Exploring Ultraviolet B in the Landscape

by

Victoria S.K. Cox

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EXPLORING ULTRAVIOLET B RADIATION IN THE LANDSCAPE

Victoria S.K. Cox
University of Guelph, 2013

Advisor:
Dr. Robert D. Brown

Ultraviolet B (UVB) radiation from the sun is the chief cause of skin cancer and is also involved in the development of Vitamin D in humans. This poses an interesting challenge, especially for people living in locations at mid to high latitudes. Through an integrative research review and controlled testing the amount of UVB humans receive in the landscape has been explored. Two existing computer models along with personal dosimeter badges were used to evaluate how much UVB students at a school in Waterloo, Ontario received under various conditions in February, 2013. Results showed that it is possible to get the equivalent of 1000 I.U. of vitamin D in February in Waterloo under ideal weather conditions, but not in most conditions. With this information, a guide has been created to optimize UVB for outdoor spaces in all seasons that children may use in northern climates. The design guide includes a summary of the geophysical variables that affect how much UVB reaches the earth’s surface and key concepts to understand including the difference between diffuse and direct radiation. This study provides evidence-based research in the area of climate responsive landscape architecture.

KEY WORDS: UVB, vitamin D, landscape, climate responsive design.
**Table of Contents**

Abstract ... ii  
Table of Contents ... iii  
Acknowledgements ... v  
List of Tables ... vi  
List of Figures ... vii  

1.0 Introduction ... 1  
1.1 The need for UVB Research and its role in Landscape Architecture ... 2  
1.2 Goals and Objectives ... 3  
1.3 Thesis Overview ... 3  

2.0 Literature Review ... 5  
2.1 Overview of Ultraviolet Radiation ... 5  
2.1.1 UVA and UVB Effects on Humans ... 5  
2.2 Variables Affecting UVB at the Earth’s Surface ... 7  
2.2.1 Solar Zenith Angle and Distance from the Sun ... 8  
2.2.2 Stratospheric Ozone ... 9  
2.2.3 Ozone, Gases and Aerosols in the Troposphere ... 10  
2.2.4 Clouds ... 11  
2.2.5 Surface Albedo and Altitude ... 13  
2.2.6 Trees and Objects in the Landscape ... 14  
2.2.7 Additional Variables ... 15  
2.3 A Meta-Analysis of Vitamin D and Skin Cancer ... 16  
2.3.1 Measurement of Risk Factors ... 18  
2.3.2 Comparing Previous Studies ... 20  
2.3.3 Identifying Missing Links ... 23  
2.4 Computer Modeling of UVB in the Landscape ... 24  
2.4.1 Field Testing FastRT and VitD_quartMED Models ... 25
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List of Tables

Table 1 – UVB Transmission of Significant Cloud Types ... 12
Table 2 – Mean Values of Albedo... 13
Table 3 – The UVA and UVB radiation and Visible Light Albedo from different Surfaces ... 14
Table 4 – Fitzpatrick Skin Type Scale ... 16
Table 5 – Recommended UVR exposure ... 22
Table 6 - Average UVB values found during test days at Millen Woods and model outputs ... 32
Table 7 – Summary of Model Results ... 36
Table 8 – Geophysical Variable Modifiable by Humans ... 40
List of Figures

Figure 1 – Vitamin D synthesis through the skin ... 6
Figure 2 – UVA and UVB penetrating in the skin ...7
Figure 3 – Global Variation in UVR ... 8
Figure 4 – The borders of the areas where 1 SDD can be obtained within 1 h near noon ... 21
Figure 5 – Data Collection ... 28
Figure 6 – Data Collection ... 28
Figure 7 – Plan view of Millen Woods School ... 29
Figure 8 – Section A of the school yard ... 30
Figure 9 – Section A of the school yard ... 30
Figure 10 – Section B of the school yard ... 30
Figure 11 – Section B of the school yard ... 30
Figure 12 – Section C of the school yard ... 30
Figure 13 – Section C of the school yard ... 30
Figure 14 – Test days at Millen Woods ... 33
Figure 15 – Design Guide ... 42
1.0 Introduction

Solar radiation has caused a considerable global disease burden and resulted in 60,000 deaths worldwide in the year 2000, primarily due to malignant melanoma caused by ultraviolet B radiation (Lucas, 2010). This has resulted in initiatives to increase shade in the landscape in an attempt to reduce skin cancer rates as it is one of the most preventable cancers (Wright, Reeder, Bodeker, Gray & Cox, 2007). Over the past decade, shade guidelines and policies have been adapted by governments in Australia, Canada and the United States.

