meet the specific SPB design objectives. The findings are presented below under the three SPB design objectives: UVR protection, microclimatic comfort and attractiveness.

5.2.1 The effectiveness of activity zones in meeting ultraviolet radiation protection

In the SPB-D methodology, the UVR protection levels of each AZ are assessed according to the proportion of the area occupied by different landscape units (LUs) in the zone and, following rules, determine the level of UVR protection provided by:

- **'adequate' UVR protection:** $\geq 80\%$ of the AZ is shaded with the required shade PF rating (i.e., LU-I type);
- **'moderate' UVR protection:** $< 80\%$ to $\geq 25\%$ of the AZ is shaded by varying levels of protection (i.e., comprising LU-I & II types); and
- **'low' UVR protection:** if $< 25\%$ of the AZ is shaded by varying levels of protection (i.e., comprising LU-I & II types).

The results reveal that, of the 91 AZs evaluated, only 8% (7 of 91) achieved the criterion for ‘adequate’ UVR protection, indicating sufficient protection from both direct and indirect UVR, followed by 27% (n=25 of 91) meeting the ‘moderate’ UVR protection level criterion subject to varying levels of protection. Finally, most AZs, 65% (n=59 out of 91), met ‘low’ UVR protection level; of these, 38% (n=35 out of 91) experienced low reflected UV; and 26% (n=24 out of 91) were exposed to high reflected UV and higher UV intensities. Table 5.1 summarises the number of AZs meeting each of the three UVR protection levels, categorised by AZ type.

Table 5.1: The distribution of activity zone type across the three ultraviolet radiation protection levels

Structured zones					
Activity zone	Total zones (n)	No. of ‘adequate’ zones	Number of ‘moderate’ zones	No. of ‘low’ zones	
				With low UV reflectivity	With high UV reflectivity
Sports fields	5	0	0	5	0
Hard-courts	11	0	1	0	10
Fixed play equipment	18	0	6	12	0
Sand pits	9	0	3	0	6
Paint marked areas	3	0	0	0	3
BMX tracks	2	0	0	2	0
Seating areas	2	1	1	0	0
Total in all schools	50	1	11	19	19
Unstructured zones					
Hard paved area	6	0	2	0	4
Grassed areas	7	0	1	6	0
Green areas	19	3	6	10	0
Classroom verandas	9	3	5	0	1
Total (all schools)	41	6	14	16	5
Total activity zones (all schools)	91	7	25	35	24

Among the two zone categories, more unstructured zones achieved higher UVR protection levels: 6% (n=6 out of 91) achieved ‘adequate’ and 15% (n=14 out of 91) achieved ‘moderate’ UVR protection (Table 5.1). Figure 5.1 presents an example of AZs meeting adequate UVR protection levels, Figure 5.1-A shows the LU map of UVR protection for two unstructured zones in School E, and Figure 5.1-B

highlights the presence of dense trees that contributed to these zones meeting adequate UVR protection criteria.

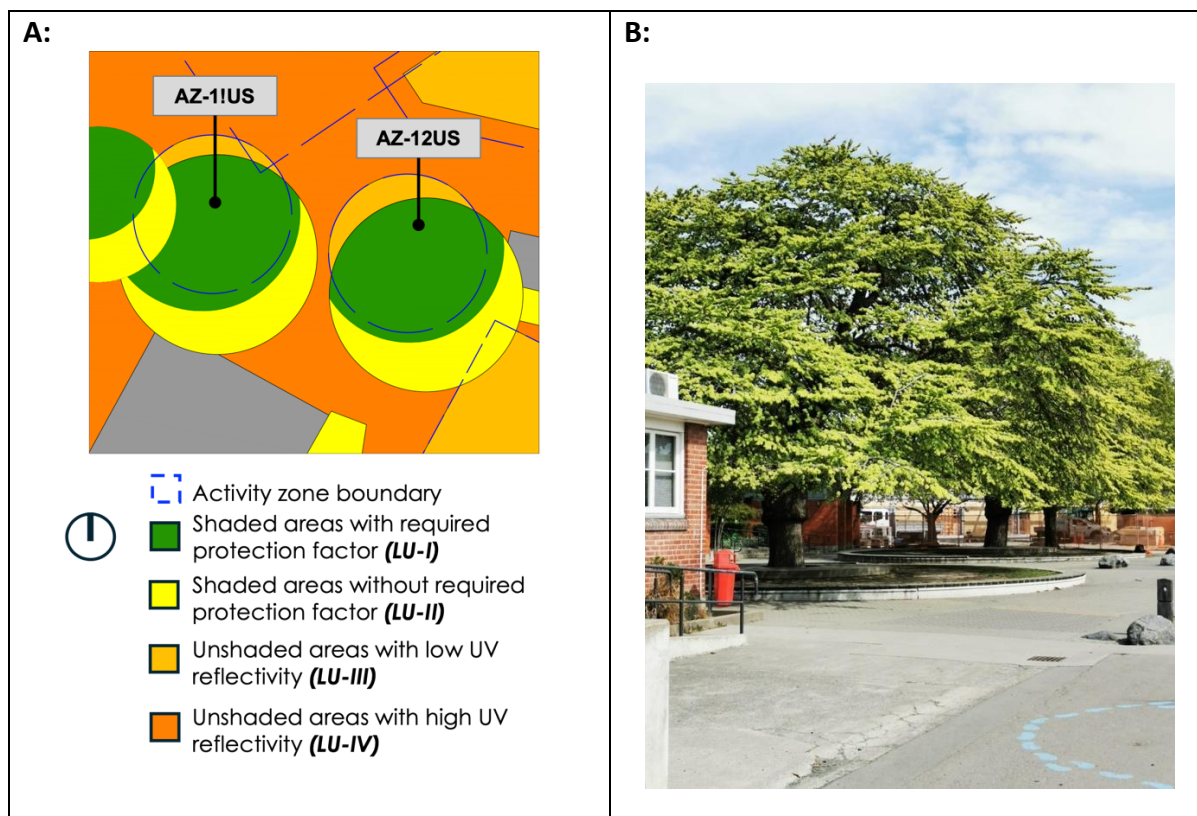


Figure 5.1: Activity zones in School E that meet the adequate ultraviolet radiation protection level.
(A): landscape unit map of ultraviolet radiation protection for two unstructured zones;
(B): site photograph showing dense tree shade covering over the zones

In contrast, only 10% of AZs (n=12 of 91) in structured zones achieved UVR protection, with just 1% (n=1) meeting the ‘adequate’ level and 12% (n=11 out of 91) meeting ‘moderate’ protection (Table 5.1). Figure 5.2 shows an example from School B of a structured zone – the covered outdoor learning area (COLA) that met ‘adequate’ UVR protection. Figure 5.2-A is the LU map of UVR protection in the AZ, and Figure 5.2-B highlights the solid roof covering the AZ, which contributes to meeting the criteria.

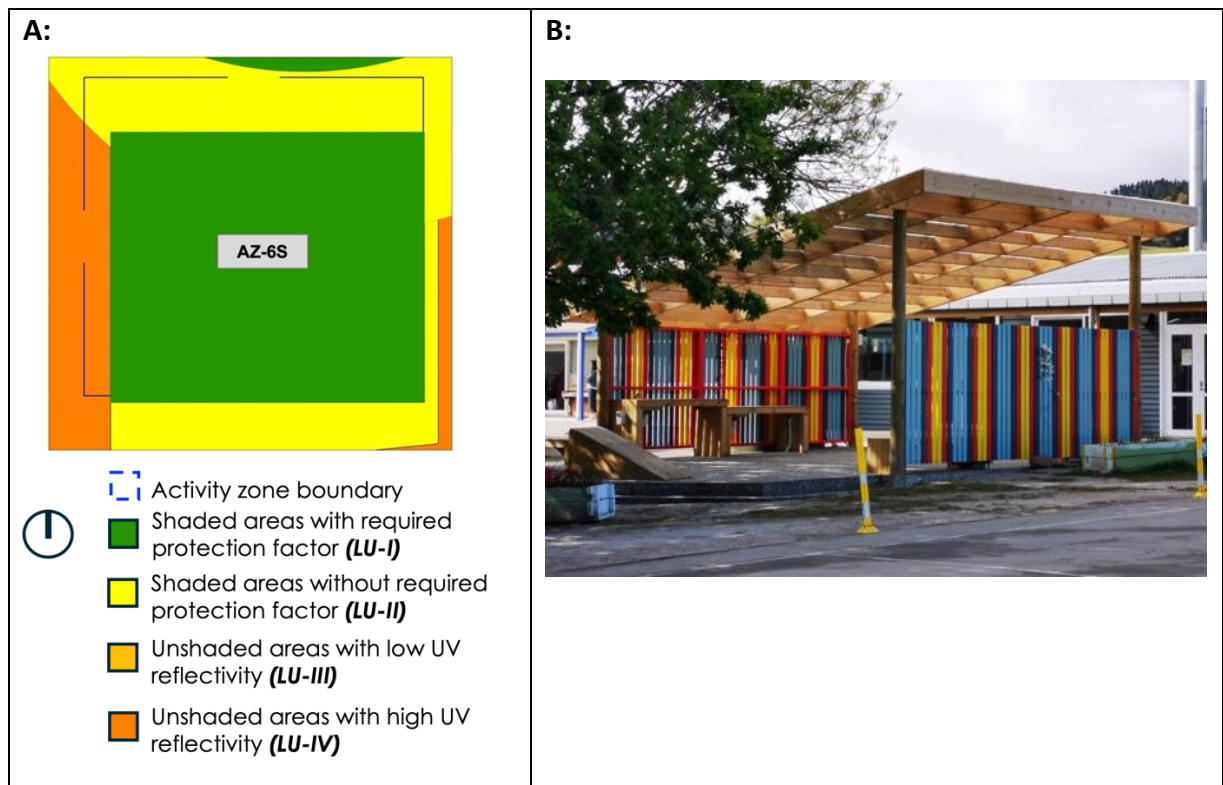


Figure 5.2: A structured activity zone in School B meeting adequate ultraviolet radiation protection (A): landscape unit map of ultraviolet radiation protection in the structured zone; (B): a site photograph showing the solid roof providing effective shade

The findings indicate that of all 91 activity zones, most (61%, n=56) had little or no shade cover (i.e., shade covering 0-25% of the zone); 29% (n=27) had partial shade cover (i.e., shade covering 25-80% of the zone) and only a small proportion (9%, n=9) had most or complete shade cover (i.e., shade covering 80-100% of the zone). Table 5.2 presents the distribution of AZs based on the shade coverage level across the study schools.

Table 5.2: The distribution of activity zones by shade coverage across the study schools

Activity zone	No. of activity zones (n)	Shade coverage			Mean shade cover (%)
		None*	Partial*	Complete*	
Structured zones					
Sports fields	5	5	0	0	2.2
Hard-courts	11	10	1	0	19.8
Fixed play equipment	18	12	6	0	22.8
Sand pits	9	5	4	0	27.2
Paint marked areas	3	3	0	0	0
BMX track	2	2	0	0	6.5
Seating areas	2	0	1	1	93.6
Total (all schools)	50	37	12	1	
Unstructured zones					
Hard paved area	6	2	4	0	27.9
Grassed area	7	6	1	0	11.2
Green area	19	10	6	3	31.9
Classroom verandas	9	1	4	5	73.5
Total (all schools)	41	19	15	8	
Total (all schools)	91	56	27	9	

*in the table:

‘none’– shade covering 0-25% of the zone

‘partial’– shade covering 25-80% of the zone

‘complete’– shade covering 80-100% of the zone

Across the study schools, the AZ types with the most or complete shade cover were predominantly classroom verandas (55%, n=5 of 9 zones), seating-based zones (50%, n=1 of 2 zones), and green areas (16%, n=3 of 19) (Table 5.2). In contrast, AZ types with little or no shade cover were sports areas (100%, n=5 of 5), paint marked areas (100%, n=3 of 3), BMX track areas (100%, n=2 of 2), hard court areas (90%, n=10 of 11), grassed areas (90%, n=6 of 7), fixed play equipment areas (66%, n=12 of 18), and sand pits (55%, n=5 of 9).

The results also reveal that paint marked areas (100%, n=3), hard courts (90%, n=10 out of 11), sand pits (66%, n=6 out of 9) and hard paved areas (66%, n=4 out of 6) were not only unshaded but also had ground surfaces with high UV albedo (i.e., UV albedo > 5%), which increases reflected UVR exposure in these zones. Figure 5.3 presents an example of a completely unshaded sand pit that is exposed to high reflected UVR. Figure 5.3-A is the LU unit map and Figure 5.3-B shows a site image of the sand pit in School D.

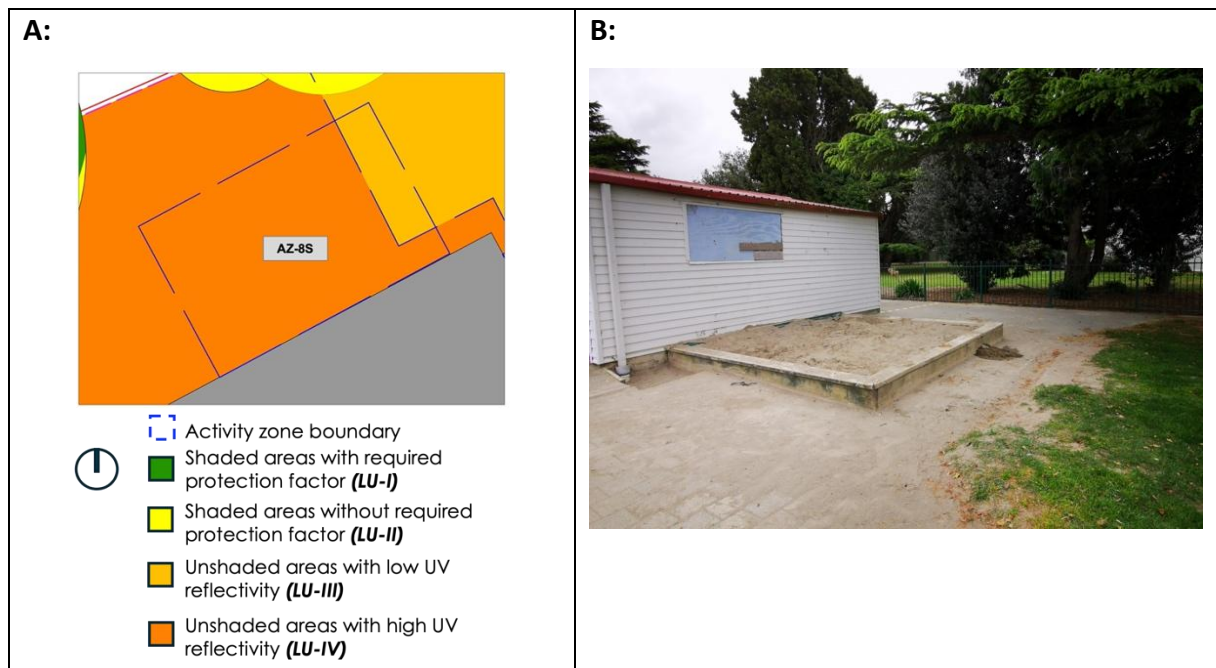


Figure 5.3: The sand pit in School D with low ultraviolet radiation protection. (A): landscape unit map of ultraviolet radiation protection in the zone; (B): a site photograph showing the unshaded condition and high ultraviolet albedo of the surface

5.2.2 The effectiveness of activity zones in meeting microclimatic comfort

In the proposed SPB-D methodology, the effectiveness of AZs in meeting microclimatic comfort (MCC) is evaluated on the ability to provide thermal comfort, which is measured by the proportional area occupied by different LUs in each zone. The classification rules are:

‘adequate’ MCC is achieved if:

- an AZ with vigorous to moderate activity levels has $\geq 80\%$ of the zone shaded with wind-exposed areas (i.e., comprising the LU-II type), and
- an AZ with light activity levels has $\geq 80\%$ of the zone shaded with wind-shaded areas (i.e., comprising LU-I type);

‘moderate’ MCC is achieved if:

- an AZ with vigorous, moderate, or light activity levels has $< 80\%$ to $\geq 25\%$ of the zone shaded with varying levels of wind exposure (i.e., LU-I and II types); and

‘low’ MCC is achieved if:

- an AZ with vigorous, moderate, or light activity levels has $< 25\%$ of the zone shaded with varying levels of wind exposure (i.e., LU-I and II types).

Based on these criteria, Table 5.3 summarises the distribution of AZs meeting the three levels of microclimatic comfort. Of the 91 AZs, only 1% ($n=1$ of 91) achieved the ‘adequate’ criterion for MCC, thus providing sufficient thermal comfort for users, followed by 36% ($n=33$ of 91) meeting the

‘moderate’ criterion, subjected to varying levels of thermal comfort, whereas most, 63% (n=57 of 91), met the ‘low’ MCC level, indicating thermal discomfort for zone users.

Table 5.3: The distribution of activity zone types across three microclimatic comfort levels of the sampled schools

Activity zone	Total number of zones (n)	No. of ‘adequate’ zones	No. of ‘moderate’ zones	No. of ‘low’ zones
Structured zones				
Sports fields	5	0	0	5
Hard-courts	11	0	1	11
Fixed play equipment	18	0	6	12
Sand pits	9	0	3	6
Paint marked areas	3	0	0	3
BMX tracks	2	0	0	2
Seating areas	2	1	1	0
Total (all schools)	50	1	11	38
Unstructured zones				
Hard paved area	6	0	4	2
Grassed area	7	0	1	6
Green area	19	0	9	10
Classroom verandas	9	0	8	1
Total (all schools)	41	0	22	19
Total activity zones (all schools)	91	1	33	57

Structured zones were more frequently associated with thermal discomfort conditions: 76% (n=38 of 50 structured zones) achieved only ‘low’ MCC levels, and 22% (n=11 of 50) achieved ‘moderate’ levels (Table 5.3). Figure 5.4 presents a structured zone, an outdoor amphitheatre in School A, that met the ‘moderate’ MCC criterion. Figure 5.4-A shows the LU map of microclimatic comfort and Figure 5.4-B shows the site image of the same AZ.

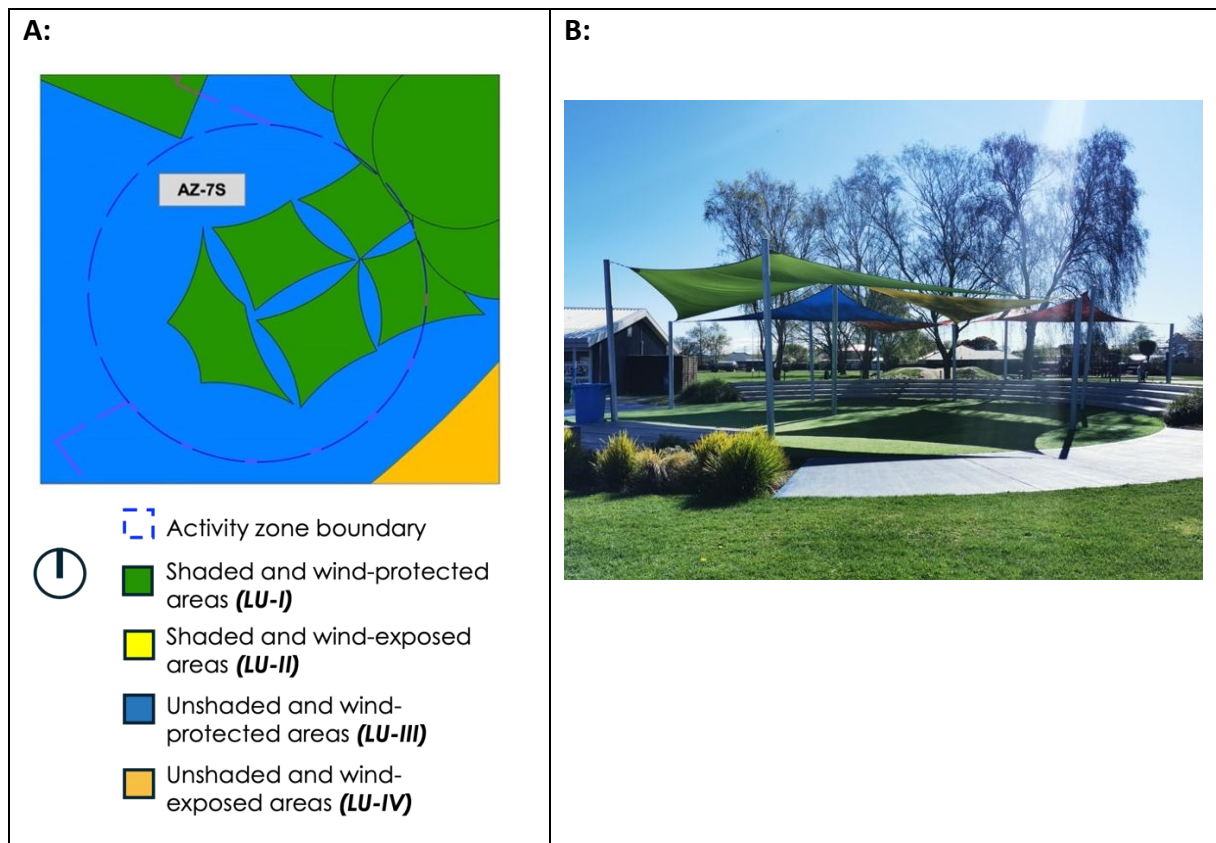


Figure 5.4: A structured zone in School A meeting the moderate microclimatic comfort criterion. (A): landscape units map of microclimatic comfort in the zone; (B): a site image of the activity zone.

Conversely, unstructured zones had comparatively better thermal conditions, with 53% (n=22 of 41) meeting ‘moderate’ MCC levels and 46% (n=19 of 41 unstructured zones) meeting ‘low’ MCC levels (Table 5.3).

The distribution of AZs based on shade provision and wind coverage is summarised in Table 5.4. Among the 91 AZs assessed, those classified as ‘vigorous’ to ‘moderate’ activity rate (i.e., having high intensity activities such as running, playing) predominantly had low mean shade coverage (from 0% to 30%) combined with a high mean wind coverage (from 54% to 100%), as highlighted in yellow in the Table 5.4. This combination of high sun exposure and high wind creates uncomfortable conditions, contributing to increased thermal discomfort for users. These include sports pitches (n=2 of 5 zones), hard court areas (n=6 of 11 zones), fixed play equipment areas (n=10 of 18 zones), paint marking areas (n=3 of 3 zones), BMX tracks (n=1 of 2 zones) and green areas (n=10 of 19 zones).

Table 5.4: The distribution of activity zones based on shade coverage and wind coverage in the study schools

Activity zone	No. of activity zones (n)	Metabolic activity rate	Shade coverage			Mean shade cover (%)	Wind coverage			Mean wind cover (%)
			None*	Partial*	Complete*		None*	Partial*	Complete*	
Structured zones										
Sports fields	5	V	5	0	0	2.2	2	1	2	54.1
Hard-courts	11	V	10	1	0	19.8	0	5	6	80.5
Fixed play equipment	18	M	12	6	0	22.8	2	6	10	75.5
Sand pits	9	L	5	4	0	27.2	1	1	7	83.0
Paint marked areas	3	V	3	0	0	0	0	0	3	100
BMX tracks	2	V	2	0	0	6.5	1	0	1	60.8
Seating areas	2	L	0	1	1	93.6	0	0	2	100
Total (all schools)	50		37	12	1		6	13	31	
Unstructured zones										
Hard paved area	6	V	2	4	0	27.9	0	1	5	92.4
Grassed area	7	M	6	1	0	11.1	1	4	2	56.7
Green area	19	M	10	6	3	31.9	1	4	14	86.3
Classroom verandas	9	M	1	4	5	73.5	0	0	9	99.0
Total (all schools)	41		19	15	8		2	9	30	
Total (all schools)	91		56	27	9		8	22	61	

*in the table:

V – vigorous activity level

M – moderate activity level

L – light activity level

‘none’ – shade/wind covering 0-25% of the zone

‘partial’ – shade/wind covering 25-80% of the zone

‘complete’ – shade/wind covering 80-100% of the zone

Among light metabolic AZs (e.g., sitting, talking), only one, a seating-based zone (i.e., COLA), had complete shade coverage (80-100%) and was fully wind-protected (80-100%). It therefore achieved an ‘adequate’ MCC level. Sand pits (n=5 of 9 zones) lacked shade cover and were not completely wind-protected, resulting in varying levels of thermal discomfort. In such light metabolic AZs, both shaded and sun-exposed environments may provide thermally uncomfortable conditions when accompanied by wind exposure.

5.2.3 The effectiveness of activity zones in meeting attractiveness

In the SPB-D methodology, the attractiveness level is determined by the presence of attractors in a zone as follows:

- **‘adequate’** attractiveness – if one or more attractors are present, or
- **‘low’** attractiveness – if one or more attractors are absent.

Based on the evaluation criteria, Table 5.5 summarises the distribution of AZs meeting ‘adequate’ and ‘low’ attractiveness levels. Of the 91 AZs, 58% (n=53 of 91) had adequate attractiveness, and 42% (n=38 of 91) were rated as less attractive. Structured zones were more likely to offer attractive

play opportunities, with 76% (n=38 of 50) meeting the criteria for adequate attractiveness, compared with only 37% (n=15 of 41) of unstructured zones meeting the criteria.

Table 5.5: The distribution of activity zone type across two attractiveness levels

Activity zone	Total number of zones (n)	No. of 'adequate' zones	No. of 'low' zones
Structured zones			
Sports fields	5	0	5
Hard-courts	11	5	6
Fixed play equipment	18	18	0
Sand pits	9	9	0
Paint marked areas	3	3	0
BMX tracks	2	2	0
Seating areas	2	1	1
Total (all schools)	50	38	12
Unstructured zones			
Hard paved area	6	6	0
Grassed area	7	2	5
Green area	19	5	14
Classroom verandas	9	2	7
Total (all schools)	41	15	26
Total activity zones (all schools)	91	53	38

In the structured zones, all fixed play equipment areas (100%, n=18), sand pits (100%, n=9), paint marked areas (100%, n=3) and BMX-Tracks (100%, n=2) in the study schools had the required attractor and achieved 'adequate' attractiveness (Table 5.5). Figure 5.5 shows a structured zone, a fixed play equipment area, where a jungle gym is an attractor to promote play opportunities for children. All sports pitches (100%, n=5), 54% of hard-court areas (n=6 of 11), and one of the two seating areas (n=1 of 2 zones) lacked a required attractor and met a 'low' attractiveness level (Table 5.5). Figure 5.6 shows an example of a structured zone, a covered outdoor learning area (COLA) in School B lacks a required attractor, such as loose parts, to encourage play in the zone.



Figure 5.5: A structured zone in School A with fixed play equipment



Figure 5.6: A structured zone in School B with a covered outdoor learning area

In unstructured zones, hard-paved areas (100%, n=6) consistently had the required attractor and therefore met the ‘adequate’ attractiveness level. Most grassed areas (71%, n=5 of 7), green areas (73%, n=14 of 19) and classroom verandas (77%, n=7 of 9) did not have any required attractor and were consequently rated as ‘low’ attractiveness (Table 5.5). Figure 5.7 shows an unstructured zone, a grassed area in School E, that incorporates an obstacle course, thus providing an attractor that supports play. In contrast, Figure 5.8 shows a grass area in School C that lacks an attractor and corresponding play opportunities.



Figure 5.7: An unstructured zone in School E showing a grassed area



Figure 5.8: An unstructured zone in School C showing a grassed area

5.3 The effectiveness of individual activity zones in meeting sun protection behaviour design criteria

Following the evaluation of specific SPB design objectives, Step 3 of the methodology was used to evaluate the effectiveness of individual AZs in meeting the required SPB design levels. According to

the SPB-D methodology, the effectiveness of individual AZs in meeting the required SPB design is determined by the number of SPB design objectives each meets so, accordingly, AZs were classified into four SPB design levels using the following rules:

- **‘high’** SPB design: if a zone achieves ‘adequate’ in ‘all three’ SPB design objectives;
- **‘moderate’** SPB design: if a zone achieves ‘adequate’ in any two SPB design objectives;
- **‘low’** SPB design: if a zone achieves ‘adequate’ in ‘at least one’ SPB design objective; and
- **‘no’** SPB design: if no zone achieves ‘adequate’ in the SPB design objectives.

Based on these criteria, Table 5.6 summarises the distribution of AZs across the four SPB design levels. Of the 91 AZs evaluated, none achieved the ‘high’ level of the SPB design criteria required to effectively support the intended SPB among children. Only a very small proportion, 2% (n=2 of 91), met the ‘moderate’ SPB design level. Most AZs, 63% (n=57), achieved ‘low’ SPB design level and 35% (n=32) met ‘no’ SPB design level.

Table 5.6: The distribution of activity zones across the four sun protection behaviour design levels

Activity zone	Number of zones (n)	SPB design levels*			
		No. of 'high' zones	No. of 'moderate' zones	No. of 'low' zones	No. of 'no' zones
Structured zones					
Sports fields	5	0	0	0	5
Hard-courts	11	0	0	5	6
Fixed play equipment	18	0	0	18	0
Sand pits	9	0	0	9	0
Paint marked areas	3	0	0	3	0
BMX tracks	2	0	0	2	0
Seating areas	2	0	1	1	0
Total (all schools)	50	0	1	38	11
Unstructured zones					
Hard paved area	6	0	0	6	0
Grassed area	7	0	0	2	5
Green area	19	0	1	6	12
Classroom verandas	9	0	0	5	4
Total (all schools)	41	0	1	19	21
Total activity zones (all schools)	91	0	2	57	32

*in the table:

‘high’– zones achieving *adequate* in all *three* SPB design objectives

‘moderate’– zones achieving *adequate* in any *two* SPB design objectives

‘low’– zones achieving *adequate* in at least *one* SPB design objective

‘no’ - zones achieving *adequate* in none of the *three* SPB design objectives

5.3.1 Activity zones meeting ‘moderate’ to ‘low’ sun protection behaviour design levels

A very small proportion, only 2% (n=2 of 91) AZs achieved the ‘moderate’ SPB design level (Table 5.6). They include a covered outdoor learning area (COLA) in School B, which provided adequate UVR protection and microclimatic comfort but was not attractive, and a green area in School C, which met adequate UVR protection level and attractiveness but did not achieve adequate microclimatic comfort.

As summarised in Table 5.6, 62% (n=57) of AZs met the ‘low’ SPB level by meeting only one SPB design objective. Among the three SPB design objectives, attractiveness was the one most commonly met, 58% of AZs (n=53 over schools) met this objective. Only 7% (n=7 over schools) met the UVR protection objective, and just one AZ achieved microclimatic comfort (Table 5.7).

Table 5.7: School-wise proportion of activity zones meeting specific sun protection behaviour design objectives

Study school	Potential SPB design area (m ²)	Total no. of activity zones (n)	UVR protection	Microclimatic comfort	Attractiveness
			No. of activity zones (n)	No. of activity zones (n)	No. of activity zones (n)
School - A	21662.28	14	0	0	7
School - B	12716.8	12	1	1	8
School - C	14576.15	19	4	0	10
School - D	13874.95	14	0	0	9
School - E	19816.01	16	2	0	8
School - F	25461.19	16	0	0	11
Total activity zones in all schools		91	7	1	53

As indicated in Table 5.7, Schools A (50%, n=7 of 14), D (64%, n=9 of 14) and F (68%, n=11 of 16) averaged 50 to 70% of AZs meeting only the attractiveness objective. In the remaining schools, an average of 60–80% of AZs met either the attractiveness or UVR protection criterion.

5.3.2 Activity zones with ‘no’ sun protection behaviour design level

As noted above, of the 91 AZs, 35% (n=32) did not meet the ‘adequate’ criterion for any of the three SPB design objectives and, therefore, had ‘no’ SPB design level (Table 5.6). Most of the zones were unstructured; 65% (n=21) of those were classified at this level. They were mainly grassed areas (71%, n=5 of 7) and green areas (63%, n=12 of 19), as summarised in Table 5.8.

Table 5.8: The distribution of activity zones by specific sun protection behaviour design objectives achieved

Activity zones	Total number of zones (n)	No. of activity zones meeting specific sun protection behaviour design objectives			
		UVR protection	Microclimatic comfort	Attractiveness	Meeting none
Structured zones					
Sports fields	5	0	0	0	5
Hard-courts	11	0	0	5	6
Fixed play equipment	18	0	0	18	0
Sand pits	9	0	0	9	0
Paint-marked areas	3	0	0	3	0
BMX tracks	2	0	0	2	0
Seating areas	2	1	1	1	0
Total (all schools)	50	1	1	38	11
Unstructured zones					
Hard paved area	6	0	0	6	0
Grassed area	7	0	0	2	5
Green area	19	3	0	5	12
Classroom verandas	9	3	0	2	4
Total (all schools)	41	6	0	15	21
Total activity zones in all schools	91	7	1	53	32

Structured zones comprise the remaining 35% (n=11) of zones with ‘no’ SPB design level; these commonly include sports pitch areas (100%, n=5), and hard-court areas (54%, n=6 out of 11) (Table 5.8).

5.4 The effectiveness of school playgrounds in meeting sun protection behaviour design criteria to support the behaviour among children during the critical protection time

Based on the evaluation of individual AZs, Step 4 of the SPB-D methodology was used to determine the effectiveness of the whole school playground in meeting the required SPB design requirements. This evaluation was based on the number of AZs classified as meeting the ‘high’ SPB design. A school playground is considered to effectively meet SPB design criteria only if 100% of its AZs meet a ‘high’ SPB design standard.

According to the criteria, as summarised in Table 5.9, no school playground achieved the required SPB design standard. This is because no AZ of all six study schools met the ‘high’ SPB design criterion by achieving all three SPB design objectives.

Table 5.9 summarises the number of AZs in each school that meet the four levels of SPB design. Only two schools, B and C, had a very small proportion of their playgrounds meeting a ‘moderate’ SPB design, with only one AZ in each school meeting this level (in blue in Figure 5.9 and Figure 5.10). These zones account for a mean coverage of 0.4% and 0.7% of the playground area (Table 5.9).

Table 5.9: The school distribution of activity zones meeting the four sun protection behaviour levels

School	Total school playground area (m ²)	Total number of activity zones (n)	‘High’ SPB design		‘Moderate’ SPB design		‘Low’ SPB design		‘No’ SPB design	
			Number of activity zones (n)	Mean % cover	Number of activity zones (n)	Mean % cover	Number of activity zones (n)	Mean % cover	Number of activity zones (n)	Mean % cover
School - A	21662.3	14	0	0	0	0	7	22.9	7	77.1
School - B	12716.8	12	0	0	1	0.4	8	76.3	3	23.4
School - C	14576.2	19	0	0	1	0.7	12	38.4	6	61.6
School - D	13875.0	14	0	0	0	0	9	41.5	5	58.5
School - E	19816.0	16	0	0	0	0	10	72.8	6	27.2
School - F	25461.2	16	0	0	0	0	11	29.3	5	70.7
Total activity zones in all schools (n)^a	18017.9	91	0	0	2	0.18	57	46.9	32	53.1

*in the table:

n refers to the distribution of activity zones at each school

(n)^a refers to the distribution of activity zones across all schools

‘high’ SPB design – meeting all three objectives

‘moderate’ SPB design – meeting two objectives

‘low’ SPB design – meeting one objective

‘no’ SPB design – not meeting any of the three objectives

In the remaining four schools (Schools A, D, E and F), playgrounds were classified as meeting the ‘low’ SPB design or ‘no’ SPB design. Notably, Schools A and F had most of their playground areas classified as having ‘no’ SPB design (orange in Figure 5.11 and Figure 5.12). In these schools, seven and five AZs, respectively, were classified as ‘no’ SPB design, accounting for 77% and 70% of the playground area (Table 5.9). The remaining portions of playgrounds, 23% in School A (yellow in Figure 5.11) and 30% in School F (yellow in Figure 5.12), were classified as having a ‘low’ SPB design. They contained seven and eleven AZs, respectively (Table 5.9).

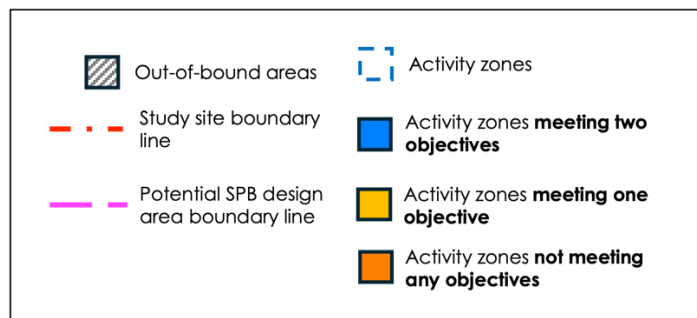


Figure 5.10: A landscape unit map of the playground in School E, showing the proportion of activity zones meeting sun protection behaviour design levels and the overall effectiveness

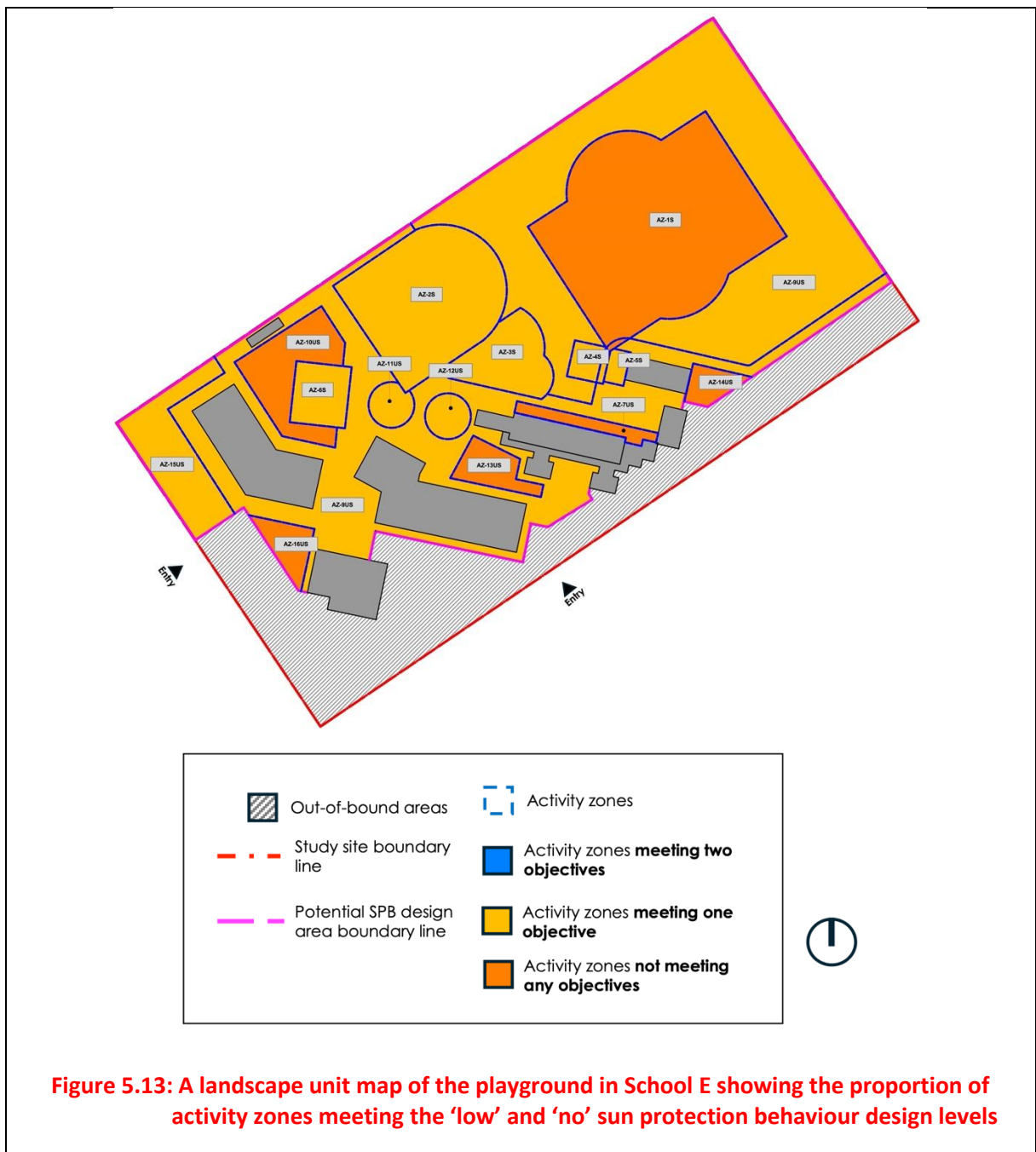


Figure 5.11: A landscape unit map of the playground in School A showing the proportion of activity zones meeting 'low' and 'no' sun protection behaviour design levels



Figure 5.12: A landscape unit map of the playground in School F showing the proportion of activity zones meeting 'low' and 'no' sun protection behaviour design levels

In contrast, Schools B and E had the predominant area of their playgrounds classified as having 'low' SPB design (in Figure 5.9 and Figure 5.13), with eight and ten AZs covering 76% and 72% of their respective playgrounds (Table 5.9). The remaining portion of their playgrounds was classified as having 'no' SPB design (orange in Figure 5.9 and Figure 5.13), comprising three and six AZs with a mean cover of 23% and 27%, respectively (Table 5.9).



School D had approximately 42% of its playground area classified as meeting the 'low' SPB design (yellow in Figure 5.14), consisting of nine AZs with a mean cover of 42% (Table 5.9) and the remaining 58% of the playground classified as having 'no' SPB design (orange in Figure 5.14), comprising five AZs with a mean cover of 59% (Table 5.9).

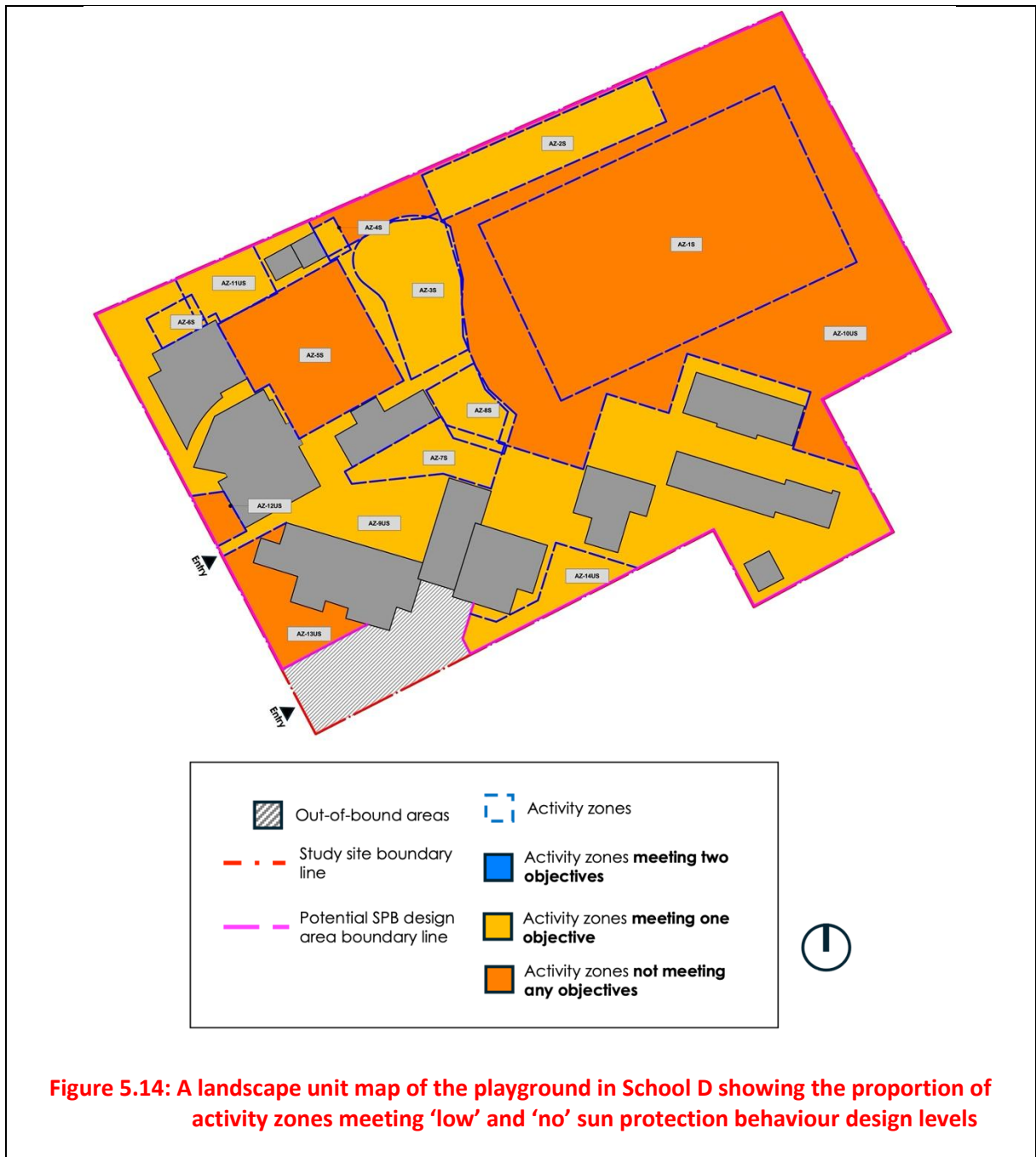


Figure 5.14: A landscape unit map of the playground in School D showing the proportion of activity zones meeting 'low' and 'no' sun protection behaviour design levels

5.5 Summary

This chapter presented the analysis results at three levels: (1) the effectiveness of activity zones in meeting specific SPB design objectives; (2) the effectiveness of activity zones in meeting SPB design criteria; and (3) the effectiveness of total school playgrounds in meeting SPB design criteria. Analysis of individual activity zones reveals that 58% (n=53 of 91 zones) achieved 'adequate' attractiveness, but only 8% (n=7 of 91) provided 'adequate' UVR protection and just one zone met the 'adequate' level for microclimatic comfort.