Although skin cancer is a major health concern, exposure to ultraviolet radiation (UVR), specifically the ultraviolet B radiation (UVB) wavelength, also results in many positive health benefits. UVB is a biologically active wavelength from the sun that reaches the earth’s surface and is the chief cause of skin reddening and skin cancer, yet it also aids in the development of Vitamin D (Field & Bishop, 2011). An interesting challenge is presented here because vitamin D is formed in the skin and recent studies have compellingly concluded that the synthesis of vitamin D in the skin is directly linked to musculoskeletal health and risk indicators relating to cancer, cardiovascular disease and multiple sclerosis (Grant, 2010). There is some argument amongst researchers regarding optimal levels of vitamin D required to prevent cancer or to improve outcomes of cancer (Field & Bishop, 2011).

It is known that vitamin D is crucial to health, and many individuals worldwide have suboptimal levels (Field & Bishop, 2011). The fact that UVB plays a role in causing major health complications while also resulting in health benefits poses a challenge, especially for people living in locations at mid to high latitudes with great seasonal variability, like Canada. After reviewing the medical literature, one study concluded that that most Canadians have vitamin D insufficiency, with a considerable proportion of the population sustaining a severe deficiency (Schwalfenberg, Genuis & Hiltz, 2010). “There is a need for studies into the required UVB dose for maintaining optimal levels of vitamin D, whereas avoiding the damaging effects of overexposure” (Seckmeyer et al., 2012, p. 215).

Although there has been an increase in the number of studies involving UVR exposure during the spring and summer months in mid to high latitudes, very little is known about UVR exposure outside of those seasons (Thieden, Philipsen & Wulf, 2005). With most planning and
landscape architecture researchers focusing on modifying the landscape in the summer months, due to high levels of solar radiation, the winter is less often considered, nor the impending likelihood of vitamin D deficiency. There is a need for research that explores how much UVB is too much, causing skin damage, and how much is too little, resulting in Vitamin D deficiency (Fioletov, McArthur, Mathews & Marrett, 2010; Seckmeyer et al., 2012). This research aims to enhance the design of landscapes, at mid to high latitudes, through evidence-based research that examines the required UVB dose for maintaining optimal levels of Vitamin D, while avoiding the damaging effects of sun over-exposure at all times of the year.

### 1.1 The Need for UVB Research and Its Role in Landscape Architecture

With shade guidelines already being published for major Canadian cities such as Toronto, Ontario, smaller cities like Waterloo, Ontario have recently adapted their own guidelines and governments are starting to formally adopt them. It is important to note that increasing skin cancer rates are a driving force behind the shade guidelines; however, due to Canada’s geographical location, many places only receive dangerous levels of solar radiation for a part of the year. It is known that people in the mid to high latitudes have little to no access to UVB rays from some point in autumn to some point in spring. As a result, many Canadians are vitamin D deficient and with many new studies arising demonstrating the potential health benefits of vitamin D, this area requires further investigation. It is currently unknown how best to advise different populations on how to balance the need to avoid melanoma with the need to avoid vitamin D deficiency (Field & Bishop, 2011). However, it is clear that rapid progress is now taking place in understanding these factors which will likely lead to improved health internationally in the future. With many geophysical variables, including latitude and solar zenith in addition to skin type, diet, etc., affecting how much UVB a person is receiving, “it is not easy as of yet to give practical advice to different populations that enables individuals to achieve ‘optimal’ levels of vitamin D, whilst avoiding skin cancer” (Field and Newton-Bishop, 2011, p. 201).