Second, the analysis of individual activity zones to meet SPB design criteria indicates that no activity zone across the six schools met the 'high' SPB design level necessary to effectively support SPB

among children. Only 2% (n=2 of 91) achieved a 'moderate' SPB design, meeting two objectives. The majority, 63% (n=57 of 91), were classified as 'low' SPB design in meeting only one objective, and 35% (n=32 of 91) were at the 'no' SPB design level.

This school-wide playground design evaluation reveals that no school playground meets the required SPB design criteria, since no activity zone met the 'high' SPB design level. Schools B and C had a minimal portion of their playgrounds classified as 'moderate' SPB design, with just one activity zone each meeting this level. Most playgrounds were categorised as having either 'low' or, for two schools, the 'no' SPB design category.

Chapter 6 integrates the findings from the methodology development, the evaluation of existing school playgrounds and the literature review to address the research questions and discusses the significance of the findings in terms of the methodological and substantive contributions to playground design and planning for improved sun protection behaviour in the context of long-term protection of children from the risks of sun overexposure.

Chapter 6

Discussion and Implications

Chapter 5 presented the findings from the evaluation of six selected Christchurch school playgrounds with the outcomes analysed over three levels. In Chapter 6, the key findings of this thesis, their significance and the contribution of this study to theory, methodology and design practice are discussed. Section 6.1 provides an overview of the research questions, summarises the key findings, the determinants influencing the observed outcomes and outlines the study's two significant contributions. Section 6.2 discusses the significance of developing the methodology and outlines its contributions. Section 6.3 presents the implications of the methodology for improved sun protection behaviour (SPB) design and planning of school playgrounds. Section 6.4 discusses the significance of the findings from evaluating existing school playgrounds and their substantive contributions to the theory on school playground design for promoting improved SPB among children.

6.1 Overview

This study investigated the potential of school playground design to promote SPB among children by integrating three critical SPB design objectives: UVR protection, microclimatic comfort and attractiveness. The role of school playground design in shaping healthy SPB required a spatially explicit, evidence-based approach that integrates multiple interdependent variables, examines how landscape characteristics influence SPB, and identifies the key factors contributing to optimal design outcomes. The study generated several key findings presented in **Table 6.1**. The table provides an overview of the sections that follow.

Based on the findings, this chapter addresses the **two significant contributions** made by the study. First, there is the development of the research framework, design and methods for a novel evidence-based SPB-D methodology (Chapter 3), tested and refined through its application to a pilot study school (Chapter 4), which resulted in a methodological contribution for effective evidence-based evaluation and design of school playgrounds to support SPB. Secondly, the evaluation of six Christchurch primary school playgrounds (Chapter 5) provided critical insights into the contribution of specific objectives towards achieving optimal SPB design, the effectiveness of AZs and overall school playgrounds in promoting SPB and their key contributing factors. These findings make a substantive contribution to existing theoretical knowledge on school playground design and planning in support of SPB among children.

Table 6.1: A summary of the study's research questions, key findings and the determinants influencing the outcomes

Research question	Key finding	Key determinants influencing outcomes
Main research question: What is the role of existing primary school playground designs in promoting sufficient SPB among young children?		
Sub-question 1: What new evidence-based methodology would improve the evaluation and design of school playgrounds in support of sun protection behaviour among children?	The novel sun protection behaviour design (SPB-D) methodology	Adoption of the landscape units' approach as the theoretical framework and the integration of multiple methods
		Spatial boundary definition of activity zones defining the analysis units
		Output at three spatial scales: • Landscape units' (LUs) • Activity zones (AZs) • Whole school playground
Sub-question 2: To what extent do individual activity zones support specific sun protection behaviour design objectives?	Only a very small proportion of activity zones met the ultraviolet radiation protection objective	• Availability of shade influenced by type, size, functionality of activity zones and shade type and design
	Most activity zones did not meet the microclimatic comfort objective	• Availability of shade influenced by type, size and functionality of activity zones • Combined effects of metabolic activity levels and wind-shade cover of activity zones
	A substantial proportion of activity zones met attractive play opportunities	• Availability of attractors influenced by activity zone type
Sub-question 3: To what extent do individual activity zones support overall sun protection behaviour (SPB) design?	Over half of activity zones met 'low' SPB design requirements, i.e., met one objective	• Attractive play opportunities were prioritised most strongly; microclimatic comfort was least considered in the design of activity zones
	One-third of activity zones met 'no' SPB design criterion, so not meeting any of the three objectives	• Activity zone types designed to support structured sports and unprogrammed areas
Sub-question 4: To what extent do overall school playground designs support sun protection behaviour among children?	One-third of school playgrounds achieved only 'low' SPB design; two-thirds were classified as having 'no' SPB design	• Typical design and spatial organisation of activity zones in school playgrounds • Availability and placement of shade

Table 6.2: An evaluation of the proposed sun protection behaviour design methodology and associated methods against the criteria for an effective evidence-based design methodology

Methods/tools Used	Integrated assessment			Presentation of spatially explicit findings	Incorporating user-friendly tools and techniques			Producing substantial evidence	Suitability at site-scale application
	Obj 1	Obj 2	Obj 3		Time-efficient	Cost-effective	Simple		
Shade simulation using SketchUp 3D modelling software	✓	✓	✗	✓	✓	✓	✓	✓	✓
Shade protection factor estimation using numerical calculation	✓	✗	✗	✗	✓	✓	✓	✓	✓
Empirical wind modelling	✗	✓	✗	✓	✓	✓	✓	✓	✓
Field observation	✓	✓	✓	✓	✗	✓	✓	✓	✓
Integrated – The proposed sun protection behaviour design (SPB-D) methodology	✓			✓	✗			✓	✓

* In the table:

Obj 1 – UVR protection

Obj 2 – Microclimatic comfort

Obj 3 – Attractive play opportunity

✓ – meets the requirement

✗ – does not meet the requirement

6.2 The methodological contribution to school playground design and planning in support of sun protection behaviour (SPB)

Landscape studies suggest that addressing complex socio-environmental challenges requires the integration of both scientific evidence and practical design solutions (Deming & Swaffield, 2011). Well-designed, evidence-based interventions, when systematically applied, can reduce environmental health risks (Li et al., 2023; Lin et al., 2022; Vanos, 2015) and support positive behavioural outcomes. Valid, reliable, objective methodologies that are simple and cost-effective enough to implement, must emerge to realise the full potential of evidence-based landscape architecture (EBLA) (Brown & Corry, 2011; Lenzholzer & Brown, 2013).

An effective evidence-based design (EBD) methodology usually meets four key objectives. It needs to: (1) allow the integration of multiple interdependent variables (Bherwani et al., 2020); (2) support a transparent, flexible, iterative process (Cortês & Lenzholzer, 2022; Lin et al., 2022), enable EBD decision-making; (3) facilitate clear, effective communication (Klemm, van Hove, et al., 2017; Lin et al., 2022) across disciplines and with stakeholders to enhance decision-making; and (4) incorporate user-friendly tools and techniques (Bherwani et al., 2020) for data collection, synthesis and analysis, leading to improved outcomes.

The review of existing methodologies (Chapter 2, Section 2.7) indicated that none fully met the requirements, highlighting the need for a novel approach. To address this methodological gap, this study integrates the strengths of existing methods and contributes to the development of a novel methodology that meets the EBD objectives as summarised in Table 6.2. The proposed SPB-D methodology contributes to: (1) enabling spatial analysis and quantification of complex design factors; (2) the generation of outputs at three spatial scales; (3) supporting consistent, valid comparisons through well-defined activity zones; and (4) allowing a transparent, flexible iterative process.

6.2.1 Enabling spatial analysis and the quantification of complex design factors

The proposed SPB-D methodology contributes a spatially explicit framework for analysing and quantifying complex, interdependent design factors influencing SPB outcomes. Pre-existing approaches often neglect the integration of multiple variables (Bherwani et al., 2020) and lack spatial analysis (Willemsen et al., 2008), thereby limiting their usefulness for targeted intervention. To address this limitation, the methodology, grounded in the landscape units (LUs) approach, provides a framework for systematically integrating and spatially mapping multiple interdependent variables. As noted by Brown (2008), the LUs approach offers a structured means of synthesising complex information into clear, concise, spatially explicit outputs. It identifies activity zones (AZs) that do not

meet the specific objectives and overall SPB design and specifies critical design variables (CDVs) contributing to these deficiencies.

Traditionally, the LUs approach has been applied to broader, large-scale landscape assessment, this study tested its effectiveness at site scale. The LUs approach developed by Hills (1974) was originally used in landscape planning to find optimal locations for different uses of the landscape. This study demonstrates its potential as an analytical framework beyond conventional landscape planning applications to address complex, spatially dependent design challenges.

The methodology proposes techniques to measure and translate diverse information forms into spatially explicit data by integrating multiple methods. For example, shade simulation using SketchUp modelling software was used to develop shade patterns to identify and map areas with and without shade. Using numerical shade protection factors supported the estimation of protection factor (PF) ratings, enabling the mapping of shaded areas with and without the required PF. Similarly, an empirical wind modelling method was used to develop site-specific wind patterns. The selection of these methods prioritised easy access and usability, ensuring that the methodology could be applied by a range of users. Though the incorporation of user-friendly tools may involve some limitations in the validity and reliability of the findings, the methodology offers a pragmatic balance between robustness and applicability, enhancing its potential for widespread adoption beyond academia.

Finally, the adoption of the critical component design (CCD) approach contributed to managing design complexity and minimising the risk of unintended outcomes. As outlined by Brown (2010), the CCD approach focuses on identifying the key elements, or characteristics, necessary to achieve positive outcomes. In this study, CCDs were defined as CDVs influencing specific SPB objectives. By concentrating on these CDVs, the methodology streamlined the complex process of measuring and mapping multiple variables influencing the SPB objectives, which would otherwise be difficult to map comprehensively. The principles of the CCD approach were subsequently applied in Step 5 of the methodology to inform adaptive design strategies through the three R's, which enabled the prioritisation of zones for phased long-term implementation.

In summary, the combined adoption of the LUs and CCD approaches together with the integration of multiple methods for measuring and mapping CDVs contributed to robust spatial analysis and effective integration of complex, interdependent design factors.

6.2.2 Generating outputs at three spatial scales

Studies have increasingly pointed to the need to shift the focus from the whole school playground to AZs in them (Anthamatten, Brink, et al., 2014; Anthamatten, Fiene, et al., 2014) because children's choices and behaviour are strongly shaped by the AZs' characteristics (Anthamatten, Brink, et al.,

2014). This limitation is partly because of a lack of methodologies capable of incorporating appropriate, scalable measurement units (Anthamatten, Fiene, et al., 2014). In this study, integrating the analysis at three spatial scales: landscape units, activity zones and school playgrounds, has helped address the gap. Focusing on both the finer details at the LU and AZ levels has contributed to identifying 'where' the problem exists (identifying the AZ), 'what' specific landscape component contributed to the problem (identifying the LU) and, finally, identifying how the overall school playground functions as an interconnected system.

6.2.3 Supporting consistent, valid comparisons through well-defined activity zones

Previous school playground studies highlight the importance of selecting appropriate analysis spatial units to enable consistent, valid comparisons (Anthamatten, Brink, et al., 2014) and to support the generalisability of findings. However, a critical review of the literature indicated that most playground research relies on broad or arbitrary definitions of AZs (Lucas & Dymont, 2010; Potente et al., 2011), raising concerns about boundary effects such as the modifiable real unit problem (Anthamatten, Brink, et al., 2014). This study addresses the gap by introducing explicit definitions and boundary rules for different AZ types, representing a critical advance in establishing robust units of analysis for evaluation. In Step 1 of the methodology, AZs are identified and classified as structured and unstructured, with clearly defined spatial boundaries and delineation rules for each AZ type. The use of well-defined analysis units enabled consistent evaluation of different AZ types and reduced bias, thereby strengthening the validity of the findings. Importantly, a comparison of AZ types in and across schools supports the development of standardised guidelines adaptable to diverse contexts.

6.2.4 Allowing a transparent, flexible iterative process

There is growing recognition of the need for transparent, flexible evaluation processes to support the EBD (Bherwani et al., 2020; Lin et al., 2022). Though an EBLA framework (Li et al., 2023) demonstrates how evidence can be incorporated at various stages of the design process, its focus has been limited to microclimatic factors. Building on the principles of the EBLA framework, the proposed SPB-D methodology extends the framework by integrating three SPB design objectives in a more comprehensive, iterative process.

The proposed methodology incorporates evidence across three stages: before, during and after design. In the 'before' (research) phase of design, the methodology provides a structured, systematic approach to inventory and analysis of baseline conditions against defined spatial targets. Consistent with the EBLA framework (Li et al., 2023), the primary objective of this phase is to establish fundamental knowledge and evidence related to the design problem. During the design phase, the

methodology supports iterative testing and continuous refinement, enabling measurable improvements in SPB design outcomes. This iteration facilitates design optimisation and is considered a core aspect of the EBLA framework (Li et al., 2023). In the post-design phase, the methodology evaluates 'where' and 'which' SPB design objectives have been met and identifies opportunities for further improvement. At this stage, the current methodology relies on modelling and projection techniques. However, it is important to acknowledge that modelling alone may be insufficient to fully assess the effectiveness of specific design solutions. This limitation highlights the need for more rigorous field-based monitoring methods to validate and refine design outcomes. By systematically incorporating evidence across all three design stages, the proposed methodology advances the EBD process by delivering transparent, reliable and replicable outcomes.

6.3 The implications of the sun protection behaviour design methodology for improved designing and planning

The outputs of the SPB-D methodology enhance our understanding of how different landscape characteristics, AZs, and school playgrounds influence SPB among children, aiding in playground design and planning for improved SPB. They support designers, planners and policymakers involved in sun protection planning for primary school children by: (1) informing healthy playground design through a multi-scale approach; (2) enabling the development of targeted intervention and efficient resource allocation; (3) supporting informed, evidence-based decision-making and fostering clear communication for effective collaboration; and (4) the broader applicability advances the theoretical and methodological understanding of school playground design and planning.

6.3.1 Informing healthy playground design

The outputs generated at three spatial scales: LUs, AZs and school playgrounds, provide a deeper understanding of how design elements interact. This multi-scale approach pinpoints 'where' problems occur (AZs), 'what' components contribute to the problem (LUs), and 'how' the overall playground functions as an interconnected whole. The approach supports cross-case analysis both within and between schools to allow the determination of patterns, themes and relationships (Yin, 2018). For example, comparing AZs in individual schools and across multiple schools helped determine AZ type, size and location, thereby influencing their effectiveness in meeting optimal SPB design criteria. Together, these insights help identify barriers and enablers and guide best practice and design guidelines to improve overall playground functionality, usability and sun protection. This ensures that children remain adequately protected, comfortable and engaged, regardless of where they choose to play in the school playground. Ultimately, this approach bridges a critical gap in understanding children's playground behaviour and demonstrates how this knowledge could inform healthy playground design (Anthamatten, Brink, et al., 2014; Dymont & O'Connell, 2013).

6.3.2 Enabling the development of targeted intervention and efficient resource allocation

To date, research on children's playground design and sun protection has largely focused on the playground as a whole (Anthamatten, Fiene, et al., 2014). However, designing and implementing intervention at this scale is challenging, resource-intensive and less effective in achieving the desired outcomes (Anthamatten, Fiene, et al., 2014; Rutkauskaite et al., 2021). This 'blanket approach', typically involving setting uniform shade targets across an entire school playground, can result in unrealistic goals that are often difficult for schools to meet. Moreover, the costs associated with implementation and maintenance have consistently been identified as key barriers to the adoption of sun protection measures in a school setting (McNoe et al., 2018). With limited resources, school authorities require a more tailored approach that enables efficient prioritisation and allocation of resources to achieve optimal outcomes. By identifying adaptive design strategies and prioritising critical AZs, the proposed SPB-D methodology directly addresses these challenges. Evaluating the effectiveness of individual AZs provides greater understanding, which enables planners, designers and policymakers to develop interventions and policies tailored to the specific needs of different AZ types. This targeted approach supports more efficient resource allocation, maximises outcomes, and overcomes the limitations of a generalised, whole playground approach, ultimately supporting the long-term success of optimal SPB outcomes.

6.3.3 Supporting informed decision-making and collaboration

Spatially characterising the landscape in terms of SPB design objectives adds a critical dimension to the study of school playgrounds, particularly when addressing such complex socio-environmental design challenges. Many existing approaches to landscape quantification often lack a spatial component (Willemen et al., 2008), underscoring the importance of presenting results in a clear, easy-to-understand format (Lin et al., 2022). Although mapping and evaluation techniques are well recognised for their effectiveness in producing spatially explicit findings and facilitating EBD design, they often remain underused in practice because of a lack of appropriate, user-friendly tools (Lin & Brown, 2021; Lin et al., 2022). This study presents a methodological advancement by developing systematic techniques to map and measure landscape characteristics in terms of SPB design. By providing a visual, quantifiable framework, the methodology supports practitioners and designers in making EBD decisions and establishing a common language that facilitates communication and collaboration among diverse stakeholders. The reliability and replicability of the methodology support designers in overcoming barriers in the EBD process, thereby enhancing the practical application of spatial analysis in the SPB design of school playgrounds.

6.3.4 Advancing theoretical and methodological understanding

The proposed methodology is applicable to both existing playgrounds requiring retrofitting and new designs. In practice, designers may be engaged to modify or design individual AZs rather than undertake entire playground redevelopment. By operating across three spatial scales, the methodology responds to this need, thereby enhancing its flexibility and adaptability to practical application.

Although the methodology was developed and tested in New Zealand, its core framework, the integration and simultaneous evaluation of three SPB design objectives (UVR protection, microclimatic comfort and attractive play opportunities), is considered critical for promoting SPB among children, irrespective of geographic or climatic context. The methodology provides guidance for climate-specific measurement and evaluation, positioning it as highly adaptable and universally applicable across diverse climatic and geographical settings without compromising its underlying structural framework.

Though the empirical findings are grounded in specific case studies, the methodology is based on well-defined spatial units, AZs and their types, allowing its extension beyond school playgrounds to other outdoor environments where spatial planning and sun protection are essential. These include public parks, childcare centres and urban play spaces, where similar interactions between activity patterns, spatial organisation and sun exposure occur. The methodology strengthens the evidence base for playground and broader children's outdoor environmental design by translating environmental and spatial data into actionable design decisions.

In summary, by providing a standardised, spatially explicit framework grounded in well-defined AZs and adaptable climate-specific measurement rules that enable consistent evaluation of SPB design objectives, the methodology advances both theoretical and methodological understanding in school playground and children's other outdoor environmental design.

6.4 The substantive contribution to existing knowledge on the role of school playground designs in promoting sun protection behaviour among children

The primary aim of this study was to investigate how school playground designs can promote sufficient SPB among children. Before this study, no studies had integrated the three critical SPB objectives in assessing school playgrounds, nor had examined the specific role of individual AZs and overall school playground design in supporting SPB. Addressing this gap, the study applies newly developed SPB-D methodology to evaluate existing school playgrounds. The findings in Chapter 5 advance understanding of the overall effectiveness of school playground designs in supporting SPB

by providing insights into: (1) how individual AZs contribute to meeting specific SPB objectives; (2) how individual AZs meet SPB design; and (3) how AZs combine in school playgrounds to achieve effective SPB design.

6.4.1 Individual activity zones contributing to meeting specific sun protection behaviour objective

The evaluation of AZs against the specific SPB design objectives (UVR protection, microclimatic comfort and attractiveness) reveals that a substantial proportion achieved the attractiveness objective (58%, n=53 of 91). In contrast, only a small proportion met the UVR protection objective (7%, n=7 of 91), and microclimatic comfort was achieved by only one AZ. These findings highlight a clear imbalance and overall inadequacy in the extent to which AZs meet specific SPB design objectives. They suggest that AZs predominantly prioritise attractive play opportunities over UVR protection and microclimatic comfort. The key factors contributing to whether AZs meet or do not meet each SPB objective are now discussed.

Key contributing factors influencing activity zones meeting/not-meeting the attractiveness objective

The findings indicated that 72% (n=38) of AZs belonging to the structured category and 28% (n=15) belonging to the unstructured category achieve the attractiveness objective. This indicates that the structured AZ category, compared with unstructured AZs, is a key contributing factor influencing overall effectiveness in meeting the objective. The findings suggest that children are more likely to use structured zones more frequently than unstructured zones because of the greater range of play opportunities they offer. For example, fixed play equipment areas, sand pits, paint marked areas and bicycle motor cross (BMX) track areas in the structured zones predominantly achieve a 'high' attractiveness rating. This is because these AZs were designed with a set purpose and are equipped with built-in play features, such as sand, fixed play equipment or paint markings, that provide sufficient play opportunities and encourage frequent use by children. This finding supports the idea that incorporating manufactured or built-in play features is significant for greater utilisation of zones through increased play among children (Anthamatten, Brink, et al., 2014; Dymont & O'Connell, 2013; Verstraete et al., 2006).

In the structured zone category, however, the AZs used for organised sports/games (e.g., sports pitches, hard-court areas) and those designated for other activities such as sitting, resting and gathering, often failed to achieve the attractiveness objective because of a lack of needed play features. For example, in the study schools, most sports pitches and approximately 50% of hard-court areas used for organised sports lacked loose sporting equipment (e.g., balls, markers). Similarly, an outdoor amphitheatre (OAT) and covered outdoor learning areas lacked loose play

equipment (e.g., bikes, scooters, crates), resulting in low attractiveness and less frequent use by children. This is supported by broader research that indicates that, although structured zones are designed to serve important school activities and programmes, they are often not effectively used by children (Anthamatten, Brink, et al., 2014). Without stimulation for play, these spaces tend to be less appealing (Chancellor, 2013; Lucas & Dymment, 2010) to children.

Conversely, most unstructured AZs failed to meet the attractiveness objective. For example, in the study schools, grassed areas, classroom verandas and green areas generally lacked the necessary loose play equipment or the required attractor to promote play, resulting in less frequent use by children. These findings support previous studies by Dymment et al. (2009) and Anthamatten, Brink, et al. (2014) that 'unprogrammed' AZs, such as grassed areas, often lack natural loose parts (e.g., rocks, sticks, boulders) or play equipment, leading to reduced play opportunities, thus making these zones less attractive to children. However, a small proportion of unstructured zones achieved a 'high' attractiveness rating. For example, hard paved areas (n=6) were predominantly equipped with loose, movable play equipment (e.g., bikes, scooters, rollers) that support play opportunities. This aligns with previous findings that well-equipped, unstructured hard-surface zones promote high intensity and greater variety of play activities among children (Dymment & O'Connell, 2013; Rutkauskaite et al., 2021).