The purpose of this study is to provide evidence-based research and to provide a guide for optimizing UVB in the landscape throughout the year in northern latitudes. This research has
the potential to assist in improving human health by exploring optimal levels of UVB to achieve vitamin D sufficiency, while avoiding sun over-exposure and taking into account Canada’s seasonal variability. A 2008 study states that “given the importance of vitamin D to human health and the fact that sunlight is the major source of vitamin D for humans, particularly in the summer months, further research is indeed needed to develop valid, reliable, inexpensive tools to quantify vitamin D from sunlight” (McCarty, 2008, p. 1100).

1.2 Goals and Objectives

The goal of this research is to investigate the amount of UVB radiation that people are exposed to in the landscape, to create evidence-based research that can inform the design of various landscapes. This goal will be achieved through the following objectives:

1. To gain understanding of UVB in the landscape at mid to high latitudes;
2. To gain an understanding of the information pertaining to maintaining optimal levels of vitamin D while avoiding the negative effects of over-exposure to UVB;
3. To test two existing computer models against measured UVB values for both controlled situations as well as a field study with students in a school yard; and
4. To discuss how this information can be applied to landscape architecture.

1.3 Thesis Overview

Addressing the first two objectives of this thesis, Chapter 2 reviews past research pertaining to UVB, factors affecting UVB reaching the earth’s surface and computer modeling of UVB. The chapter provides an overview of past research, synthesizing information from previous studies through an integrative research review. Addressing objective 3, Chapter 3 outlines the methodological approaches used in this study and Chapter 4 provides the results of testing two existing computer models against measured UVB values for both controlled situations as well as a field study. Chapter 5 addresses objective 4 by providing a discussion of the results, implications for climate responsive landscape architecture and provides guidelines for outdoor spaces for children in northern climates and discusses future research. Chapter 6
concludes with the applicability of this research to the profession of landscape architecture, health care professionals and the health of those living at mid to high latitudes.
2.0 Literature Review

2.1 Overview of Ultraviolet Radiation

The sun emits significant energy in the visible light, ultraviolet and infrared bands, and small amounts of energy in the radio, microwave, X-ray and gamma ray bands. UV radiation is part of the electromagnetic spectrum that reaches the earth from the sun. Wavelengths ($\lambda$) in the range of 200-400 nm represent the ultraviolet (UV) region of the electromagnetic spectrum (Madronich et al., 1998). The UV region of the electromagnetic spectrum is further divided into smaller, more specific bands. Radiation of wavelengths between 200nm and 280nm is called UVC, radiation between 280nm and 320nm is called UVB and between 320nm and 400nm is UVA (Moan, 2001). UVC is not freely transmitted through the atmosphere and is absorbed by atmospheric ozone, UVB is 90% absorbed by atmospheric ozone and UVA transmits freely through the earth’s atmosphere, almost completely passing through the ozone layer. UVA and UVB reaching earth’s surface is important to study because of their interactions with biological material and the impending implications for human health (Calbo et al., 2005).

2.1.1 UVA and UVB Effect on Humans

UVA and UVB radiation has both positive and negative effects on human health. UVA are longer wavelengths (320nm-400nm) and penetrate past the top layer of the skin causing damage to connective tissue. UVA wavelengths cause an immediate tan and are responsible for aging and wrinkling of the skin in addition to increasing a person’s risk of skin cancer. UVA wavelengths are the principle cause for melanoma. UVB penetrates less deeply, as the wavelengths are shorter (280nm-320nm) than UVA; however, it still causes burning and aging of the skin after 16-25 hours of exposure to the ‘minimal erythema dose’ (MED), which is defined as the quantity of UV radiation needed to cause slight erythema with clearly defined edges (Mahe, Correa, Godin-Beekmann, Haeffelin, Jegou, Saiag & Beauchet, 2012). UVB is also responsible for delayed tanning, which can cause skin cancer and eye damage, as well as weaken the immune system. However, UVB wavelengths are also responsible for the synthesis of vitamin D in the skin (Lucas et al., 2006). Vitamin D is derived from a pro-vitamin in the skin, 7-dehydrocholesterol, which requires photoactivation by UVB (Field & Newton-Bishop, 2011).
Figure 1 demonstrates how UVB is synthesized into vitamin D in the skin and body organs. The pro-vitamin 7-dehydrocholesterol is metabolized into 25(OH)D₃; this is then metabolized further in the kidneys into 1,25(OH)₂D₃, which is the active metabolite of vitamin D (Field & Newton-Bishop, 2011). Figure 2 illustrates how far UVA and UVB wavelengths penetrate into skin.