Overall, the findings demonstrate that the presence and type of a play attractor, particularly built-in or loose play features, are more influential in determining whether an AZ meets the attractiveness objective. Structured zones were generally more effective because of their purposeful design and inclusion of manufactured play elements. However, structured zones lacking play stimulation were no more attractive than unstructured ones. Conversely, most unstructured zones were less effective because of insufficient attractors, those equipped with loose, movable play equipment achieved high attractiveness, highlighting that the provision of appropriate play features is critical to supporting frequent use and diverse play across all AZs.

Key contributing factors influencing activity zones meeting/not-meeting the ultraviolet radiation protection objective

The results show that only a small proportion of AZs (35%, n=32) achieved the criterion for 'moderate' to 'adequate' UVR protection, characterised by 'partial' to 'complete' shade cover. In contrast, most AZs (65%, n=59) met the 'low UVR' protection criterion and were predominantly unshaded. This indicates that most AZs offered only minimal UVR protection, suggesting that children using these zones are highly exposed to both direct and indirect UVR. Despite differences in methodology, comparison with a previous New Zealand study that examined 472 activity areas across 50 playgrounds in Wellington (Gage, Robinson, et al., 2018) reveals similar findings. The

proportion of unshaded activity areas was similar in both studies (67% for Gage, Robinson, et al. (2018) versus 65% in this study). The findings are also consistent with international studies that report that most activity areas had no shade cover (Anderson et al., 2014; Cimino et al., 2022).

A substantial proportion of AZs (29%, n=26) were identified as 'critical'. They include sand-pits (n=6), paint marked areas (n=3), hard-court areas (n=11), hard-paved areas (n=4) and BMX tracks (n=2). These zones were characterised by no shade cover and the presence of high UV reflective ground surfaces (e.g., sand, concrete, asphalt), contributing to high direct and reflected UVR. The literature indicates that the characteristics of school play environments (Downs et al., 2008) and particularly the UV albedo of ground surfaces, as important determinants of total UV exposure (Downs et al., 2008; Holman et al., 2018; Schneider et al., 2020), especially in open environments where protective shading is absent (Mackay, 2016). The influence of ground surface UV reflectance is particularly pronounced during summer lunch breaks, when the sun is at a high solar elevation and unshaded, high albedo ground surfaces reflect greater amounts of UVR, thereby increasing ambient UV exposure (Turner & Parisi, 2018). Studies have shown that an increase in surface UV albedo from 0.1 to 0.7 corresponds to an increase in UV intensity from approximately 3% to 39% (Turner & Parisi, 2018). As a result, individuals spending time in high UV environments such as beaches, sand pits and other open, reflective settings are subjected to substantially higher total UV exposure (Greenwood et al., 2000; Holman et al., 2018). In line with these findings, the study's results indicate that children using these 'critical' zones may experience elevated UV exposure because of the combined effects of direct and reflected UVR, increasing the risk of serious short- and long-term health problems (Downs et al., 2008; Schneider et al., 2020). This emphasises the importance of ground surface material selection in AZs as a key design consideration to reduce UVR exposure and protect children (Cherian & Subasinghe, 2023; Cimino et al., 2022; Schneider et al., 2020).

The results also show that the availability of shade, expressed in terms of shade quantity (determined by the proportion of shade), is influenced by the size and type of AZs and shade quality (determined by the shade PF) is influenced by the type and design of the shade provided. Together, these factors determine the extent to which AZs meet the effectiveness criteria for UVR protection. The two key contributing factors: (1) the size and type of the AZs; and (2) the shade type and design, are discussed in detail in the following sections.

The size and types of activity zones

The study's findings show that shade quantity, measured by the proportion of shade cover in AZs, is strongly influenced by the size and type of AZs that, in turn, determine the potential of AZs to achieve varying levels of UVR protection. In the study schools, predominantly small-sized AZs (e.g., classroom verandas, covered outdoor learning areas, green areas) range from 50 m² to 150 m² and

achieve 'adequate' UVR protection (85%, n=6 of 7). This aligns with previous studies that report that defined activity areas such as seating and eating areas in large playgrounds tend to have relatively higher mean shade coverage (Gage, Robinson, et al., 2018; Schneider et al., 2020).

Medium-sized zones (e.g., fixed play equipment areas, outdoor amphitheatres), ranging from 150 m² to 700 m², most commonly achieved 'moderate' UVR protection (52%, n=13 of 25). In contrast, large-sized zones (e.g., sports pitches, hard-court areas, hard paved areas, grassed areas, BMX tracks), ranging from 2,000 m² to 12, 000 m², were predominantly unshaded and consistently provided 'low' UVR protection (47%, n=28 of 59). These findings are well-supported by existing shade guidelines that indicate that providing effective shade coverage is more feasible for smaller, well-defined areas than for large, open activity areas (Greenwood et al., 2000; TCPC, 2010). Large zones typically demand greater shade coverage and are more likely to remain unshaded because of the scale, cost and functional constraints (TCPC, 2010). Furthermore, AZs in which users are typically in motion, such as sports pitches, hard-courts and hard paved areas, present inherent challenges in providing adequate shade cover without interfering with the play (TCPC, 2010).

It is important to note that direct comparison with existing studies is limited because of differences in the methodology and a lack of studies that spatially define AZs. In this context, the study's findings provide clear evidence that AZ size and type are critical design determinants to optimise UVR protection. The results also highlight the need for innovative solutions or alternative strategies to achieve optimal UVR protection in zones that present special design challenges.

Shade type and design

Shade type and design strongly influence shade quality, measured by the shade PF ratings offered by the shaded areas and, therefore, determine the effectiveness of AZs in meeting 'adequate' UVR protection. In the study schools, AZs with built shade (e.g., classroom verandas, covered outdoor learning areas) most frequently achieved 'adequate' UVR protection (57%, n=4 of 7). These zones were characterised by both greater shade cover and better shade quality (i.e., shaded areas with PF > 6), offering sufficient protection from both direct and indirect UVR and supporting activities of at least one hour duration. Key design features contributing to these higher PF ratings include the use of solid shade materials (e.g., polycarbonate sheet, metal, timber) with low UV transmittance (Greenwood et al., 2000) and structures with lower sky view factor (SVF) (see [Appendix](#) for details). These findings are consistent with Gies and Mackay (2004), who note that permanent built shade structures offer high levels of protection (97-99%) and greater shade cover (i.e., 74% shade cover by built versus 49% by natural), highlighting their suitability as cost-effective solutions for AZs used by large groups for prolonged periods.

Conversely, semi-permanent built shade types (e.g., shade sails) commonly seen over fixed play equipment areas (n=6), sands (n=3) and an outdoor amphitheatre (n=1), predominantly result in AZs meeting 'moderate' UVR protection levels (40%, n=10 of 25). The widespread use of shade cloth with high SVF and high UV transmittance contributed to lower PF ratings ($PF < 6$), indicating increased exposure to diffuse UVR. As a result, these AZs cannot provide sufficient protection for extended use (e.g., one hour during critical protection time), requiring users to rely on additional personal protection measures. Similar findings were reported by Gies and Mackay (2004) who note that shade cloth is commonly used in schools over play equipment areas, sand pits and court areas because of its affordability, capacity to cover large areas and accommodate many children, despite providing lower protection (in the range of 47–95%). This demonstrates that the prevalent use of shade cloth is because of its affordability (Gies & Mackay, 2004). This emphasises the need to combine it with other sun-safety strategies to ensure children are adequately protected when using these zones.

Finally, natural shade, primarily provided by trees, was most frequently observed over green areas (n=9) and grassed areas (n=1) and provided varying levels of shade coverage and PF rating. In three of nine green areas, the presence of multiple, dense canopy trees planted closely significantly reduced the SVF, resulting in both greater shade coverage and higher PF ratings that enabled these zones to achieve 'adequate' UVR protection. The remaining zones showed considerable variability because of differences in tree number, canopy size, density and spacing, which affect their overall capacity to reduce both direct and indirect UVR exposure. These findings align with a previous study highlighting the importance of established tree cover and the marked differences in shade availability between schools with and without mature vegetation (Gies & Mackay, 2004).

Overall, the evaluation of the UVR protection objective demonstrates that most AZs provide insufficient UVR protection, with nearly two-thirds remaining unshaded and a substantial proportion classified as 'critical' because of the combined effects of no shade and high UV reflective ground surfaces. AZ size, type and function strongly influence the availability of shade cover, whereas shade type and design affect the shade PF that, together, determine the overall effectiveness of AZs in meeting the required level of UVR protection. In other words, smaller, well-defined AZs with permanent built shade were most effective, whereas semi-permanent and natural shade resulted in more variable UVR protection levels. These findings highlight the importance of integrated shade and AZ design, supported by additional sun protection strategies to reduce children's total UV exposure in AZs.

Key contributing factors influencing activity zones meeting/not-meeting microclimatic comfort objective

One of the key findings is that, of 91 AZs assessed, only one achieved the criteria for ‘adequate’ microclimatic comfort, i.e., no zone provided sufficient thermal comfort for children, particularly during the CPT. As a result, when children use these zones, they are exposed to increased thermal risk, including thermal burns (Harrington et al., 1995) and heat-related stress or illness (Armstrong et al., 2007). These findings align with previous studies characterising school playgrounds as ‘schoolyard heat islands’ (Antoniadis et al., 2018; Antoniadis et al., 2016), with most areas of school playgrounds being thermally uncomfortable and potentially unsafe for children (Cheng, 2020).

Most AZs classified as hosting vigorous to moderate metabolic activity levels (88%, n=80 out of 91) were characterised by low shade cover and high wind cover, conditions that increase heat stress and contribute to meeting the ‘low’ microclimatic comfort level. For example, sports pitches (n=5), hard-court areas (n=6), fixed play equipment areas (n=12), paint marked areas (n=3) and BMX Tracks (n=2) had low mean shade cover (19.84%), and high wind-shade cover (80.49%). In addition, because of the prevalent use of ground surfaces with high thermal properties (e.g., concrete, asphalt), AZs such as hard-court areas, sand pits, paint marked areas and hard paved areas were identified as ‘critical’ zones. Children using these zones not only experience poor thermal comfort but may also be exposed to increased surface heating, increasing the risk of thermal burns when exposed to direct solar radiation (Vanos et al., 2017).

A smaller proportion of AZs were classified as having a low metabolic activity level (12%, n=11 of 91) and were of ‘low’ microclimatic comfort despite having adequate shade cover, primarily because of high wind exposure that contributed to heat loss. For example, the covered outdoor learning area (COLA) in School B had complete shade cover, but was fully exposed to wind, resulting in a low microclimatic comfort level. This is significant, given the study context of Christchurch, where relatively low ambient air temperatures (i.e., between 12°C and 25°C) combined with wind can cause cold stress even during summer (Perera, 2022), leading children using these zones to experience thermal discomfort (see [Chapter 3, Section 3.3](#) for details of Christchurch conditions).

In general, the findings indicate that shade availability, together with the combined effects of wind cover and metabolic activity level, were the primary determinants contributing to AZs failing to meet the required levels of microclimatic comfort.

Availability of shade cover

The findings reveal that shade availability is most critical in influencing a substantial proportion of AZs failing to achieve the criteria for ‘adequate’ microclimatic comfort. As noted previously, shade

availability was primarily influenced by AZ size, type and function. For example, only one AZ, COLA, had a high mean shade cover (93.6%), enabling it to meet adequate microclimatic comfort; most zones (n=56) had low mean shade cover, ranging from 0-35%. Although much of the literature on playground microclimate is from warmer climate zones, the studies consistently report that where children engage in daily physical activities, they have limited shade cover (either in full sun - < 2% or only partly shaded - 20-80%) that directly contributes to increased heat gain and reduced thermal comfort (Antoniadis et al., 2016; Cheng, 2020; Vanos et al., 2017). Consistent with these studies, the findings demonstrate that inadequate shade provision is a primary contributor to thermal discomfort across all climate zones.

The combined effects of wind-shade cover and metabolic activity rate in zones

Studies suggest that physical activity is an important predictor of children's outdoor thermal comfort and behaviour (Vanos et al., 2017). The study's findings indicate that most AZs were classified as vigorous to moderate activity (e.g., 87%, n=80 of 91) and predominantly wind-shaded (67% of zones with a mean wind-shade cover of 83%), primarily contributing to a higher proportion of zones not meeting the criteria for 'adequate' microclimatic comfort. This suggests that zones with high metabolic activity levels combined with high wind-shade coverage can result in increased energy budgets (lack of convective cooling), ultimately leading to reduced thermal comfort among children (Vanos et al., 2017). This finding supports previous studies that show reduced airflow worsens outdoor thermal comfort, decreasing outdoor recreational activity and amplifying the urban heat island effect (Antoniadis et al., 2016; Xu et al., 2022)

The findings also suggest that the wind environment design of Christchurch school playgrounds is adapted to the local climate to block cold winter winds. However, this can lead to thermal discomfort in summer, especially in zones designated for vigorous activity. Conversely, zones with low metabolic activity that remain exposed to wind may experience cold stress even in summer. This highlights the importance of considering unique regional characteristics, accounting for seasonal variation and adapting the design of the wind environment based on different activity levels in playground spaces (Xu et al., 2022).

6.4.2 Individual activity zones meeting sun protection behaviour design levels

The results indicated that most AZs were not designed to promote sufficient SPB among children because they provide insufficient UVR protection, increased thermal discomfort and limited play opportunities. Consequently, children using these zones during CPT are exposed to increased risk of excessive UVR exposure and its associated health impacts. For example, across the study schools, no AZ (100%, n=91) achieved a 'high' SPB design because none met all three SPB objectives simultaneously.

The effectiveness of AZs in meeting SPB design levels was determined by the number of SPB objectives met. Given that no AZ in the study schools achieved a 'high' SPB design (met all three SPB objectives) and only a very small proportion (2%, n=2 of 91) achieved a 'moderate' SPB design (met two objectives), there is insufficient evidence to clearly identify the factors contributing to AZs achieving higher SPB design levels. Therefore, this section focuses on interpreting the significance of the findings and examining the contributing factors associated with AZs that met 'low' and 'no' SPB design levels.

Key contributing factors influencing activity zones meeting 'low' sun protection behaviour design

The results demonstrate that the primary SPB design objective contributing to AZs meeting a 'low' SPB design was attractiveness, with UVR protection contributing to a lesser extent and microclimatic comfort having a negligible contribution. This suggests that most AZs were predominantly designed to offer attractive play opportunities while lacking adequate UVR protection and microclimatic comfort. For example, in the study schools, most structured zones with built-in play features (n=34) (e.g., sand pits, fixed play equipment, paint marked areas), and some unstructured zones (e.g., hard paved areas) provide sufficient play opportunities and contribute to meeting the attractiveness objective. However, these zones lacked adequate shade to meet the required UVR protection and microclimatic comfort objectives. Thus, though children frequently use these zones for play, they are left unprotected from direct and indirect UVR and may experience microclimatic discomfort during their time of use, thereby increasing their risk of excessive UVR exposure and associated health impacts. This finding is supported by Boldemann et al. (2006) who noted that children were attracted to swings because of their location in full sun, combined with their prolonged duration of stay, resulted in high UV exposure and an increased risk of sunburn.

UVR protection is the next influencing objective contributing to fewer zones meeting a 'low' SPB design. For example, in the study schools, a small number of structured zones (e.g., classroom verandas, n=3) predominantly met adequate UVR protection but failed to meet the microclimatic comfort and attractiveness objectives. This suggests that, although these zones provide adequate UVR protection, their lack of play opportunities and microclimatic discomfort reduce their appeal and frequency of use, resulting in the underuse of these well-protected areas. This aligns with observations by Mackay (2003b), who reports that many existing shaded areas in school playgrounds were not preferred play locations because of their poor microclimatic conditions and low appeal.

Building on these findings, it is evident that the design of AZs primarily prioritises the attractiveness objective. This reflects the literature, as noted by Pellegrini (1995) and Moore (1997), that 'traditional' school playgrounds typically allocate spaces for self-directed play through fixed play

equipment, sand features or painted markings. Such elements provide ample play opportunities and encourage frequent use by children (Chancellor, 2013), which explains the reason for a substantial proportion of AZs meeting the attractiveness objective. However, UVR protection, primarily determined by the availability of shade, is often perceived as a greater design challenge because of associated financial constraints (McNoe & Reeder, 2019). Studies indicate that schools operating under budget limitations tend to prioritise resource allocation toward installing prefabricated play equipment because of its high affordability (Chancellor, 2013). This helps to explain the widespread prevalence of play focused AZs in school playgrounds; zones are frequently implemented without concurrent investment in shade infrastructure, thereby leaving children inadequately protected from UVR exposure.

Microclimatic comfort emerged as the least prioritised objective in AZ design. This finding is supported by microclimatic studies showing that designers often face considerable challenges in integrating microclimatic considerations into landscape design for outdoor thermal comfort (Lin & Brown, 2021; Lin et al., 2022). As noted in previous studies, these challenges largely arise from the inherent complexity of microclimatic processes, a lack of user-friendly assessment tools, and the absence of clear, best-practice guidelines to support the effective understanding and implementation of microclimatically comfortable designs (Cortezão & Lenzholzer, 2022).

Another possible explanation for the low prioritisation of microclimatic comfort is the role of climate zones in shaping perceptions of outdoor thermal comfort. The study context, Christchurch, located in a temperate oceanic climatic zone (Peel et al., 2007), is widely considered adaptive (Tavares, 2015) and is often perceived as thermally comfortable compared with more extreme climate zones, such as hot, arid or hot, humid tropical climates. This perception may partly explain the limited emphasis placed on outdoor thermal comfort in the design of outdoor areas in temperate climates, especially for Christchurch (Perera et al., 2021). However, Christchurch's unique, highly variable climate, characterised by cold, overcast south-westerly days and warm, or hot, north-westerly days (Tavares, 2015), calls for a more context-specific approach to designing thermally comfortable outdoor environments, rather than relying solely on generic international standards. The study findings highlight the urgent need to prioritise microclimatic comfort in the design of children's outdoor environments, especially because climate change is contributing to an increasing number of hot days, increasing the risk of overheated surfaces and heightened climate-related health risks for children (Vanos, 2015) across all climatic zones.

Key contributing factors influencing activity zones meeting 'no' sun protection behaviour design

Nearly one-third of AZs failed to meet all three SPB design objectives, resulting in a 'no' SPB design. This means that these zones were not attractive because of limited play opportunities or no adequate UVR protection or microclimatic comfort. For example, in the study schools, predominant unstructured zones (e.g., grassed areas) and structured zones (e.g., sports fields, hard-court areas) lacking necessary play features and shade contributed to this outcome. The findings suggest that school playgrounds largely comprised AZ types that are barren, hard and primarily designed to support structured sports while offering limited play opportunities for diverse play, resulting in lesser use (Anthamatten, Brink, et al., 2014) and increased solar UVR exposure and thermal discomfort. Studies suggest that AZ types such as sports fields and court-based areas (e.g., basketball courts), which serve important functions to school programmes are often not used effectively (Anthamatten, Brink, et al., 2014) and further areas adjoining them (e.g., grassed areas) are frequently 'unprogrammed' and lack equipment or play features, rendering them less stimulating and consequently less frequently used by children (Dyment & O'Connell, 2013).

Overall, the evaluation of individual AZs and their SPB design levels indicates that the high prevalence of AZs exhibiting only 'low' SPB design is largely because of a strong emphasis on play opportunities, with UVR protection and microclimatic comfort given less consideration. Microclimatic comfort is the least prioritised objective, highlighting the need for more developed and accessible tools (Lin & Brown, 2021; Lin et al., 2022) and clear design guidelines (Lin et al., 2022; Queensland University of Technology, 2021) to support the balanced integration of all three SPB design objectives. Many AZs classified as having 'no' SPB design, largely redundant and inadequately protected spaces, collectively highlight the need for innovative solutions and alternative approaches (Gage et al., 2022). Together with a broader reconsideration and refocusing of current approaches to AZ design.

6.4.3 School playgrounds contributing to achieving sun protection behaviour design

The results of evaluating the whole school playground and combining the findings of individual AZs indicate that primary school playgrounds in Christchurch are not effectively designed to support the necessary SPB among the children. Across the six study schools, no school playground met the criteria for effective SPB design. Thus, children using these playgrounds during CPT may have limited opportunities to engage in sufficient SPB, as protected areas do not consistently coincide with key AZs, potentially increasing exposure to harmful solar UVR. Though there are methodological differences, this finding is consistent with a previous study by Gage et al. (2017) that examined children's use of shaded areas and found that children were not sufficiently using the available shaded areas and were exposed to high UV levels during outdoor play.

Nearly one-third of sampled school playgrounds achieved only 'low' SPB design, indicating that, though children frequently use these zones in the school playground, they are not protected from UVR exposure and experience microclimatic discomfort during at least a portion of use time. In contrast, approximately two-thirds of the school playgrounds were classified as having 'no' SPB design because they failed to provide UVR protection, microclimatic comfort and adequate play opportunities. For example, in four of the study schools, AZs that primarily met the attractiveness objective covered approximately 20-40% of the total school playground area, whereas AZs that did not meet all three SPB objectives, covered approximately 60-70% of the playground area. This implies that a substantial portion of existing school playground area is not effectively used, but is left unprotected, placing children at increased risk of UVR exposure.

These outcomes reflect the typical design and spatial organisation of AZs in school playgrounds in Christchurch. They typically prioritise large sports fields for structured sports characterised by expansive, open grassed areas and hard-court areas for formal games. This observation aligns with Collins et al. (2006) who investigated primary schools in Auckland, New Zealand, and noted that the layout and design of school playgrounds in New Zealand was strongly shaped by cultural values that prioritise organised sports and formal games, contributing to ongoing challenges in integrating sun protection strategies into school playground design.

Another key observation relates to the limited availability and poor placement of shade in school playgrounds. Overall shade cover across the study schools was low (mean shade cover 14%) and was most commonly observed along the perimeter of the school property where it was not effectively used by the children. In contrast, high-use AZs, such as fixed play equipment areas and sand pits often situated adjacent to classrooms, were largely unshaded. As noted in previous studies, this spatial configuration may be influenced by safety, visibility and supervision requirements (Chancellor, 2013; Sandseter et al., 2020), which suggests that the placement of shaded areas and the layout of AZs are critical design considerations for promoting sufficient SPB among children. This is supported by a study that showed that main play areas where children often engage in play typically have significantly less shade and greater UVR exposure than the surrounding peripheral areas of playgrounds (Cimino et al., 2022).

Together, the findings suggest that playground design decisions tend to focus on the whole-school playground scale rather than on the spatial performance of individual AZs. This study has demonstrated that SPB outcomes are strongly shaped at the AZ scale. Achieving effective SPB design across school playgrounds therefore requires greater emphasis on the design, location and integration of AZs. This reinforces the importance of recognising the micro-geographies of school

playgrounds (Anthamatten, Fiene, et al., 2014; Collins et al., 2006) when designing for effective behavioural outcomes.

Overall, the findings reinforce the need to reconsider current approaches to school playground design and functional priorities (Dyment & O'Connell, 2013; Sandseter et al., 2020), which includes re-evaluating the type, size and spatial arrangement of AZs in the playground (Dyment & O'Connell, 2013) to maximise effective use of playground space while prioritising UVR protection and microclimatic comfort alongside play opportunities.

6.5 Summary

This chapter synthesised the study's key findings and discussed their significance in relation to both methodological and substantive contributions. First, it highlights the methodological contribution of the study by demonstrating how the SPB-D methodology supports more effective, evidence-based school playground design and planning, and outlines the implications for practitioners, planners and policymakers involved in sun protection planning for school playgrounds.

Second, the chapter discussed the study's substantive contributions to theory and demonstrates how the characteristics of activity zones influence whether specific SPB design objectives were met, which SPB design objectives most strongly contributed to effective SPB design at the activity zone level and, finally, how the spatial layout and organisation of activity zones affected the overall capacity of school playgrounds to support the required SPB among children.

Chapter 7 presents the study's conclusions, summarises the research questions, methods used, the study's limitations and suggests directions for future research.

Chapter 7

Conclusion

Chapter 6 highlighted the study's significance in terms of its contributions and implications for school playground design and planning to support sun protection behaviour (SPB). Chapter 7 presents the study's conclusions, summarises the research questions, and presents the study's limitations and recommendations. Section 7.1 presents the research questions and approaches adopted and summarises the key findings and their significance. Section 7.2 discusses the study's limitations and the proposed methodology. Section 7.3 outlines recommendations for future research aimed at addressing the identified limitations. Finally, Section 7.4 presents practical recommendations to maximise sun protection behaviour in school playgrounds to enhance the health and well-being of the children and associated adults.

7.1 A summary of the research objectives, approach and key contributions

The study's primary research question was to explore the role of school playground design in promoting sufficient sun protection behaviour (SPB) among primary school children (see [Chapter 1](#)). Recently, an increasing body of research has highlighted the importance of landscape design in addressing complex socioenvironmental problems (Deming & Swaffield, 2011), including the role of school playground design in protecting children from overexposure to harmful solar UVR through the promotion of SPB. Central to this challenge is the effective integration of three critical SPB design objectives: UVR protection, microclimatic comfort, and attractiveness.

To date, no previous studies have comprehensively integrated all three objectives in a single evaluation framework. Existing studies typically assessed school playgrounds with respect to individual objectives, limiting their ability to understand interactions and competing priorities among multiple interdependent design factors that collectively influence SPB outcomes. A review of current assessment methodologies identified methodological limitations, including the absence of robust, evidence-based approaches with clearly defined targets for measuring each SPB design objective.

The study's geographical location, Christchurch, is characterised by very high UVI levels and highly variable microclimatic conditions that strongly influence children's choice and use of protected areas (Gage, Barr, et al., 2018) in school playgrounds. These characteristics make Christchurch a particularly appropriate setting to investigate how school playground design can support SPB and to explore design-based strategies aimed at mitigating the long-term risks associated with excessive UV exposure among children. To address these challenges and answer the primary research question,

the study was guided by four sub-questions that were addressed through 10 research objectives (see Table 1.1).

The study was conducted in two stages (see Figure 3.1) using a combination of research methods. Stage 1 focused on developing a new, improved, evidence-based SPB-D methodology to address research objectives one to four. Adopting the landscape units' approach as the theoretical framework enabled the effective integration of multiple research methods, including shade simulation, shade protection factor estimation, empirical wind modelling, field observation and the critical component design (CCD) approach (see Chapter 3). The proposed SPB-D methodology was then tested and refined through its application to a pilot study school to ensure its practical applicability (see Chapter 4).

Stage 2 adopted a case study research design to evaluate six selected Christchurch school playgrounds, with the aim of exploring the potential of existing school playground design to promote sufficient SPB and address research questions five to ten. The newly developed SPB-D methodology was systematically applied (Steps 1 to 4), thus enabling a comprehensive evaluation of playground design at three spatial levels (see Chapter 5).

The study produced two key contributions (see Chapter 6). First, it advances methodology through the development of a new evidence-based SPB-D methodology to support the design and planning of school playgrounds. The proposed methodology is practical and applicable for both researchers and designers, by enabling the evaluation of both existing and newly developed designs and supporting informed, evidence-based decision-making to achieve optimal SPB outcomes. Second, the study makes a substantive contribution to theory by demonstrating that 'activity zone' is the key spatial scale in the design of school playgrounds, particularly to ensure children are adequately protected regardless of where they choose to play. The SPB outcomes are strongly shaped by the interaction of activity zone (AZ) type, size and function. Importantly, the SPB outcomes do not solely depend on individual design elements but are shaped by the broader spatial organisation and prioritisation of AZs in school playgrounds.

7.2 Limitations

Given the limited scope of previous research in the area, the underlying definition of SPB and the integration of the three SPB design objectives required to promote SPB were developed based on a critical review of the literature. Though other design or contextual objectives may also influence SPB, their identification and evaluation were beyond the scope of this study and require further research. The following sections outline the key limitations of this study and of its proposed methodology.

A key methodological limitation is the classification and spatial delineation of AZs that served as the primary analysis unit. Because of the absence of established definitions in the literature, the identification and mapping of AZs relied on observational data and generalisations from previous studies. Though this provided a systematic, structured approach, it may have influenced the results. To strengthen the validity and reliability of the methodology, further research is required to test and refine the AZ classification across a wider range of activity types, school contexts and environmental settings. Such work would support the development of more robust, transferable definitions, thereby strengthening the method's reliability and applicability.

The study's geographical scope was limited to Christchurch, and the proposed methodology was developed, applied and tested in this specific context. Although the proposed SPB-D methodology was developed for universal application, incorporating critical design components relevant across different climate zones, with guidelines provided where possible for adaptation to other climatic conditions, its empirical application beyond Christchurch was outside the study's scope.

Consistent with Te Tiriti o Waitangi, the study did not specifically examine cultural approaches to school playground design or evaluate design features and materials from the perspectives of Te Ao Māori or the diverse cultural backgrounds of tamariki. The study acknowledges that certain aspects of the methodology, particularly the construct of attractive play, are not culturally neutral. In this research, attractiveness was conceptualised in terms of play opportunities, informed by theories of environmental affordance and children's play behaviour. Accordingly, the literature reviewed and incorporated into the framework focused primarily on studies examining the relationship between environmental characteristics and play opportunities, rather than on culturally specific interpretations of play preferences. To enhance the framework's broader relevance, the assessment was based on activity zone types commonly found across the study schools, emphasising fundamental play opportunities that are likely to be shared across different school settings. Nevertheless, the study acknowledges that the existing literature examining school ground design, environmental affordances, and play opportunities across diverse cultural contexts remains limited.

While consideration of cultural perspectives and requirements is important and warrants further investigation, it goes beyond the scope of this study. The primary aim of the research was to investigate the three critical factors influencing school playground design and integrate them into a coherent framework. However, the study acknowledges that the framework represents an initial step rather than a comprehensive model. Further refinement could strengthen its responsiveness to cultural perspectives, including Te Ao Māori, as well as other contextual, community-specific, and place-based considerations relevant to school playground design and assessment.

Similarly, the proposed SPB-D methodology measures and maps shade and wind cover patterns at a single point in time, specifically the critical protection time (CPT) of each site, when children are exposed to the highest UVR levels and require maximum protection. This approach enables assessment during periods of greatest risk and helps provide adequate protection at other times of the day; however, it does not fully capture temporal and seasonal variability. While maximising shade is important for reducing summer UVR exposure, excessive shading may inadvertently restrict access to winter sunlight. In the New Zealand context, winter solar access is an important consideration, contributing to both thermal comfort and health benefits in school environments. Therefore, a balance is required between summer sun protection and winter solar access. Future research should evaluate the methodology under different temporal and seasonal conditions to enhance its validity, robustness, and applicability. Such work could support the development of seasonally responsive design recommendations that reflect New Zealand's unique climatic conditions, providing adequate shade during high-risk summer periods while maintaining beneficial solar access during winter.

Additionally, vitamin D requirements of children with higher melanin levels, which are particularly important at this latitude during winter were recognised as a relevant consideration given the cultural diversity of the child population. However, a detailed examination of these differing vitamin D needs was beyond the scope of this study. Future research should therefore test the framework across a wider range of geographical, climatic, and cultural settings to evaluate its transferability, adaptability, and broader applicability. Such research should also incorporate culturally diverse perspectives on play and attractiveness, alongside consideration of differing vitamin D requirements among different population groups, to further strengthen and extend the framework.

A further limitation of this study relates to the establishment of evaluation targets to measure specific SPB design objectives and the overall SPB design. Because of the limited availability and accessibility of relevant data in the literature, the evaluation targets used were based on a rationale derived from previous studies. Though this provided a systematic, theoretically informed basis for analysis, it may have introduced potential bias and could have resulted in an underestimation of effectiveness across the three spatial analysis scales. To improve the reliability, accuracy and validity of the methodology, future research should test and refine the targets using objective, empirical measurements. As noted in previous studies, limitations in evidence-based design processes are largely due to gaps in empirical research and the limited accessibility of relevant data (Bherwani et al., 2020; Cortesão & Lenzholzer, 2022). This situation calls for more comprehensive reporting and wider dissemination of research findings to support evidence-based design practice.

The SPB-D methodology integrates various techniques to produce spatially explicit, evidence-based results that support informed decision-making. However, several of these methods have inherent limitations. For example, empirical wind pattern tracing relies on external datasets that may affect the accuracy of results. More advanced wind modelling techniques, although more precise, may be constrained by their feasibility of use. Similarly, the evaluation of attractiveness was not based on direct behavioural observation. Instead, it was derived from literature generalisations regarding environmental affordances and children's play preferences. As such, the assessment represents a theoretically informed estimate rather than an empirically validated measure and may not fully capture children's actual behavioural responses. More precise data collection methods, such as systematic behavioural observation or GPS-based tracking, would enhance accuracy. In addition, UV reflection was assessed using ground surface albedo values without accounting for multiple reflections, limiting the ability to determine the cumulative effects of albedo on shade quality. These methodological choices were guided by the need to incorporate user-friendly tools that are accessible to a broad range of users. More accurate methods often require more sophisticated software/hardware, higher user skill levels, more data inputs and longer time periods (Muangsri et al., 2022), which may reduce their practicality and usability for design application.

Finally, although the methodology was developed to address the practitioners' needs, the process proved to be relatively time-intensive and methodologically complex. Though this level of detail supports robust analysis, further refinement is needed to streamline the process and improve usability. Future research should therefore focus on simplifying and optimising the methodology to enhance its practicality and accessibility for landscape practitioners and designers to achieve effective, optimal SPB design.

7.3 Future research

The study identifies three main areas of recommendation for future research. First, the exploration of the broader application of the SPB-D methodology and testing its adaptability and effectiveness would enhance the generalisability and transferability of findings to other settings and contexts. Second, developing a software-based application of the methodology could support SPB design optimisation and be a critical next step in advancing evidence-based design practice. Finally, investigating the enablers of and barriers to implementation would help address the practical challenges.

7.3.1 Exploring the broader applicability of the methodology

The methodology presents several opportunities for further expansion and broader application across diverse contexts and other complex environmental problems. As environmental challenges

become increasingly complex, the field of landscape design requires more robust methodologies capable of generating effective spatial solutions (Lin et al., 2022). This study demonstrates that the SPB-D methodology, through its spatially explicit framework and ability to generate outputs at three spatial scales, effectively supports informed design decision-making. Future research focused on refining specific aspects of the methodology could enhance its applicability and effectiveness.

Future research should focus on refining AZ definitions across school types (primary, intermediate and secondary schools), playground size and diverse cultural contexts to support the development of more standardised and transferable AZ typologies. Further application and testing of the methodology across different climate zones and incorporating temporal and seasonal variation would enhance the generalisability of the findings. Such research would contribute to a greater understanding of microclimatic influences on children's behaviour (Mårtensson et al., 2009), and support the development of more effective sun protection strategies that are responsive to seasonal and climatic conditions. It would also support the development of adaptive design approaches that balance seasonal trade-offs, maximising shade for summer sun protection while ensuring appropriate solar access and thermal comfort during winter.

Finally, future research is required to validate and refine the SPB evaluation targets through objective measurements and behavioural data, including comparisons between hypothesised targets and observed outcomes. This would contribute to the development of a shared, accessible evidence base for SPB design benchmarks, thereby strengthening evidence-based design in landscape practice.

7.3.2 Towards a software-based application for sun protection behaviour design optimisation

To address the implementation gap identified in landscape studies (Bherwani et al., 2020), this study sought to develop an evidence-based design methodology responsive to the practical needs of professionals involved in school playground design and planning. Though the methodology successfully met most criteria for an effective evidence-based design methodology, the integration of multiple design objectives such as UVR protection, thermal comfort, and attractive play opportunities resulted in a relatively complex evaluation process.

Future research should therefore focus on streamlining the methodology through the development and testing of digital or software-based tools. A crucial step in the methodology was measuring and mapping the critical design variables (CDVs) using site-specific spatial data that are often not readily available. The methodology showed that mapping was systematic and effective in visualising critical areas such as zones with high UV exposure and low thermal comfort. However, as the number of

CDVs increases, the complexity and difficulty of mapping also increases (Lin et al., 2022). This emphasises the need for digital tools capable of seamlessly integrating complex, often intangible variables that are otherwise difficult to accommodate in conventional design software such as AutoCAD or SketchUp (Lin et al., 2022). Enhancing the capacity to visualise and synthesise these complex interdependent variables is critical to bridging the research-practice-implementation gap (Lin et al., 2022).

In addition, future software-based tools could enhance data accuracy, enable real-time data integration, and automate assessment processes, such as calculating shade provision or estimating the proportional area of different landscape units. This would significantly improve efficiency, reduce the time and cost associated with manual assessment and support the generation of SPB design compliance reports aligned with safety and environmental standards. Such tools would also facilitate the development and comparison of multiple design scenarios, allowing practitioners to test and evaluate alternative design solutions more effectively.

Overall, the development of a software-based SPB design tool represents a critical next step in translating research into practice. By improving the usability for landscape designers, urban planners and school administrators, future research in this area could support more data-driven, efficient and effective playground design.

7.3.3 Identifying the enablers of and barriers to integrating sun protection behaviour in school playground design

The study demonstrates that school playgrounds in Christchurch are not designed to adequately support SPB among children and identifies several critical design attributes contributing to this shortfall. Previous studies suggest that school playgrounds are often designed with adult-centred priorities such as safety and surveillance (Chancellor, 2013). In addition, broader systemic barriers, including financial constraints, lack of awareness and limited policy support (Reeder et al., 2016), which may further influence playground design decisions and require further investigation. Accordingly, future research is needed to investigate the enablers and barriers to influencing the integration of SPB focused design in school playgrounds.

Future research involving school authorities and teachers would enhance our understanding of the broader functional needs of schools, such as the need to accommodate organised sports and games, ensuring safety and surveillance, and addressing maintenance requirements, and how these factors influence decisions in both AZs and overall playground design. Such insights are essential to be able to support schools in adopting more effective sun protection measures and implementing practical design strategies.

In addition, future studies should employ more robust sampling strategies, including stratification by playground characteristics, the inclusion of high-performing exemplar playgrounds, and representation of both public and private schools. Such approaches would help reduce potential selection bias and improve the generalisability of findings.

Participatory research approaches and observing children's play behaviour before and after playground modifications could provide deeper insights into the physical characteristics of AZs that influence play choices and sun protection behaviours. Collaboration with design experts could bring valuable perspectives for developing child-friendly outdoor activity areas that effectively balance sun protection, microclimatic comfort, engagement and functional requirements.

7.4 Recommendations for maximising sun protection in school playgrounds

Overall, improving sun protection in school playgrounds requires a dual approach that combines evidence-based design interventions with clear policy frameworks. Accordingly, two key recommendations are proposed for practitioners and planners responsible for implementing sun protection measures in schools: (1) the development of evidence-based design guidelines; and (2) the establishment of policies with clear spatial targets.

7.4.1 The development of evidence-based design guidelines

This study demonstrates that AZs and school playgrounds can effectively support sun protection when sun protection knowledge is properly integrated into the design and implementation. As highlighted, a gap exists between research and implementation (Bherwani et al., 2020), contributing to the current challenges in applying the knowledge effectively. To bridge this gap and support practitioners and planners, effective evidence-based design guidelines are needed (Klemm, Lenzholzer, et al., 2017; van den Brink et al., 2016).

Though some design guidelines are currently available, they tend to address specific SPB design objectives, e.g., shade guidelines focusing solely on UVR protection (Greenwood et al., 2000) or playground design guidelines emphasising thermal comfort (Kennedy et al., 2020). Given the critical role of SPB design in promoting children's long-term health, there is a need for more comprehensive design guidelines that integrate all three objectives. In particular, such guidelines should be developed across two key spatial scales: the AZ scale and the playground scale. Drawing on the study's findings and the insights gained, a set of best-practice design guidelines can be formulated for each AZ type. These guidelines should address the three SPB design objectives independently while responding to the specific functional requirements of the zone.

For each AZ, the recommendations should translate evidence into clearly defined, measurable performance criteria including: (i) the required shade quantity, expressed as minimum mean shade cover; (ii) the target shade protection factor (PF) necessary to support the anticipated duration and intensity of activities; (iii) the appropriate level of wind protection, determined in relation to the metabolic activity rate typical of the zone; and (iv) the provision of specific play features or equipment encourages use of the zone. At a broader school playground scale, the recommendations should address overall spatial configuration, particularly the optimal spatial arrangement of AZs, identifying which zone types could be strategically located, enhancing shade efficiency and improved use of shaded areas.

The development of such structured, evidence-based design guidelines would serve as practical tools, translating scientific evidence into practical design solutions (Klemm, Lenzholzer, et al., 2017) that provide both theoretical guidance and practical recommendations for urban planners and landscape designers in optimising children's activity spaces and improving the thermal environment (Luyao et al., 2025).

7.4.2 Establishment of policies with clear spatial targets

Sun protection and skin cancer prevention initiatives continue to face significant challenges. In New Zealand, limited political prioritisation has been identified as a major barrier to achieving effective outcomes (McNoe et al., 2022). This lack of priority is partly driven by evidence gaps (McNoe et al., 2022), including uncertainty about the effectiveness of shade (Holman et al., 2018), the safe levels of sun exposure for children (Gage et al., 2022), and a perceived conflict between UVR protection and microclimatic comfort (Gage et al., 2022). Strong political support and well-resourced health policies are essential, particularly to create a supportive environment that encourages and sustains sun protection behaviour (McNoe et al., 2022).

Schools, however, often struggle to implement existing sun protection measures because of competing priorities and limited resources (McNoe & Reeder, 2019), particularly with regard to the blanket approach to shade provision across the entire school playground. To better support schools, planners and policymakers need to establish clear, well-defined spatial targets tailored to specific AZ types rather than focusing on the whole school playground. For example, AZ types characterised by prolonged, sedentary use (e.g., seating or eating areas) may require higher levels of shade provision (e.g., complete or 100% shade cover) and improved thermal comfort (e.g., full wind protection). Active play zone types (e.g., sports pitches) may adopt more flexible targets that balance UVR protection (e.g., partial or 30-40% shade cover) with heat dissipation (e.g., fully wind exposed).

Embedding these zone-specific targets in existing school sun protection policies, design guidelines and audit processes can facilitate phased implementation by prioritising critical activity zones associated with high UV exposure and thermal risk. This targeted approach not only enables more efficient allocation of funding and infrastructure investment, but also supports regular compliance reporting and monitoring, strengthening enforcement while reducing ambiguity in interpretation and application. Furthermore, the establishment of measurable targets provide policymakers with evidence to advocate prioritising sun protection in schools and to attract political support and resources necessary for effective, targeted interventions. In addition, future research could explore the application of weighted assessments that assign greater importance to highly attractive AZs that are likely to encourage prolonged use by children. Such an approach would assist schools in identifying priority areas for intervention and enable the more effective and efficient allocation of resources to maximise sun protection outcomes.

7.5 Conclusions

This study introduced the SPB-D methodology in response to the need for an effective, evidence-based design approach to improving school playgrounds for optimal SPB among children. For the first time, the study integrated three critical SPB design objectives: UVR protection, microclimatic comfort and attractiveness, in a single framework for evaluating, designing and prioritising AZs in terms of meeting specific objectives and the overall capacity of the school playground to achieve the required SPB design standards. By generating outputs across three spatial scales, the proposed SPB-D methodology provides a comprehensive understanding of how landscape units, individual AZs, and the school playground as a whole contribute to effective SPB design.

The evaluation of existing primary school playgrounds in Christchurch revealed that they were generally not designed to promote sufficient SPB, leaving children exposed to high levels of UV radiation during critical protection times. The findings highlight the importance of AZs in SPB design and suggest the need to shift the focus from the overall playground scale to the AZ scale. The current approach, which prioritises AZs for functional needs such as organised sports and games while giving less consideration to UVR protection and microclimatic comfort, emphasises the importance of rethinking both AZs and overall school playground design. By adopting a more balanced approach, AZs can be designed for improved UVR protection, comfort and engaging play opportunities, thereby enhancing the overall effectiveness of school playgrounds in promoting SPB and protecting children from overexposure and associated long-term health risks.

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Appendix A

A Glossary of Terms and Their Definitions

The key terms and their definition as used in this thesis are:

Activity zone (AZ) – a designated space in a larger environment, such as a playground, that is specifically designed for or supports a particular type of activity. For example, a sports pitch, sand pit.

Attractiveness – is the ability of an activity zone to provide engaging play opportunities for children, leading to greater use of the zone.

Attractor – is a play feature or equipment needed to promote play or physical activity, such as a ball, swing, play markings.

Critical design variables (CDVs) – are key variables that directly influence specific sun protection behaviour (SPB) design objectives. For example, UVR protection is determined by shade cover, shade protection factor and ground surface UV reflectivity.

Direct UVR - is the radiation received directly from the sun (Greenwood et al., 2000).

Evidence-based landscape architecture (EBLA) is defined as the "deliberate and explicit use of scholarly evidence in making decisions about the use and shaping of the land" (Brown and Corry (2011, p. 328).

Indirect UVR – is reflected from a surface material or diffused (scattered) by clouds or atmospheric particles (Greenwood et al., 2000).

Landscape units (LUs) – distinct, homogenous areas that share similar biophysical characteristics, in support of a particular land use (Lyle, 1999). In this study, they refer to landscape characteristics pertaining to a specific SPB design objective.

Metabolic equivalents (METS) – units expressing the metabolic rate of an activity as a multiple of the resting metabolic rate (Jetté et al., 1990).

Microclimatic comfort (MCC) – is microclimatic conditions in outdoor environments that are comfortable (Brown & Gillespie, 1995) for most individuals in the environment, which includes thermal comfort (ASHRAE, 1989; Brown & Gillespie, 1995) and wind comfort (Ebrahimabadi, 2015).