Figure 1- Vitamin D synthesis through the skin
2.2 Variables Affecting UVB at the Earth’s Surface

Although the distance between the Earth and the sun is very large, the fluence rate of solar radiation on earth before it passes through the atmosphere is 1360 W/m$^2$ (Moan, 2001). This number, 1360 W/m$^2$, is titled the solar constant. Roughly 40% of the solar constant is reflected back to space while the remaining 60% is responsible for life on earth (Moan, 2001). About 8% of radiation energy reaching the earth’s atmosphere, before attenuation, is within the UV spectrum with 1.3% accounting for UVB wavelengths and 6.7% accounting for UVA wavelengths (Moan, 2001). About 6% of radiant energy within the UV spectrum reaches the earth’s surface at sea level with 0.3% in the UVB wavelength range and 5.7% in the UVA wavelength range.

UVB transmission is controlled largely by ozone and other atmospheric gasses which absorb UVB wavelengths (Kerr & Fioletov, 2008; Madronich et al., 1998). UVB levels at the earth’s surface are also affected by astronomical parameters such as solar zenith angle. Physical characteristics of the earth’s surface, like altitude and albedo as well as meteorological conditions including cloudiness, all affect UV transmission levels (Madronich, McKenzie, Bjorn & Caldwell, 1998; Porfirio, De Souza, Lyra & Maringolo Lemes, 2012). In addition to the
geophysical variables, there are factors that determine how much UVB a person receives in the landscape such as percentage of body exposed to the sun, time in the sun, skin type, age, weight and genetic factors (Fioletov et al., 2010).

2.2.1 Solar Zenith Angle and Distance from the Sun

Latitude provides a rough approximation to global variation in UVR as can be seen in Figure 3. The earth is closest to the sun in early January and furthest in July and, due to the elliptical nature of the earth’s orbit around the sun, there is a 7% difference in intensity between the hemispheres for any level of latitude, with the southern hemisphere having a greater intensity (Lucas et al., 2006). The amount of UVB reaching the earth’s surface is dependent on the angle at which the sun’s rays pass through the atmosphere, otherwise known as the solar zenith angle (Lucas et al., 2006). Locations at low latitudes that are close to the equator have more intense solar radiation consisting of shorter wavelengths which is directly related to the low angle of incidence of the UVR (Lucas et al., 2006).

Figure 3: Global Variation in UVR, adapted from Lucas et al., 2006, p. 6
The higher the solar zenith angle, the less UVB will fall on a horizontal surface (Fioletov & Kerr, 2008). The sun-earth distance is 3.4% smaller on January 3rd than on July 5th, thus the solar constant is 6.9% larger in the summer of the southern hemisphere (Moan, 2001). Lastly, a related factor is the solar cycle which lasts 11 years and causes periodic changes in the sun’s activity, which responsible for 0.1% of variation in the total solar energy output (Calbo et. al., 2005).

2.2.2 Stratospheric Ozone

The amount of UVB reaching a human on the earth’s surface primarily depends on the amount of atmospheric ozone that is available to absorb it. The most significant absorber of UVB is stratospheric ozone; however, tropospheric ozone also absorbs UVB to a lesser extent (Madronich et al., 1998). Most ozone (about 90%) resides between 12 and 17 kilometers above the Earth’s surface in the stratosphere. In the stratosphere, oxygen molecules, O2, react with either UVC or UVB to split the O2 molecule into two oxygen atoms. When an individual oxygen atom combines with an oxygen molecule, O3 is created and this is what eliminates UVC and UVB from reaching the earth surface. Though more O3 creation takes place at the equator, convection gathers more O3 to higher global latitudes (Moan, 2001). Total column ozone is an important parameter to understand, which is the thickness (in $10^{-5}$ m) of the column at a standard temperature and pressure conditions, measured in Dobson Units (DU) (Calbo et al., 2005).

The annual fluence of UVB varies more than UVA and has more variation at high latitudes than at low latitudes due to absorption by stratospheric ozone (Moan, 2001). In the southern hemisphere there is a large increase in UVB in the spring due to total column stratospheric ozone depletion; this phenomenon is similar to the Antarctic region and has not been observed in the northern hemisphere (Moan, 2001). In general UV radiation is enhanced in the southern hemisphere because of total column ozone (Fioletov & Kerr, 2008). There is a global concern with the levels of ultraviolet radiation from the sun reaching the earth’s surface due to the depletion of stratospheric ozone over the past century (Grant, Heisler & Gao, 2002; McKenzie, Smale & Kotkamp, 2004; Porfírio, De Souza, Lyra & Maringolo Lemes, 2012).
However, it is also important to note that recent climate models have predicted the recovery of stratospheric ozone at mid to high latitudes and that there is an expected recovery of the ozone due to the decreased use of ozone-depleting substances (Greenfield et al. 2012). With an increase in stratospheric ozone, less UVB will transmit through the ozone and thus there will be a decrease in UVB irradiance reaching the earth’s surface; there is an estimated 10 – 15% decrease in erythemal UV expected over the current century (Greenfield et al. 2012).

2.2.3 Ozone, Gases and Aerosols in the Troposphere

The other 10% of ozone in earth’s atmosphere lies in the troposphere which reaches 12km above the earth’s surface. Ozone found in the troposphere is the result of photochemical and chemical reactions that involve UV, nitrogen oxides and volatile organic compounds (Calbo et al., 2005). Although beneath the stratosphere, the troposphere plays a role in UVB absorption. Compared to the stratosphere, the troposphere has larger concentrations of scattering elements, such as dust and water vapour, which make the photon path length longer. This longer path length yields more interaction with ozone, which absorbs UVB (Moan, 2001). In summary, tropospheric scattering causes an increase in photon path lengths, making absorption by ozone more likely as UVB penetrates through the atmosphere; although tropospheric scattering has a lower net reduction effect on UVB than stratospheric ozone due to the sheer volume of ozone in the stratosphere (Moan, 2001).

Atmospheric gasses found in the troposphere caused by human activity, such as sulfur dioxide and nitrogen dioxide, organic gasses, chlorine and bromide, can also cause UVB absorption and scattering. However, concentrations of these gasses over widespread areas are often not high enough to have an absorbing effect of UVB at the earth’s surface, unless located in close proximity to an emission source (Fioletov & Kerr, 2008). Small particles suspended in the air (aerosols) can also reduce UVB at the earth’s surface (Madronich et al., 1998). Aerosols are usually found in the lowest part of the troposphere and are often associated with pollution (Madronich et al., 1998). Aerosol particles may be highly absorbing or scatter and re-direct radiation; it is possible that scattering can actually increase UVB on non-horizontal surfaces at the earth’s crust due to added radiation incident from low angles (Madronich et al., 1998).
Aerosols have been shown to have relatively minor effects on the absorption and scattering UVB radiation through the results of a sensitivity study, with the exception of major events such as a volcano eruption that can blast large amounts of ash and sulfur dioxide in the atmosphere (Kudish & Evseev, 2011; Madronich et al., 1998).

2.2.4 Clouds

Clouds, located in the troposphere, have a significant effect on UVB reaching the earth’s surface and cause more variability in surface UVR than all other geophysical variables (Fioletov & Kerr, 2008). Clouds generally reduce UVB, but different factors including cloud type, cloud cell morphology, cloud coverage, the size of water droplets and ice crystals in the cloud can cause variability (Madronich et al., 1998). Solar zenith angle and different cloud altitudes also have an effect on cloud transmission of UVB (Kuchinke & Nunez, 1998). Absorbers, such as tropospheric ozone within the cloud, can reduce UVB at the earth’s surface (Madronich et al., 1998). Due to the shorter wavelengths that make up UVB, large photon path lengths in clouds can increase absorption and decrease transmission (Madronich et al., 1998).