Minimum erythemat dose (MED) – is the minimal UVR dose necessary to elicit a visible erythema or reddening, in an individual, typically assessed 8 –24 hours after irradiation.

Protection factor (PF) - is defined as the ratio of UVR measured in full sun to that measured under shade (Gies & Mackay, 2004).

School playground - comprises all outdoor areas, also referred to as '**activity zones**', that have the potential for play and outdoor recreational activities in a school.

Standard erythemat dose (SED) - is a standardised unit used to quantify the amount of erythemally effective UVR radiation (UVR_{eff}), and is independent of skin type; 1 SED = 100 Jm⁻² (McKenzie & Lucas, 2018).

Sun Protection Behaviour (SPB) – is the action of protecting oneself from overexposure to solar UVR such as sunscreen and protective clothing. In landscape design, it is the action of occupying or conducting activities in spaces that are designed to protect people from overexposure.

SPB design – the design of playgrounds and outdoor areas that support the intended sun protection behaviour.

Structured activity zone – an area that is organised or has a set purpose or location and is specifically designed by adults for a particular activity (Hyndman, 2015; Sener et al., 2008) (e.g., a basketball court, a sandpit, an area for sitting or eating).

SPB design objectives – the three key factors essential for promoting the intended SPB: UVR protection, microclimatic comfort and attractiveness.

Sky view factor (SVF) - is the proportion of the open sky visible from a specific point under a shade canopy (Mackay, 2009)

Shade quantity – is the amount or proportion of shade available at a given location measured by assessing the percentage of shade covering.

Shade quality – is the level of UVR protection offered by shade from both direct and indirect UVR, measured by the protection factor (PF).

Thermal comfort – is the condition of the mind that expresses satisfaction with the thermal environment (ASHRAE, 1989).

Unstructured activity zone - an area that is less organised, without a set purpose, location or design for a particular activity, but is often shaped by children's imagination (Hyndman, 2015; Sener et al., 2008) (e.g., open areas of asphalt or grass, a woodland).

UVR protection – is the provision of adequate protection from both direct and indirect UVR (Mackay, 2016).

UV Index (UVI) - is a standard measurement tool developed to indicate the intensity of UVR reaching the Earth's surface (McKenzie, 2017), values range from zero upwards.

UV albedo – is the ratio of reflected (upwelling) irradiance to incident (downwelling) irradiance, typically expressed as a value between 0 and 1 (Turner & Parisi, 2018).

Wind comfort – is the mechanical effect of wind, including its force on people and objects, which affects outdoor comfort of individuals (Blocken & Carmeliet, 2004).

Wind cover – is the extent of an area protected from prevailing winds by natural or artificial wind barriers such as trees, or built structures.

Wind-protected area – is the extent of an area with the wind speed reduced by at least 50% compared with that measured in an open area (Chiesa & Grosso, 2017).

Wind-exposed area - is the extent of an area with uninterrupted wind speed, i.e., the same as in an open area (Chiesa & Grosso, 2017).

Appendix B

Ethics Approval

Research Management Office

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PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

27 September 2019

Application No: 2019-59

Title: An exploration of the effectiveness of sun protection programme implementation within primary schools

Applicant: A Sukumar

The Lincoln University Human Ethics Committee has reviewed the above noted application.
Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed. I am pleased to give final approval to your project.

Please note that this approval is valid for three years from today's date at which time you will need to reapply for renewal.

Once your field work has finished can you please advise the Human Ethics Secretary, Alison Hind, and confirm that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely



Grant Tavinor
Chair, Human Ethics Committee

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

Appendix C

Data Input Sheets

This section presents the site audit tools used in this study to gather site related information.

Table C.1: Site audit tool for collecting details of built structures within the study school

Built Structure No.	Description	Roof form	Roofing material	Plinth height (m)	Height to roof/pole (m)	Total height (m)	Remarks
B1							
B2							
V1							
V2							
S1							

In the table:

- B – Buildings
- V – Verandas
- S – Shade structures (portable/fixed)

Table C.2: Site audit tool for collecting details of natural structures within the study school

Natural Structure No.	Description	Evergreen or Deciduous (E/D)	Canopy Density (H/M/L)	Canopy height (m)	Total height (m)	Remarks
T1						
T2						
C1						

In the table:

- T – Trees
- C – Vegetation clusters
- E – Evergreen
- D – Deciduous
- H – Heavy canopy density
- M – Medium canopy density
- L – Light canopy density

Table C.3: Site audit tool for collecting details of purpose-built wind barriers within the study school

Purpose-built Wind Barrier No.	Description	Porosity (S/M/L)	Total height (m)	Remarks
W1				
F1				
H1				

In the table:

- W – Walls
- F – Fences
- H – Hedges
- S – Solid porosity
- M – Moderate porosity
- L – Light porosity

Appendix D

Study Site Information

This appendix provides additional information on the study sites.

A sample SPB design map indicating site elements related to the SPB design objectives.



Figure D.1: Sun protection behaviour design base map indicating site elements mapped in relation to the design objectives for School-C

A sample activity zones map indicating the structured and unstructured zones

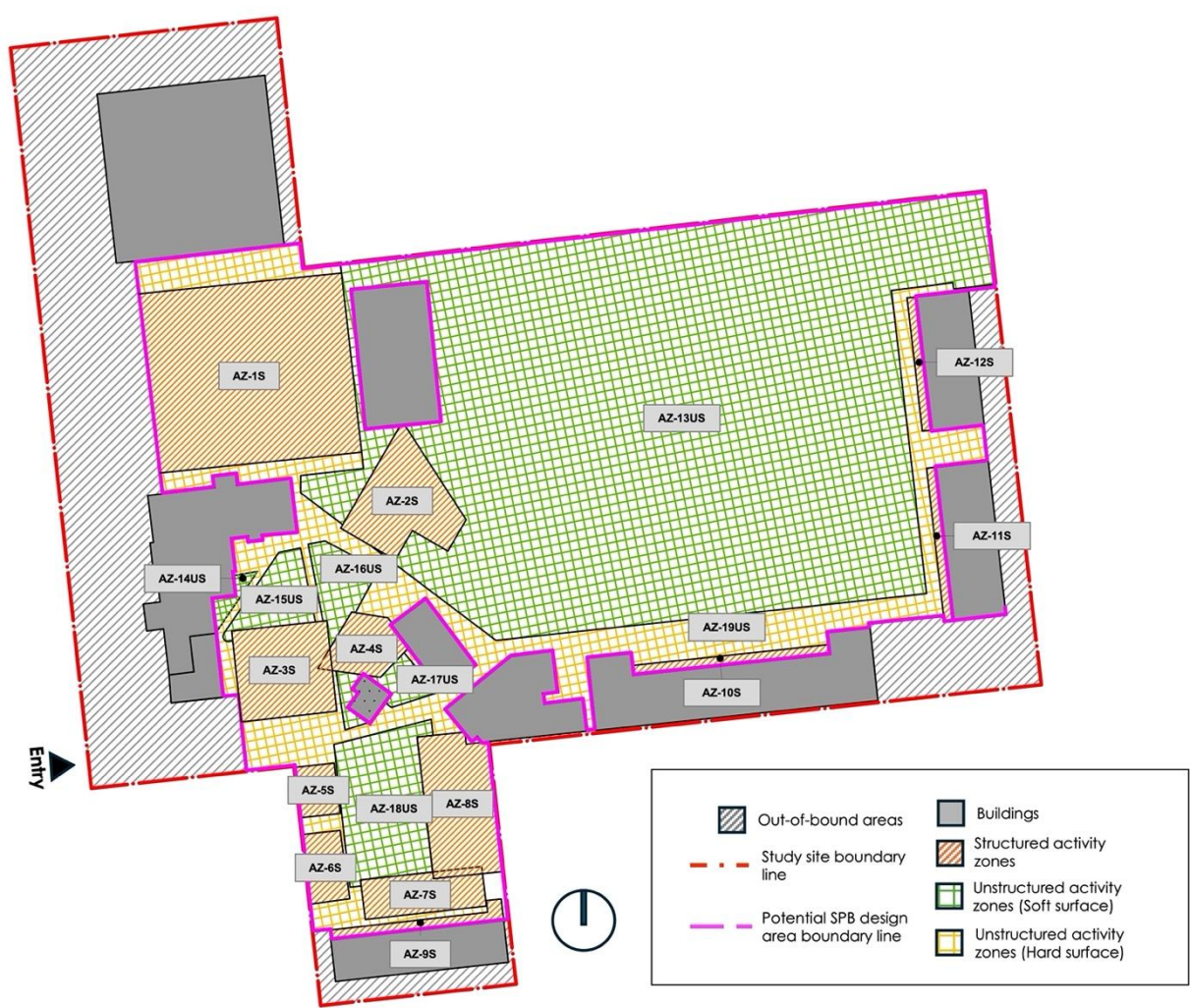


Figure D.2: Activity zones map displaying zones classified and delineated as structured and unstructured zones for School-C

Table D.1: A summary of activity zone details for School-A

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - A	AZ-1S	Structured	Sports pitch (Multiple)	5833.80	26.93
	AZ-2S	Structured	Sand pit	143.02	0.66
	AZ-3S	Structured	BMX - Track	571.80	2.64
	AZ-4S	Structured	Play equipment-I	370.20	1.71
	AZ-5S	Structured	Hard court-I	744.68	3.44
	AZ-6S	Structured	Hard court-II	456.95	2.11
	AZ-7S	Structured	Outdoor Amphitheatre	398.53	1.84
	AZ-8S	Structured	Play equipment-II	462.44	2.13
	AZ-9US	Unstructured	Classroom Verandah-I	84.73	0.39
	AZ-10US	Unstructured	Hard paved area	2657.97	12.27
	AZ-11US	Unstructured	Classroom Verandah-II	350.87	1.62
	AZ-12US	Unstructured	Green area-I	262.76	1.21
	AZ-13US	Unstructured	Green area-II	998.99	4.61
	AZ-14US	Unstructured	Grassed area	8325.54	38.43
Total # activity zones	14	# Structured - 8 and # Unstructured - 6		21662.28	100.00

Table D.2: A summary of activity zone details for School-B

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - B	AZ-1S	Structured	Sports pitch (Multiple)	2552.28	20.07
	AZ-2S	Structured	Hard court	506.34	3.98
	AZ-3S	Structured	Play equipment-I	377.90	2.97
	AZ-4S	Structured	Play equipment-II	623.93	4.91
	AZ-5S	Structured	Sand pit	71.44	0.56
	AZ-6S	Structured	COLA	50.32	0.40
	AZ-7US	Unstructured	Hard paved area	1251.00	9.84
	AZ-8US	Unstructured	Classroom Verandah-I	104.49	0.82
	AZ-9US	Unstructured	Classroom Verandah-II	19.97	0.16
	AZ-10US	Unstructured	Green area-I	394.30	3.10
	AZ-11US	Unstructured	Grassed area	4776.59	37.56
	AZ-12US	Unstructured	Green area-II	1988.24	15.63
Total # activity zones	12	# Structured - 6 and # Unstructured - 6		12716.80	100.00

Table D.3: A summary of activity zone details for School-C

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - C	AZ-1S	Structured	Hard court-I	1469.87	10.08
	AZ-2S	Structured	Play equipment-I	348.04	2.39
	AZ-3S	Structured	Hard court-II	351.36	2.41
	AZ-4S	Structured	Play equipment-II	150.12	1.03
	AZ-5S	Structured	Play equipment-III	80.15	0.55
	AZ-6S	Structured	Sand pit	107.78	0.74
	AZ-7S	Structured	Paint marking	194.81	1.34
	AZ-8S	Structured	Play equipment-IV	394.37	2.71
	AZ-9US	Unstructured	Classroom Verandah-I	76.85	0.53
	AZ-10US	Unstructured	Classroom Verandah-II	79.72	0.55
	AZ-11US	Unstructured	Classroom Verandah-III	61.40	0.42
	AZ-12US	Unstructured	Classroom Verandah-IV	53.74	0.37
	AZ-13US	Unstructured	Hard paved area	2201.45	15.10
	AZ-14US	Unstructured	Green area-I	35.53	0.24
	AZ-15US	Unstructured	Green area-II	170.01	1.17
	AZ-16US	Unstructured	Green area-III	152.19	1.04
	AZ-17US	Unstructured	Green area-IV	105.30	0.72
	AZ-18US	Unstructured	Grassed area-I	494.48	3.39
	AZ-19US	Unstructured	Grassed area-II	8048.98	55.22
Total # activity zones	19	# Structured - 8 and # Unstructured - 11		14576.15	100.00

Table D.4: A summary of activity zone details for School-D

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - D	AZ-1S	Structured	Sports pitch (Single)	3256.00	23.47
	AZ-2S	Structured	Play equipment-I	621.99	4.48
	AZ-3S	Structured	Play equipment-II	625.50	4.51
	AZ-4S	Structured	Sand pit-I	44.39	0.32
	AZ-5S	Structured	Hard court-I	919.76	6.63
	AZ-6S	Structured	Hard court-II	88.27	0.64
	AZ-7S	Structured	Play equipment-III	317.28	2.29
	AZ-8S	Structured	Sand pit-II	233.20	1.68
	AZ-9US	Unstructured	Hard paved area	3336.46	24.05
	AZ-10US	Unstructured	Grassed area	3492.01	25.17
	AZ-11US	Unstructured	Green area-I	219.71	1.58
	AZ-12US	Unstructured	Green area-II	83.30	0.60
	AZ-13US	Unstructured	Green area-III	367.05	2.65
	AZ-14US	Unstructured	Green area-IV	270.03	1.95
Total # activity zones	14	# Structured - 8 and # Unstructured - 6		13874.95	100.00

Table D.5: A summary of activity zone details for School-E

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - E	AZ-1S	Structured	Sports pitch (Multiple)	3786.33	19.11
	AZ-2S	Structured	Hard court-I	1930.98	9.74
	AZ-3S	Structured	Play equipment-I	660.47	3.33
	AZ-4S	Structured	Play equipment-II	145.71	0.74
	AZ-5S	Structured	Sand pit	94.03	0.47
	AZ-6S	Structured	Play equipment-III	386.22	1.95
	AZ-7US	Unstructured	Classroom Verandah	187.03	0.94
	AZ-8US	Unstructured	Hard paved area	4196.16	21.18
	AZ-9US	Unstructured	Grassed area	5786.14	29.20
	AZ-10US	Unstructured	Green area-I	722.59	3.65
	AZ-11US	Unstructured	Green area-II	176.71	0.89
	AZ-12US	Unstructured	Green area-III	176.71	0.89
	AZ-13US	Unstructured	Green area-IV	287.62	1.45
	AZ-14US	Unstructured	Green area-V	176.54	0.89
	AZ-15US	Unstructured	Green area-VI	864.19	4.36
	AZ-16US	Unstructured	Green area-VII	238.58	1.20
Total # activity zones	16	# Structured - 6 and # Unstructured - 10		19816.01	100.00

Table D.6: A summary of activity zone details for School-F

School	AZ Code	Zone Category	Activity area	Area in sq.m.	Mean % cover
School - F	AZ-1S	Structured	Sports pitch (Multiple)	4151.61	16.31
	AZ-2S	Structured	BMX - Track	2062.76	8.10
	AZ-3S	Structured	Hard court-I	250.43	0.98
	AZ-4S	Structured	Play equipment-I	373.47	1.47
	AZ-5S	Structured	Paint marking-I	111.99	0.44
	AZ-6S	Structured	Sand pit-I	77.41	0.30
	AZ-7S	Structured	Sand pit-II	116.97	0.46
	AZ-8S	Structured	Sand pit-III	149.68	0.59
	AZ-9S	Structured	Play equipment-II	338.98	1.33
	AZ-10S	Structured	Paint marking-II	122.54	0.48
	AZ-11S	Structured	Hard court-II	593.82	2.33
	AZ-12S	Structured	Play equipment-III	279.50	1.10
	AZ-13S	Structured	Hard court-III	661.29	2.60
	AZ-14S	Structured	Play equipment-IV	444.63	1.75
	AZ-15US	Unstructured	Hard paved area	3373.53	13.25
	AZ-16US	Unstructured	Grassed area	12352.58	48.52
Total # activity zones	16	# Structured - 14 and # Unstructured - 2		25461.19	100.00

Appendix E

A Summary of Ultraviolet Radiation Protection Evaluation

This section summarises school activity zones' evaluation results of for protection.

E.1 Landscape units map of ultraviolet radiation protection evaluation

A sample map of landscape units developed for UVR protection evaluation at School-A



Figure E.1: A landscape units map of ultraviolet radiation protection for School-A

E.2 A summary of ultraviolet radiation protection results by school

Table E.1: A summary of ultraviolet radiation protection evaluation results for School-A

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Sports pitch (Multiple)	5833.8	26.9	0.00	1.75	98.25	0.00	0.92	Low
AZ-2S	Structured	Sand pit	143.0	0.7	0.00	26.60	48.73	24.66	26.60	Moderate
AZ-3S	Structured	BMX - Track	571.8	2.6	7.85	5.22	86.94	0.00	13.06	Low
AZ-4S	Structured	Play equipment-I	370.2	1.7	0.00	0.00	100.00	0.00	0.00	Low
AZ-5S	Structured	Hard court-I	744.7	3.4	0.00	0.00	27.84	72.16	0.00	Low
AZ-6S	Structured	Hard court-II	456.9	2.1	0.00	0.00	30.66	69.34	0.00	Low
AZ-7S	Structured	Outdoor Amphitheatre	398.5	1.8	5.51	28.64	0.00	65.84	34.16	Moderate
AZ-8S	Structured	Play equipment-II	462.4	2.1	0.00	10.89	79.52	9.59	21.77	Low
AZ-9US	Unstructured	Classroom Verandah-I	84.7	0.4	0.00	19.56	0.00	80.44	19.56	Low
AZ-10US	Unstructured	Hard paved area	2657.9	12.3	0.00	10.56	0.00	89.44	17.02	Low
AZ-11US	Unstructured	Classroom Verandah-II	350.9	1.6	37.69	18.65	0.00	43.65	51.38	Moderate
AZ-12US	Unstructured	Green area-I	262.8	1.2	0.00	18.12	81.88	0.00	0.00	Low
AZ-13US	Unstructured	Green area-II	998.9	4.6	0.00	0.00	100.00	0.00	5.73	Low
AZ-14US	Unstructured	Grassed area	8325.5	38.4	10.21	1.27	88.52	0.00	13.15	Low
Total # activity zones - 14	# structured - 8 and # unstructured - 6		21662.3	100.0	61.26	141.27	742.34	455.12	203.34	# Low – 11 # Moderate – 3 # Adequate - 0

Table E.2: A summary of ultraviolet radiation protection evaluation results for School-B

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Sports pitch (Multiple)	2552.28	20.1	0.00	0.00	100	0.00	0.00	Low
AZ-2S	Structured	Hard court	506.34	4.0	3.19	4.52	1.57	90.72	7.71	Low
AZ-3S	Structured	Play equipment-I	377.9	3.0	0.00	20.09	79.91	0.00	20.09	Low
AZ-4S	Structured	Play equipment-II	623.93	4.9	7.66	16.88	58.18	17.29	24.53	Moderate
AZ-5S	Structured	Sand pit	71.44	0.6	0.00	0.00	73.78	26.22	0.00	Low
AZ-6S	Structured	COLA	50.32	0.4	93.60	0.00	0.00	6.40	93.60	Adequate
AZ-7US	Unstructured	Hard paved area	1251	9.8	8.35	18.66	0.00	72.99	27.01	Low
AZ-8US	Unstructured	Classroom Verandah-I	104.49	0.8	0.00	58.69	0.00	41.31	58.69	Moderate
AZ-9US	Unstructured	Classroom Verandah-II	19.97	0.2	0.00	90.44	0.00	9.56	90.44	Moderate
AZ-10US	Unstructured	Green area-I	394.3	3.1	0.00	7.35	92.65	0.00	7.35	Low
AZ-11US	Unstructured	Grassed area	4776.59	37.6	7.84	3.22	88.94	0.00	11.06	Low
AZ-12US	Unstructured	Green area-II	1988.24	15.6	10.45	13.94	75.61	0.00	24.39	Low
Total # activity zones - 12	# structured - 6 and # unstructured - 6		12716.80	100.0	131.09	233.79	570.62	264.49	364.88	# Low – 8 # Moderate – 3 # Adequate - 1

Table E.3: A summary of ultraviolet radiation UVR protection evaluation results for School-C

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Hard court-I	1469.87	10.1	5.17	1.08	0.00	93.75	6.24	Low
AZ-2S	Structured	Play equipment-I	348.04	2.4	47.96	13.26	38.78	0.00	57.35	Moderate
AZ-3S	Structured	Hard court-II	351.36	2.4	45.67	2.24	8.68	43.41	47.91	Moderate
AZ-4S	Structured	Play equipment-II	150.12	1.0	52.60	0.00	24.32	23.08	52.35	Moderate
AZ-5S	Structured	Play equipment-III	80.15	0.5	42.33	2.83	12.39	42.45	78.73	Moderate
AZ-6S	Structured	Sand pit	107.78	0.7	22.99	45.42	0.00	31.59	68.30	Moderate
AZ-7S	Structured	Paint marking	194.81	1.3	0.00	0.00	0.00	100.00	0.00	Low
AZ-8S	Structured	Play equipment-IV	394.37	2.7	9.17	27.05	63.78	0.00	37.00	Moderate
AZ-9US	Unstructured	Classroom Verandah-I	76.85	0.5	78.28	0.00	0.00	21.72	100.00	Moderate
AZ-10US	Unstructured	Classroom Verandah-II	79.72	0.5	84.62	0.00	0.00	15.38	100.00	Adequate
AZ-11US	Unstructured	Classroom Verandah-III	61.40	0.4	93.32	0.00	0.00	6.68	100.00	Adequate
AZ-12US	Unstructured	Classroom Verandah-IV	53.74	0.4	89.77	0.00	0.00	10.23	100.00	Adequate
AZ-13US	Unstructured	Hard paved area	2201.45	15.1	5.38	13.12	0.00	81.50	23.74	Low
AZ-14US	Unstructured	Green area-I	35.53	0.2	0.00	47.40	52.60	0.00	35.27	Moderate
AZ-15US	Unstructured	Green area-II	170.01	1.2	42.53	9.86	47.60	0.00	52.40	Moderate
AZ-16US	Unstructured	Green area-III	152.19	1.0	0.00	0.00	100.00	0.00	0.00	Low
AZ-17US	Unstructured	Green area-IV	105.30	0.7	89.98	0.00	10.03	0.00	90.48	Adequate
AZ-18US	Unstructured	Grassed area-I	494.48	3.4	0.00	0.00	100.00	0.00	0.00	Low
AZ-19US	Unstructured	Grassed area-II	8048.98	55.2	6.77	5.40	87.84	0.00	12.91	Low
Total # activity zones - 19	# structured - 8 and # unstructured - 11		14576.15	100.0	716.55	167.65	546.02	469.79	962.68	# Low – 6 # Moderate – 9 # Adequate - 4

Table E.4: A summary of ultraviolet radiation protection evaluation results for School-D

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Sports pitch (Single)	3256.00	23.5	0.00	0.00	100.00	0.00	0.00	Low
AZ-2S	Structured	Play equipment-I	621.99	4.5	10.08	15.18	74.74	0.00	25.23	Low
AZ-3S	Structured	Play equipment-II	625.50	4.5	4.27	8.61	64.11	23.01	12.71	Low
AZ-4S	Structured	Sand pit-I	44.39	0.3	0.00	0.00	55.28	44.72	0.00	Low
AZ-5S	Structured	Hard court-I	919.76	6.6	0.00	0.00	0.00	100.00	0.00	Low
AZ-6S	Structured	Hard court-II	88.27	0.6	0.00	0.00	12.59	87.41	0.00	Low
AZ-7S	Structured	Play equipment-III	317.28	2.3	0.00	18.84	20.15	61.02	17.73	Low
AZ-8S	Structured	Sand pit-II	233.20	1.7	0.00	16.66	61.46	21.88	16.66	Low
AZ-9US	Unstructured	Hard paved area	3336.46	24.0	6.66	21.87	0.00	71.47	28.53	Low
AZ-10US	Unstructured	Grassed area	3492.01	25.2	0.00	9.00	91.00	0.00	9.00	Low
AZ-11US	Unstructured	Green area-I	219.71	1.6	4.87	7.15	87.98	0.00	12.02	Low
AZ-12US	Unstructured	Green area-II	83.30	0.6	0.00	9.60	90.40	0.00	9.60	Low
AZ-13US	Unstructured	Green area-III	367.05	2.6	0.00	16.58	83.42	0.00	16.58	Low
AZ-14US	Unstructured	Green area-IV	270.03	1.9	0.00	52.89	47.11	0.00	52.89	Moderate
Total # activity zones - 14	# structured - 8 and # unstructured - 6		13874.95	100.0	25.88	176.38	788.22	409.51	200.96	# Low – 13 # Moderate – 1 # Adequate - 0

Table E.5: A summary of ultraviolet radiation protection evaluation results for School-E

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Sports pitch (Multiple)	3786.33	19.1	5.53	4.18	89.92	0.37	10.08	Low
AZ-2S	Structured	Hard court-I	1930.98	9.7	12.29	5.20	3.57	78.93	17.49	Low
AZ-3S	Structured	Play equipment-I	660.47	3.3	0.00	0.00	83.79	16.21	0.00	Low
AZ-4S	Structured	Play equipment-II	145.71	0.7	0.00	0.00	55.29	44.71	0.00	Low
AZ-5S	Structured	Sand pit	94.03	0.5	0.00	0.00	0.00	100.00	0.00	Low
AZ-6S	Structured	Play equipment-III	386.22	1.9	32.96	16.61	12.57	37.85	49.58	Moderate
AZ-7US	Unstructured	Classroom Verandah	187.03	0.9	41.40	0.00	0.00	58.60	41.40	Moderate
AZ-8US	Unstructured	Hard paved area	4196.16	21.2	3.46	35.43	0.00	61.11	38.89	Moderate
AZ-9US	Unstructured	Grassed area	5786.14	29.2	27.63	7.49	64.88	0.00	35.12	Moderate
AZ-10US	Unstructured	Green area-I	722.59	3.6	24.04	11.53	64.43	0.00	35.57	Moderate
AZ-11US	Unstructured	Green area-II	176.71	0.9	87.77	0.00	0.00	12.23	87.77	Adequate
AZ-12US	Unstructured	Green area-III	176.71	0.9	81.42	0.00	0.00	18.58	81.42	Adequate
AZ-13US	Unstructured	Green area-IV	287.62	1.5	0.00	4.07	95.93	0.00	4.07	Low
AZ-14US	Unstructured	Green area-V	176.54	0.9	0.00	11.71	88.29	0.00	11.71	Low
AZ-15US	Unstructured	Green area-VI	864.19	4.4	33.42	15.07	51.51	0.00	48.49	Moderate
AZ-16US	Unstructured	Green area-VII	238.58	1.2	0.00	32.01	67.99	0.00	32.01	Moderate
Total # activity zones - 16	# structured - 6 and # unstructured - 10		19816.01	100.0	349.92	143.32	678.17	428.59	493.61	# Low – 7 # Moderate – 7 # Adequate - 2

Table E.6: A summary of ultraviolet radiation protection evaluation results for School-F

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Mean % cover				Mean shade cover (%)	UVR protection evaluation
					LU-I	LU-II	LU-III	LU-IV		
AZ-1S	Structured	Sports pitch (Multiple)	4151.61	16.3	0.00	0.00	100	0.00	0.00	Low
AZ-2S	Structured	BMX - Track	2062.76	8.1	0.00	0.00	96.08	3.92	0.00	Low
AZ-3S	Structured	Hard court-I	250.43	1.0	0.00	0.00	0.00	100.00	0.00	Low
AZ-4S	Structured	Play equipment-I	373.47	1.5	0.00	0.00	89.17	10.83	0.00	Low
AZ-5S	Structured	Paint marking-I	111.99	0.4	0.00	0.00	0.00	100.00	0.00	Low
AZ-6S	Structured	Sand pit-I	77.41	0.3	0.00	38.07	57.05	4.88	38.07	Moderate
AZ-7S	Structured	Sand pit-II	116.97	0.5	0.00	21.89	0.00	78.11	34.19	Low
AZ-8S	Structured	Sand pit-III	149.68	0.6	0.00	24.06	0.00	75.94	61.01	Low
AZ-9S	Structured	Play equipment-II	338.98	1.3	0.00	5.84	60.52	33.64	5.85	Low
AZ-10S	Structured	Paint marking-II	122.54	0.5	0.00	0.00	0.00	100.00	0.00	Low
AZ-11S	Structured	Hard court-II	593.82	2.3	0.00	0.00	0.00	100.00	0.00	Low
AZ-12S	Structured	Play equipment-III	279.50	1.1	0.00	0.00	78.31	21.69	0.00	Low
AZ-13S	Structured	Hard court-III	661.29	2.6	0.00	0.00	0.00	100.00	0.00	Low
AZ-14S	Structured	Play equipment-IV	444.63	1.7	0.00	7.55	72.17	20.29	7.55	Low
AZ-15US	Unstructured	Hard paved area	3373.53	13.2	19.56	13.15	0.00	67.30	32.70	Moderate
AZ-16US	Unstructured	Grassed area	12352.58	48.5	0.00	0.00	100.00	0.00	0.00	Low
Total # activity zones - 16	# structured - 14 and # unstructured - 2		25461.19	100.0	19.56	110.57	653.29	816.58	179.37	# Low – 14 # Moderate – 2 # Adequate - 0

Appendix F

A Summary of Microclimatic Comfort Evaluation

This section summarises school activity zones' evaluation results for microclimatic comfort.

F.1 A landscape units map of microclimatic comfort evaluation

A sample map of landscape units developed for microclimatic comfort evaluation at School-C

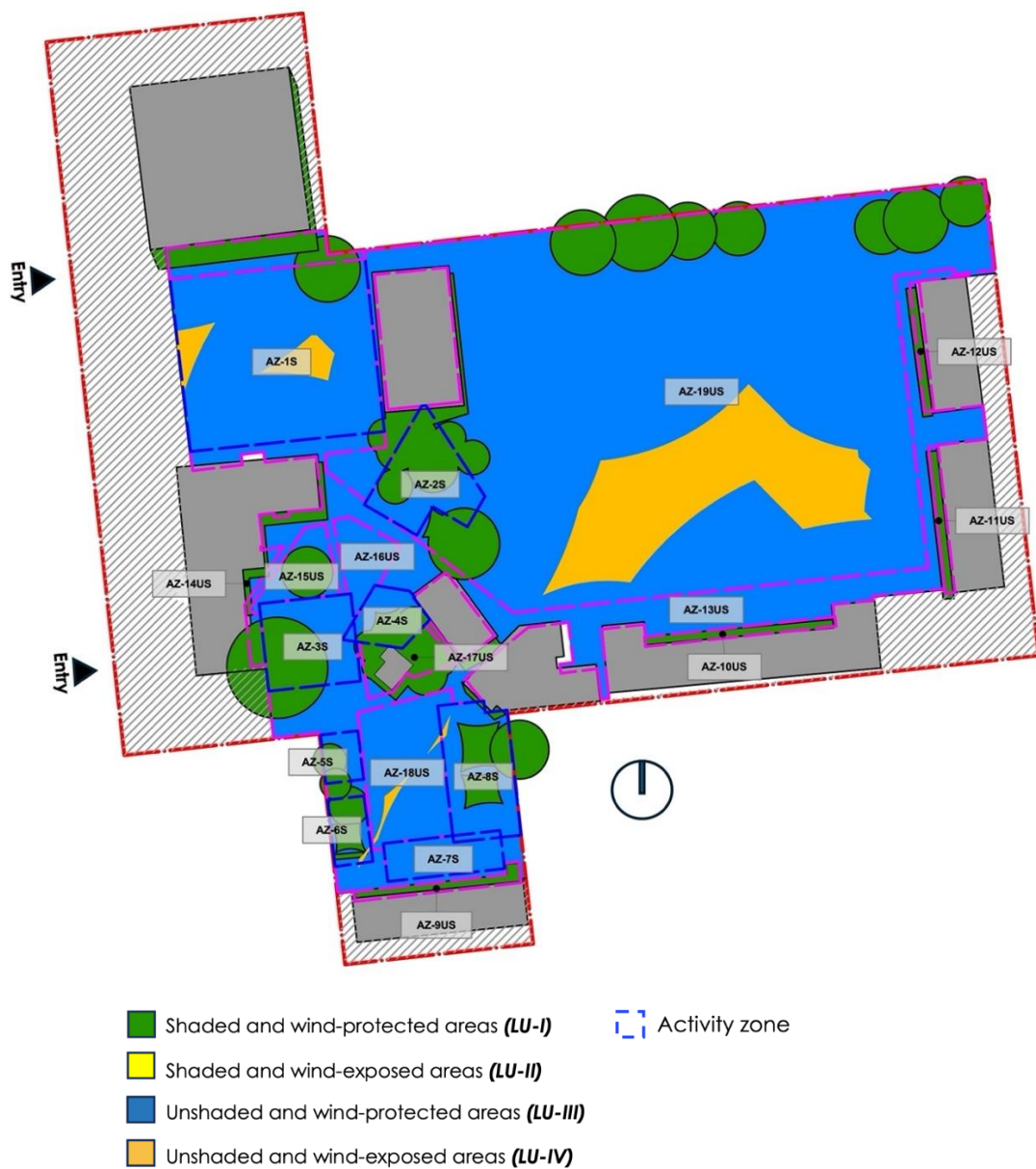


Figure F.1: A landscape units map of microclimatic comfort for School-C

F.2 A summary of microclimatic comfort results by school

Table F.1: A summary of the microclimatic comfort evaluation results for School-A

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Sports pitch (Multiple)	5833.8	26.9	V	0.92	0.00	83.01	16.07	0.92	83.93	Low
AZ-2S	Structured	Sand pit	143.0	0.7	L	4.59	22.01	54.61	18.78	26.60	59.21	Low
AZ-3S	Structured	BMX - Track	571.8	2.6	V	13.06	0.00	85.00	1.94	13.06	98.06	Low
AZ-4S	Structured	Play equipment-I	370.2	1.7	M	0.00	0.00	39.85	60.15	0.00	39.85	Low
AZ-5S	Structured	Hard court-I	744.7	3.4	V	0.00	0.00	67.31	32.69	0.00	67.31	Low
AZ-6S	Structured	Hard court-II	456.9	2.1	V	0.00	0.00	48.24	51.76	0.00	48.24	Low
AZ-7S	Structured	Outdoor Amphitheatre	398.5	1.8	L	34.16	0.00	65.84	0.00	34.16	100.00	Low
AZ-8S	Structured	Play equipment-II	462.4	2.1	M	21.77	0.00	1.91	76.32	21.77	23.68	Low
AZ-9US	Unstructured	Classroom Verandah-I	84.7	0.4	M	19.56	0.00	80.44	0.00	19.56	100.00	Low
AZ-10US	Unstructured	Hard paved area	2657.9	12.3	V	17.02	0.00	47.44	35.54	17.02	64.46	Low
AZ-11US	Unstructured	Classroom Verandah-II	350.9	1.6	M	51.38	0.00	48.62	0.00	51.38	100.00	Low
AZ-12US	Unstructured	Green area-I	262.8	1.2	M	0.00	0.00	0.00	100.00	0.00	0.00	Low
AZ-13US	Unstructured	Green area-II	998.9	4.6	M	5.73	0.00	52.93	41.34	5.73	58.66	Low
AZ-14US	Unstructured	Grassed area	8325.5	38.4	M	13.15	0.00	33.33	53.53	13.15	46.47	Low
Total # activity zones - 14	# structured - 8 and # unstructured - 6		21662.3	100.0		181.33	22.01	708.55	488.11	203.34	889.88	# Low – 14 # Moderate – 0 # Adequate - 0

Table F.2: A summary of microclimatic comfort evaluation results for School-B

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Sports pitch (Multiple)	2552.28	20.1	V	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-2S	Structured	Hard court	506.34	4.0	V	7.71	0.00	92.29	0.00	7.71	100.00	Low
AZ-3S	Structured	Play equipment-I	377.9	3.0	M	0.00	20.09	69.38	10.53	20.09	69.38	Low
AZ-4S	Structured	Play equipment-II	623.93	4.9	M	24.53	0.00	34.70	40.77	24.53	59.23	Low
AZ-5S	Structured	Sand pit	71.44	0.6	L	0.00	0.00	6.40	93.60	0.00	6.40	Low
AZ-6S	Structured	COLA	50.32	0.4	L	93.60	0.00	6.40	0.00	93.60	100.00	Low
AZ-7US	Unstructured	Hard paved area	1251	9.8	V	27.01	0.00	72.99	0.00	27.01	100.00	Low
AZ-8US	Unstructured	Classroom Verandah-I	104.49	0.8	M	49.79	8.90	41.31	0.00	58.69	91.10	Low
AZ-9US	Unstructured	Classroom Verandah-II	19.97	0.2	M	90.44	0.00	9.56	0.00	90.44	100.00	Adequate
AZ-10US	Unstructured	Green area-I	394.3	3.1	M	7.35	0.00	53.54	39.10	7.35	60.90	Low
AZ-11US	Unstructured	Grassed area	4776.59	37.6	M	10.62	0.44	26.48	62.45	11.06	37.10	Low
AZ-12US	Unstructured	Green area-II	1988.24	15.6	M	23.33	1.06	21.67	53.95	24.39	45.00	Low
Total # activity zones - 12	# structured - 6 and # unstructured - 6		12716.80	100.0		334.39	30.50	534.72	300.40	364.88	869.11	# Low – 11 # Moderate – 0 # Adequate - 1

Table F.3: A summary of microclimatic comfort evaluation results for School-C

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Hard court-I	1469.87	10.1	V	6.24	0.00	85.52	8.24	6.24	91.76	Low
AZ-2S	Structured	Play equipment-I	348.04	2.4	M	57.35	0.00	42.65	0.00	57.35	100.00	Low
AZ-3S	Structured	Hard court-II	351.36	2.4	V	47.91	0.00	52.09	0.00	47.91	100.00	Low
AZ-4S	Structured	Play equipment-II	150.12	1.0	M	52.35	0.00	47.65	0.00	52.35	100.00	Low
AZ-5S	Structured	Play equipment-III	80.15	0.5	M	78.73	0.00	21.27	0.00	78.73	100.00	Low
AZ-6S	Structured	Sand pit	107.78	0.7	L	68.30	0.00	30.00	1.71	68.30	98.29	Low
AZ-7S	Structured	Paint marking	194.81	1.3	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-8S	Structured	Play equipment-IV	394.37	2.7	M	37.00	0.00	62.26	0.74	37.00	99.26	Low
AZ-9US	Unstructured	Classroom Verandah-I	76.85	0.5	M	100.00	0.00	0.00	0.00	100.00	100.00	Low
AZ-10US	Unstructured	Classroom Verandah-II	79.72	0.5	M	100.00	0.00	0.00	0.00	100.00	100.00	Low
AZ-11US	Unstructured	Classroom Verandah-III	61.40	0.4	M	100.00	0.00	0.00	0.00	100.00	100.00	Low
AZ-12US	Unstructured	Classroom Verandah-IV	53.74	0.4	M	100.00	0.00	0.00	0.00	100.00	100.00	Low
AZ-13US	Unstructured	Hard paved area	2201.45	15.1	V	23.74	0.00	76.26	0.00	23.74	100.00	Low
AZ-14US	Unstructured	Green area-I	35.53	0.2	M	35.27	0.00	64.73	0.00	35.27	100.00	Low
AZ-15US	Unstructured	Green area-II	170.01	1.2	M	52.40	0.00	47.60	0.00	52.40	100.00	Low
AZ-16US	Unstructured	Green area-III	152.19	1.0	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-17US	Unstructured	Green area-IV	105.30	0.7	M	90.48	0.00	10.02	0.00	90.48	100.50	Low
AZ-18US	Unstructured	Grassed area-I	494.48	3.4	M	0.00	0.00	96.81	3.19	0.00	96.81	Low
AZ-19US	Unstructured	Grassed area-II	8048.98	55.2	M	12.91	0.00	72.10	14.99	12.91	85.01	Low
Total # activity zones - 19	# structured - 8 and # unstructured - 11		14576.15	100.0		962.68	0.00	908.96	28.86	962.68	1871.64	# Low – 19 # Moderate – 0 # Adequate - 0

Table F.4: A summary of microclimatic comfort evaluation results for School-D

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Sports pitch (Single)	3256.00	23.5	V	0.00	0.00	20.54	79.46	0.00	20.54	Low
AZ-2S	Structured	Play equipment-I	621.99	4.5	M	25.23	0.00	74.77	0.00	25.23	100.00	Low
AZ-3S	Structured	Play equipment-II	625.50	4.5	M	12.71	0.00	57.03	30.26	12.71	69.74	Low
AZ-4S	Structured	Sand pit-I	44.39	0.3	L	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-5S	Structured	Hard court-I	919.76	6.6	V	0.00	0.00	76.28	23.72	0.00	76.28	Low
AZ-6S	Structured	Hard court-II	88.27	0.6	V	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-7S	Structured	Play equipment-III	317.28	2.3	M	17.73	0.00	82.27	0.00	17.73	100.00	Low
AZ-8S	Structured	Sand pit-II	233.20	1.7	L	16.66	0.00	66.88	16.46	16.66	83.54	Low
AZ-9US	Unstructured	Hard paved area	3336.46	24.0	V	28.53	0.00	61.97	9.50	28.53	90.50	Low
AZ-10US	Unstructured	Grassed area	3492.01	25.2	M	9.00	0.00	33.82	57.19	9.00	42.81	Low
AZ-11US	Unstructured	Green area-I	219.71	1.6	M	12.02	0.00	87.98	0.00	12.02	100.00	Low
AZ-12US	Unstructured	Green area-II	83.30	0.6	M	9.60	0.00	90.40	0.00	9.60	100.00	Low
AZ-13US	Unstructured	Green area-III	367.05	2.6	M	16.58	0.00	62.08	21.34	16.58	78.66	Low
AZ-14US	Unstructured	Green area-IV	270.03	1.9	M	52.89	0.00	47.11	0.00	52.89	100.00	Low
Total # activity zones - 14	# structured - 8 and # unstructured - 6		13874.95	100.0		200.96	0.00	961.11	237.93	200.96	1162.07	# Low – 14 # Moderate – 0 # Adequate - 0

Table F.5: A summary of microclimatic comfort evaluation results for School-E

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Sports pitch (Multiple)	3786.33	19.1	V	10.08	0.00	56.33	33.59	10.08	66.41	Low
AZ-2S	Structured	Hard court-I	1930.98	9.7	V	17.49	0.00	82.51	0.00	17.49	100.00	Low
AZ-3S	Structured	Play equipment-I	660.47	3.3	M	0.00	0.00	69.14	30.86	0.00	69.14	Low
AZ-4S	Structured	Play equipment-II	145.71	0.7	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-5S	Structured	Sand pit	94.03	0.5	L	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-6S	Structured	Play equipment-III	386.22	1.9	M	49.58	0.00	35.47	14.95	49.58	85.05	Low
AZ-7US	Unstructured	Classroom Verandah	187.03	0.9	M	41.40	0.00	58.60	0.00	41.40	100.00	Low
AZ-8US	Unstructured	Hard paved area	4196.16	21.2	V	38.89	0.00	60.83	0.28	38.89	99.72	Low
AZ-9US	Unstructured	Grassed area	5786.14	29.2	M	35.12	0.00	41.97	22.91	35.12	77.09	Low
AZ-10US	Unstructured	Green area-I	722.59	3.6	M	35.57	0.00	60.49	3.94	35.57	96.06	Low
AZ-11US	Unstructured	Green area-II	176.71	0.9	M	87.77	0.00	12.23	0.00	87.77	100.00	Low
AZ-12US	Unstructured	Green area-III	176.71	0.9	M	81.42	0.00	18.58	0.00	81.42	100.00	Low
AZ-13US	Unstructured	Green area-IV	287.62	1.5	M	4.07	0.00	95.93	0.00	4.07	100.00	Low
AZ-14US	Unstructured	Green area-V	176.54	0.9	M	11.71	0.00	88.29	0.00	11.71	100.00	Low
AZ-15US	Unstructured	Green area-VI	864.19	4.4	M	48.49	0.00	51.51	0.00	48.49	100.00	Low
AZ-16US	Unstructured	Green area-VII	238.58	1.2	M	32.01	0.00	67.99	0.00	32.01	100.00	Low
Total # activity zones - 16	# structured - 6 and # unstructured - 10		19816.01	100.0		493.61	0.00	999.86	106.53	493.61	1493.47	# Low – 16 # Moderate – 0 # Adequate - 0

Table F.6: A summary of microclimatic comfort evaluation results for School-F

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Metabolic activity rate	Mean % cover				Mean shade cover (%)	Mean wind cover (%)	Microclimatic comfort evaluation
						LU-I	LU-II	LU-III	LU-IV			
AZ-1S	Structured	Sports pitch (Multiple)	4151.61	16.3	V	0.00	0.00	0.00	100.00	0.00	0.00	Low
AZ-2S	Structured	BMX - Track	2062.76	8.1	V	0.00	0.00	23.60	76.40	0.00	23.60	Low
AZ-3S	Structured	Hard court-I	250.43	1.0	V	0.00	0.00	71.13	28.87	0.00	71.13	Low
AZ-4S	Structured	Play equipment-I	373.47	1.5	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-5S	Structured	Paint marking-I	111.99	0.4	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-6S	Structured	Sand pit-I	77.41	0.3	L	38.07	0.00	61.93	0.00	38.07	100.00	Low
AZ-7S	Structured	Sand pit-II	116.97	0.5	L	34.19	0.00	65.81	0.00	34.19	100.00	Low
AZ-8S	Structured	Sand pit-III	149.68	0.6	L	61.01	0.00	38.99	0.00	61.01	100.00	Low
AZ-9S	Structured	Play equipment-II	338.98	1.3	M	5.85	0.00	94.15	0.00	5.85	100.00	Low
AZ-10S	Structured	Paint marking-II	122.54	0.5	M	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-11S	Structured	Hard court-II	593.82	2.3	V	0.00	0.00	100.00	0.00	0.00	100.00	Low
AZ-12S	Structured	Play equipment-III	279.50	1.1	M	0.00	0.00	6.70	93.30	0.00	6.70	Low
AZ-13S	Structured	Hard court-III	661.29	2.6	V	0.00	0.00	30.70	69.30	0.00	30.70	Low
AZ-14S	Structured	Play equipment-IV	444.63	1.7	M	0.00	7.55	36.22	56.23	7.55	36.22	Low
AZ-15US	Unstructured	Hard paved area	3373.53	13.2	V	32.16	0.55	67.30	0.00	32.70	99.45	Low
AZ-16US	Unstructured	Grassed area	12352.58	48.5	M	0.00	0.00	11.34	88.66	0.00	11.34	Low
Total # activity zones - 16	# structured - 14 and # unstructured - 2		25461.19	100.0		171.28	8.09	907.87	512.76	179.37	1079.15	# Low – 16 # Moderate – 0 # Adequate - 0

Appendix G

A Summary of the Attractiveness Evaluation

This section presents summarises school-wise activity zones' evaluation results of attractiveness.