Calbo et al., (2005) reviewed studies published prior to 2005 relating to quantifying the ratio between UV magnitude in clouded skies and in cloudless conditions. They used the cloud modification factor (CMF) as a common variable to compare studies and discovered there is a large range of CMF values. They also discovered a widespread agreement that there remain some major difficulties in describing cloud effects of UV and that there is limited spatial coverage in the databases used and also that validation tasks and portability tasks are missing. Fioletov & Kerr (2008) describe a popular method for quantifying cloud effects of UVR as cloud transmittance (CT). This is the ratio between measured surface global irradiance and that calculated for a cloudless sky. CT values range from 0.3 to 0.8 for overcast conditions and can be less than 0.05 under thick cumulonimbus clouds (Fioletov & Kerr, 2008). Although measurements are approximate, the UVB transmission through different cloud types in southwest Sweden have been established in a study by Kuchinke & Nunez (1998) as can be seen in Table 1.
Table 1: UVB Transmission of Significant Cloud Types, adapted from Kuchinke & Nunez, 1998, p. 155

<table>
<thead>
<tr>
<th>Cloud Type</th>
<th>UVB Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratus</td>
<td>0.79</td>
</tr>
<tr>
<td>Stratocumulus</td>
<td>0.62</td>
</tr>
<tr>
<td>Pannus (stratus fractus/cumulus fractus)</td>
<td>0.16</td>
</tr>
<tr>
<td>Altostratus</td>
<td>0.39*</td>
</tr>
<tr>
<td>Altostratus (single opaque layer)</td>
<td>0.70</td>
</tr>
<tr>
<td>Altostratus (multiple opaque layer)</td>
<td>0.72</td>
</tr>
<tr>
<td>Altostratus (high invading towers)</td>
<td>0.78</td>
</tr>
<tr>
<td>Cirrus (sparsely distributed filaments)</td>
<td>0.97</td>
</tr>
<tr>
<td>Cirrus (invading filaments)</td>
<td>0.95</td>
</tr>
<tr>
<td>Cirrrostratus (unobtrusive)</td>
<td>0.94</td>
</tr>
<tr>
<td>Cirrostratus (entire celestial dome)</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Although clouds can have a major reducing effect on UVB, in some instances UVB irradiances can be higher under clouded skies than clear skies if bright broken clouds exist and direct sunlight is scattered (Madronich et al., 1998). Cloud enhancement is described in studies, but the magnitude of the enhancement is not well established (Calbo et al., 2005). In a study whose location limited the zenith angle to between 35-70 degrees, a strong supporting trend appeared within this range to support the idea that zenith angle has a small effect on UVB transmission. It was concluded that when UVB enhancement took place, it was not due to the zenith angle, but rather due to the spatial pattern of cloud distribution through a phenomenon called cloud side reflection. It is known that direct beam solar transmission results in high UVB exposure, but cloud side reflection also has the ability to yield high solar transmission levels. Though low cumuliform clouds are likely to result in transmissions higher than or less than those observed in clear-sky conditions, these cloud types are responsible for generating 70% of enhanced UVB recordings when 411 cloud samples were compared. This conclusion directly correlates to results by Kuchinke and Nunez (1998), Estupiñán (1996), as well as Mims and Frederick (1994).
2.2.5 Surface Albedo and Altitude

The albedo is the ratio of sunlight reflected by an object and of the light it receives/absorbs (Chadysiene & Girgzdys, 2008). It can be quantified between the value of 0, meaning no light is reflected, to the value of 1, meaning all is reflected; or it can be expressed as a percentage (Chadysiene & Girgzdys, 2008). Although it is affected by all of the previous geophysical variables mentioned, the average albedo of our planet is 0.3 meaning that 30% of the sunlight reaching earth is reflected back into space (Chadysiene & Girgzdys, 2008). Table 2 shows the mean value for albedo in the UVB range for different surface conditions. Snow has the highest albedo and reflects and scatters UVB at the earth’s surface. Darker surfaces, like asphalt, have low albedo values, while natural landscape such as fields and forests have even lower values. A 2008 study by Chadysiene and Girgzdys confirms that, in clear-sky conditions, snow has the maximum albedo of all surfaces at about 90%. Secondly, sand has a maximum albedo of 10% and grass has the lowest maximum albedo of about 2-3%. Table 3 compares UVA and UVB radiation from sand, grass, water and snow. An important note is that as the altitude increases, the air mass through which solar radiation must pass decreases resulting in more intense UVB at higher altitudes, which also has implications for surface albedo as snow albedo increases with altitude (Lucas et al. 2006).