G.1 Landscape units map of attractiveness evaluation

A sample map of landscape units developed for attractiveness evaluation of School-B.



Figure G.1: A landscape units map of attractiveness of School-B

G.2 A summary of attractiveness results by school

Table G.1: A summary of attractiveness evaluation results for School-A

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Sports pitch (Multiple)	5833.8	26.9	No	Low
AZ-2S	Structured	Sand pit	143.0	0.7	Sand	Adequate
AZ-3S	Structured	BMX - Track	571.8	2.6	Track, Bikes	Adequate
AZ-4S	Structured	Play equipment-I	370.2	1.7	Fixed play equipment	Adequate
AZ-5S	Structured	Hard court-I	744.7	3.4	No	Low
AZ-6S	Structured	Hard court-II	456.9	2.1	No	Low
AZ-7S	Structured	Outdoor Amphitheatre	398.5	1.8	Scooter	Adequate
AZ-8S	Structured	Play equipment-II	462.4	2.1	Fixed play equipment	Adequate
AZ-9US	Unstructured	Classroom Verandah-I	84.7	0.4	No	Low
AZ-10US	Unstructured	Hard paved area	2657.9	12.3	Bikes, scooter, paint markings	Adequate
AZ-11US	Unstructured	Classroom Verandah-II	350.9	1.6	green area	Adequate
AZ-12US	Unstructured	Green area-I	262.8	1.2	No	Low
AZ-13US	Unstructured	Green area-II	998.9	4.6	No	Low
AZ-14US	Unstructured	Grassed area	8325.5	38.4	No	Low
Total # activity zones - 14	# structured - 8 and # unstructured - 6		21662.3	100.0		# Low – 7 # Adequate - 7

Table G.2: A summary of attractiveness evaluation results for School-B

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Sports pitch (Multiple)	2552.28	20.1	No	Low
AZ-2S	Structured	Hard court	506.34	4.0	Scooter	Adequate
AZ-3S	Structured	Play equipment-I	377.9	3.0	Fixed play equipment	Adequate
AZ-4S	Structured	Play equipment-II	623.93	4.9	Fixed play equipment	Adequate
AZ-5S	Structured	Sand pit	71.44	0.6	Sand	Adequate
AZ-6S	Structured	COLA	50.32	0.4	No	Low
AZ-7US	Unstructured	Hard paved area	1251	9.8	Scooter, Bikes	Adequate
AZ-8US	Unstructured	Classroom Verandah-I	104.49	0.8	Loose parts	Adequate
AZ-9US	Unstructured	Classroom Verandah-II	19.97	0.2	No	Low
AZ-10US	Unstructured	Green area-I	394.3	3.1	No	Low
AZ-11US	Unstructured	Grassed area	4776.59	37.6	Dense vegetation, Loose parts	Adequate
AZ-12US	Unstructured	Green area-II	1988.24	15.6	Dense vegetation, Bike track	Adequate
Total # activity zones - 12	# structured - 6 and # unstructured - 6		12716.80	100.0		# Low – 4 # Adequate - 8

Table G.3: A summary of attractiveness evaluation results for School-C

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Hard court-I	1469.87	10.1	Skateboard and Bicycle	Adequate
AZ-2S	Structured	Play equipment-I	348.04	2.4	Fixed play equipment	Adequate
AZ-3S	Structured	Hard court-II	351.36	2.4	Skateboard and Bicycle	Adequate
AZ-4S	Structured	Play equipment-II	150.12	1.0	Fixed play equipment	Adequate
AZ-5S	Structured	Play equipment-III	80.15	0.5	Fixed play equipment	Adequate
AZ-6S	Structured	Sand pit	107.78	0.7	Sand	Adequate
AZ-7S	Structured	Paint marking	194.81	1.3	Play markings	Adequate
AZ-8S	Structured	Play equipment-IV	394.37	2.7	Fixed play equipment	Adequate
AZ-9US	Unstructured	Classroom Verandah-I	76.85	0.5	No	Low
AZ-10US	Unstructured	Classroom Verandah-II	79.72	0.5	No	Low
AZ-11US	Unstructured	Classroom Verandah-III	61.40	0.4	No	Low
AZ-12US	Unstructured	Classroom Verandah-IV	53.74	0.4	No	Low
AZ-13US	Unstructured	Hard paved area	2201.45	15.1	Skateboard and Bicycle	Adequate
AZ-14US	Unstructured	Green area-I	35.53	0.2	No	Low
AZ-15US	Unstructured	Green area-II	170.01	1.2	No	Low
AZ-16US	Unstructured	Green area-III	152.19	1.0	No	Low
AZ-17US	Unstructured	Green area-IV	105.30	0.7	Dense vegetation and loose parts	Adequate
AZ-18US	Unstructured	Grassed area-I	494.48	3.4	No	Low
AZ-19US	Unstructured	Grassed area-II	8048.98	55.2	No	Low
Total # activity zones - 19	# structured - 8 and # unstructured - 11		14576.15	100.0		# Low – 9 # Adequate - 10

Table G.4: A summary of attractiveness evaluation results for School-D

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Sports pitch (Single)	3256.00	23.5	No	Low
AZ-2S	Structured	Play equipment-I	621.99	4.5	Play equipment	Adequate
AZ-3S	Structured	Play equipment-II	625.50	4.5	Play equipment	Adequate
AZ-4S	Structured	Sand pit-I	44.39	0.3	Sand	Adequate
AZ-5S	Structured	Hard court-I	919.76	6.6	No	Low
AZ-6S	Structured	Hard court-II	88.27	0.6	Scooter, bikes	Adequate
AZ-7S	Structured	Play equipment-III	317.28	2.3	Play equipment	Adequate
AZ-8S	Structured	Sand pit-II	233.20	1.7	Sand	Adequate
AZ-9US	Unstructured	Hard paved area	3336.46	24.0	Scooter, bikes and paint markings	Adequate
AZ-10US	Unstructured	Grassed area	3492.01	25.2	No	Low
AZ-11US	Unstructured	Green area-I	219.71	1.6	Dense green vegetation and loose parts	Adequate
AZ-12US	Unstructured	Green area-II	83.30	0.6	No	Low
AZ-13US	Unstructured	Green area-III	367.05	2.6	No	Low
AZ-14US	Unstructured	Green area-IV	270.03	1.9	Dense green vegetation and loose parts	Adequate
Total # activity zones - 14	# structured - 8 and # unstructured - 6		13874.95	100.0		# Low – 5 # Adequate - 9

Table G.5: A summary of attractiveness evaluation results for School-E

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Sports pitch (Multiple)	3786.33	19.1	No	Low
AZ-2S	Structured	Hard court-I	1930.98	9.7	Scooters, Bikes	Adequate
AZ-3S	Structured	Play equipment-I	660.47	3.3	Play equipment	Adequate
AZ-4S	Structured	Play equipment-II	145.71	0.7	Play equipment	Adequate
AZ-5S	Structured	Sand pit	94.03	0.5	Sand	Adequate
AZ-6S	Structured	Play equipment-III	386.22	1.9	Play equipment	Adequate
AZ-7US	Unstructured	Classroom Verandah	187.03	0.9	No	Low
AZ-8US	Unstructured	Hard paved area	4196.16	21.2	Scooters, Bikes	Adequate
AZ-9US	Unstructured	Grassed area	5786.14	29.2	Obstacle course	Adequate
AZ-10US	Unstructured	Green area-I	722.59	3.6	No	Low
AZ-11US	Unstructured	Green area-II	176.71	0.9	No	Low
AZ-12US	Unstructured	Green area-III	176.71	0.9	No	Low
AZ-13US	Unstructured	Green area-IV	287.62	1.5	No	Low
AZ-14US	Unstructured	Green area-V	176.54	0.9	No	Low
AZ-15US	Unstructured	Green area-VI	864.19	4.4	Dense green vegetation	Adequate
AZ-16US	Unstructured	Green area-VII	238.58	1.2	No	Low
Total # activity zones - 16	# structured - 6 and # unstructured - 10		19816.01	100.0		# Low – 8 # Adequate - 8

Table G.6: A summary of attractiveness evaluation results for School-F

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	Attractors	Attractiveness evaluation
AZ-1S	Structured	Sports pitch (Multiple)	4151.61	16.3	No	Low
AZ-2S	Structured	BMX - Track	2062.76	8.1	Bikes	Adequate
AZ-3S	Structured	Hard court-I	250.43	1.0	No	Low
AZ-4S	Structured	Play equipment-I	373.47	1.5	Fixed play equipment	Adequate
AZ-5S	Structured	Paint marking-I	111.99	0.4	Play marking	Adequate
AZ-6S	Structured	Sand pit-I	77.41	0.3	Sand	Adequate
AZ-7S	Structured	Sand pit-II	116.97	0.5	Sand	Adequate
AZ-8S	Structured	Sand pit-III	149.68	0.6	Sand	Adequate
AZ-9S	Structured	Play equipment-II	338.98	1.3	Fixed play equipment	Adequate
AZ-10S	Structured	Paint marking-II	122.54	0.5	Play marking	Adequate
AZ-11S	Structured	Hard court-II	593.82	2.3	No	Low
AZ-12S	Structured	Play equipment-III	279.50	1.1	Fixed play equipment	Adequate
AZ-13S	Structured	Hard court-III	661.29	2.6	No	Low
AZ-14S	Structured	Play equipment-IV	444.63	1.7	Fixed play equipment and sand	Adequate
AZ-15US	Unstructured	Hard paved area	3373.53	13.2	Bikes, scooter	Adequate
AZ-16US	Unstructured	Grassed area	12352.58	48.5	No	Low
Total # activity zones - 16	# structured - 14 and # unstructured - 2		25461.19	100.0		# Low – 5 # Adequate - 11

Appendix H

A Summary of Sun Protection Behaviour Design Evaluation

This section summarise school activity zone evaluation results of SPB design.

Table H.1: A summary of sun protection behaviour design evaluation results for School-A

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Sports pitch (Multiple)	5833.8	26.9	Low	Low	Low	No
AZ-2S	Structured	Sand pit	143.0	0.7	Moderate	Low	Adequate	Low
AZ-3S	Structured	BMX - Track	571.8	2.6	Low	Low	Adequate	Low
AZ-4S	Structured	Play equipment-I	370.2	1.7	Low	Low	Adequate	Low
AZ-5S	Structured	Hard court-I	744.7	3.4	Low	Low	Low	No
AZ-6S	Structured	Hard court-II	456.9	2.1	Low	Low	Low	No
AZ-7S	Structured	Outdoor Amphitheatre	398.5	1.8	Moderate	Low	Adequate	Low
AZ-8S	Structured	Play equipment-II	462.4	2.1	Low	Low	Adequate	Low
AZ-9US	Unstructured	Classroom Verandah-I	84.7	0.4	Low	Low	Low	No
AZ-10US	Unstructured	Hard paved area	2657.9	12.3	Low	Low	Adequate	Low
AZ-11US	Unstructured	Classroom Verandah-II	350.9	1.6	Moderate	Low	Adequate	Low
AZ-12US	Unstructured	Green area-I	262.8	1.2	Low	Low	Low	No
AZ-13US	Unstructured	Green area-II	998.9	4.6	Low	Low	Low	No
AZ-14US	Unstructured	Grassed area	8325.5	38.4	Low	Low	Low	No
Total # activity zones - 14	# structured - 8 and # unstructured - 6		21662.3	100.0	# Low - 11 # Moderate - 3 # Adequate - 0	# Low - 14 # Moderate - 0 # Adequate - 0	# Low - 7 # Adequate - 7	# No - 7 # Low - 7 # Moderate - 0 # High - 0

Table H.2: A summary of sun protection behaviour design evaluation results for School-B

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Sports pitch (Multiple)	2552.28	20.1	Low	Low	Low	No
AZ-2S	Structured	Hard court	506.34	4.0	Low	Low	Adequate	Low
AZ-3S	Structured	Play equipment-I	377.9	3.0	Low	Low	Adequate	Low
AZ-4S	Structured	Play equipment-II	623.93	4.9	Moderate	Low	Adequate	Low
AZ-5S	Structured	Sand pit	71.44	0.6	Low	Low	Adequate	Low
AZ-6S	Structured	COLA	50.32	0.4	Adequate	Low	Low	Low
AZ-7US	Unstructured	Hard paved area	1251	9.8	Low	Low	Adequate	Low
AZ-8US	Unstructured	Classroom Verandah-I	104.49	0.8	Moderate	Low	Adequate	Low
AZ-9US	Unstructured	Classroom Verandah-II	19.97	0.2	Moderate	Adequate	Low	Low
AZ-10US	Unstructured	Green area-I	394.3	3.1	Low	Low	Low	No
AZ-11US	Unstructured	Grassed area	4776.59	37.6	Low	Low	Adequate	Low
AZ-12US	Unstructured	Green area-II	1988.24	15.6	Low	Low	Adequate	Low
Total # activity zones - 12	# structured - 6 and # unstructured - 6		12716.80	100.0	# Low - 8 # Moderate - 3 # Adequate - 1	# Low - 11 # Moderate - 0 # Adequate - 1	# Low - 4 # Adequate - 8	# No - 2 # Low - 10 # Moderate - 0 # High - 0

Table H.3: A summary of sun protection behaviour design evaluation results for School-C

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Hard court-I	1469.87	10.1	Low	Low	Adequate	Low
AZ-2S	Structured	Play equipment-I	348.04	2.4	Moderate	Low	Adequate	Low
AZ-3S	Structured	Hard court-II	351.36	2.4	Moderate	Low	Adequate	Low
AZ-4S	Structured	Play equipment-II	150.12	1.0	Moderate	Low	Adequate	Low
AZ-5S	Structured	Play equipment-III	80.15	0.5	Moderate	Low	Adequate	Low
AZ-6S	Structured	Sand pit	107.78	0.7	Moderate	Low	Adequate	Low
AZ-7S	Structured	Paint marking	194.81	1.3	Low	Low	Adequate	Low
AZ-8S	Structured	Play equipment-IV	394.37	2.7	Moderate	Low	Adequate	Low
AZ-9US	Unstructured	Classroom Verandah-I	76.85	0.5	Moderate	Low	Low	No
AZ-10US	Unstructured	Classroom Verandah-II	79.72	0.5	Adequate	Low	Low	Low
AZ-11US	Unstructured	Classroom Verandah-III	61.40	0.4	Adequate	Low	Low	Low
AZ-12US	Unstructured	Classroom Verandah-IV	53.74	0.4	Adequate	Low	Low	Low
AZ-13US	Unstructured	Hard paved area	2201.45	15.1	Low	Low	Adequate	Low
AZ-14US	Unstructured	Green area-I	35.53	0.2	Moderate	Low	Low	No
AZ-15US	Unstructured	Green area-II	170.01	1.2	Moderate	Low	Low	No
AZ-16US	Unstructured	Green area-III	152.19	1.0	Low	Low	Low	No
AZ-17US	Unstructured	Green area-IV	105.30	0.7	Adequate	Low	Adequate	Moderate
AZ-18US	Unstructured	Grassed area-I	494.48	3.4	Low	Low	Low	No
AZ-19US	Unstructured	Grassed area-II	8048.98	55.2	Low	Low	Low	No
Total # activity zones - 19	# structured - 8 and # unstructured - 11		14576.15	100.0	# Low – 6 # Moderate – 9 # Adequate - 4	# Low – 19 # Moderate – 0 # Adequate - 0	# Low – 9 # Adequate - 10	# No – 6 # Low – 12 # Moderate - 1 # High - 0

Table H.4: A summary of sun protection behaviour design evaluation results for School-D

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Sports pitch (Single)	3256.00	23.5	Low	Low	Low	No
AZ-2S	Structured	Play equipment-I	621.99	4.5	Low	Low	Adequate	Low
AZ-3S	Structured	Play equipment-II	625.50	4.5	Low	Low	Adequate	Low
AZ-4S	Structured	Sand pit-I	44.39	0.3	Low	Low	Adequate	Low
AZ-5S	Structured	Hard court-I	919.76	6.6	Low	Low	Low	No
AZ-6S	Structured	Hard court-II	88.27	0.6	Low	Low	Adequate	Low
AZ-7S	Structured	Play equipment-III	317.28	2.3	Low	Low	Adequate	Low
AZ-8S	Structured	Sand pit-II	233.20	1.7	Low	Low	Adequate	Low
AZ-9US	Unstructured	Hard paved area	3336.46	24.0	Low	Low	Adequate	Low
AZ-10US	Unstructured	Grassed area	3492.01	25.2	Low	Low	Low	No
AZ-11US	Unstructured	Green area-I	219.71	1.6	Low	Low	Adequate	Low
AZ-12US	Unstructured	Green area-II	83.30	0.6	Low	Low	Low	No
AZ-13US	Unstructured	Green area-III	367.05	2.6	Low	Low	Low	No
AZ-14US	Unstructured	Green area-IV	270.03	1.9	Moderate	Low	Adequate	Low
Total # activity zones - 14	# structured - 8 and # unstructured - 6		13874.95	100.0	# Low – 13 # Moderate – 1 # Adequate - 0	# Low – 14 # Moderate – 0 # Adequate - 0	# Low – 5 # Adequate - 9	# No – 5 # Low – 9 # Moderate - 0 # High - 0

Table H.5: A summary of sun protection behaviour design evaluation results for School-E

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Sports pitch (Multiple)	3786.33	19.1	Low	Low	Low	No
AZ-2S	Structured	Hard court-I	1930.98	9.7	Low	Low	Adequate	Low
AZ-3S	Structured	Play equipment-I	660.47	3.3	Low	Low	Adequate	Low
AZ-4S	Structured	Play equipment-II	145.71	0.7	Low	Low	Adequate	Low
AZ-5S	Structured	Sand pit	94.03	0.5	Low	Low	Adequate	Low
AZ-6S	Structured	Play equipment-III	386.22	1.9	Moderate	Low	Adequate	Low
AZ-7US	Unstructured	Classroom Verandah	187.03	0.9	Moderate	Low	Low	No
AZ-8US	Unstructured	Hard paved area	4196.16	21.2	Moderate	Low	Adequate	Low
AZ-9US	Unstructured	Grassed area	5786.14	29.2	Moderate	Low	Adequate	Low
AZ-10US	Unstructured	Green area-I	722.59	3.6	Moderate	Low	Low	No
AZ-11US	Unstructured	Green area-II	176.71	0.9	Adequate	Low	Low	Low
AZ-12US	Unstructured	Green area-III	176.71	0.9	Adequate	Low	Low	Low
AZ-13US	Unstructured	Green area-IV	287.62	1.5	Low	Low	Low	No
AZ-14US	Unstructured	Green area-V	176.54	0.9	Low	Low	Low	No
AZ-15US	Unstructured	Green area-VI	864.19	4.4	Moderate	Low	Adequate	Low
AZ-16US	Unstructured	Green area-VII	238.58	1.2	Moderate	Low	Low	No
Total # activity zones - 16	# structured - 6 and # unstructured - 10		19816.01	100.0	# Low - 7 # Moderate - 7 # Adequate - 2	# Low - 16 # Moderate - 0 # Adequate - 0	# Low - 8 # Adequate - 8	# No - 6 # Low - 10 # Moderate - 0 # High - 0

Table H.6: A summary of sun protection behaviour SPB design evaluation results for School-F

AZ Code	Activity zone category	Activity zone	Area in sq.m.	Mean % cover	UVR protection evaluation	Microclimatic comfort evaluation	Attractiveness evaluation	SPB design outcome
AZ-1S	Structured	Sports pitch (Multiple)	4151.61	16.3	Low	Low	Low	No
AZ-2S	Structured	BMX - Track	2062.76	8.1	Low	Low	Adequate	Low
AZ-3S	Structured	Hard court-I	250.43	1.0	Low	Low	Low	No
AZ-4S	Structured	Play equipment-I	373.47	1.5	Low	Low	Adequate	Low
AZ-5S	Structured	Paint marking-I	111.99	0.4	Low	Low	Adequate	Low
AZ-6S	Structured	Sand pit-I	77.41	0.3	Moderate	Low	Adequate	Low
AZ-7S	Structured	Sand pit-II	116.97	0.5	Low	Low	Adequate	Low
AZ-8S	Structured	Sand pit-III	149.68	0.6	Low	Low	Adequate	Low
AZ-9S	Structured	Play equipment-II	338.98	1.3	Low	Low	Adequate	Low
AZ-10S	Structured	Paint marking-II	122.54	0.5	Low	Low	Adequate	Low
AZ-11S	Structured	Hard court-II	593.82	2.3	Low	Low	Low	No
AZ-12S	Structured	Play equipment-III	279.50	1.1	Low	Low	Adequate	Low
AZ-13S	Structured	Hard court-III	661.29	2.6	Low	Low	Low	No
AZ-14S	Structured	Play equipment-IV	444.63	1.7	Low	Low	Adequate	Low
AZ-15US	Unstructured	Hard paved area	3373.53	13.2	Moderate	Low	Adequate	Low
AZ-16US	Unstructured	Grassed area	12352.58	48.5	Low	Low	Low	No
Total # activity zones - 16	# structured - 14 and # unstructured - 2		25461.19	100.0	# Low - 14 # Moderate - 2 # Adequate - 0	# Low - 16 # Moderate - 0 # Adequate - 0	# Low - 5 # Adequate - 11	# No - 5 # Low - 11 # Moderate - 0 # High - 0