Table 2: Mean Values of Albedo, adapted from Blumthaler & Ambach, 1988, p. 87

<table>
<thead>
<tr>
<th>Material and Description</th>
<th>Albedo - solar erythemic range</th>
<th>Albedo - total solar radiation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field, land</td>
<td>11.5</td>
<td>2.2</td>
<td>varying moisture</td>
</tr>
<tr>
<td>Asphalt</td>
<td>10.6</td>
<td>5.5</td>
<td>differently worn</td>
</tr>
<tr>
<td>Primitive Rock</td>
<td>14.4</td>
<td>3.7</td>
<td>varying size, partly overgrown by lichen</td>
</tr>
<tr>
<td>Tennis Court</td>
<td>17.6</td>
<td>2.9</td>
<td>polyurethane, differently worn</td>
</tr>
<tr>
<td>Stream sand</td>
<td>23.8</td>
<td>9.1</td>
<td>sedimentation on embankment</td>
</tr>
<tr>
<td>Alpine pasture</td>
<td>22.5</td>
<td>4.9</td>
<td>transversed by limestone</td>
</tr>
<tr>
<td>Grassland, corn</td>
<td>20.7</td>
<td>1.3</td>
<td>varying heights</td>
</tr>
<tr>
<td>Limestone</td>
<td>26.2</td>
<td>11.2</td>
<td>rock debris of different size</td>
</tr>
<tr>
<td>Glacier Ice</td>
<td>10.5</td>
<td>7.8</td>
<td>very dirty</td>
</tr>
<tr>
<td>Water</td>
<td>9.1</td>
<td>4.8</td>
<td>clear waters, bog-lake, river</td>
</tr>
<tr>
<td>New Dry Snow</td>
<td>87</td>
<td>94.4</td>
<td>high mountain areas</td>
</tr>
<tr>
<td>New Wet Snow</td>
<td>74.5</td>
<td>79.2</td>
<td>high mountain area, varyingly dirty</td>
</tr>
<tr>
<td>Old Dry Snow</td>
<td>79.2</td>
<td>82.2</td>
<td>high mountain area, varyingly dirty</td>
</tr>
<tr>
<td>Old Wet Snow</td>
<td>72.4</td>
<td>74.4</td>
<td>high mountain area, varyingly dirty</td>
</tr>
</tbody>
</table>
Table 3: The UVA and UVB radiation and Visible Light Albedo from different Surfaces, adapted from Chadyšien & Girgždys, 2008, p.86

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>UVA Albedo %</th>
<th>UVB Albedo %</th>
<th>Part of UVA Albedo %</th>
<th>Part of UVB Albedo %</th>
<th>Visible Light Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>13</td>
<td>9</td>
<td>59</td>
<td>41</td>
<td>20-30</td>
</tr>
<tr>
<td>Grass</td>
<td>2</td>
<td>2</td>
<td>50</td>
<td>50</td>
<td>15-25</td>
</tr>
<tr>
<td>Water</td>
<td>7</td>
<td>5</td>
<td>58</td>
<td>42</td>
<td>3-10</td>
</tr>
<tr>
<td>Snow</td>
<td>94</td>
<td>88</td>
<td>52</td>
<td>48</td>
<td>50-95</td>
</tr>
</tbody>
</table>

2.2.6 Trees and Objects in the Landscape

There are objects on the earth’s surface, such as trees, shrubs and buildings, that affect the amount of UVB a person receives. In a study looking at the spectral properties of plant leaves it was concluded that leaf reflectance of UVB and the whole UV region was very low in taller plants, around 5%, and transmittance was essentially zero regardless of plant species and seasonal change (Yoshimura et al., 2010). Incident UV is reduced by 5% by being reflected and reduces to zero being absorbed by the leaf. Although taller trees provide a canopy of protection for humans, low shrubs and hedges can assist in intercepting diffuse radiation from other sources (Yoshimura et al., 2010). Foliage surfaces reduce incident UVR by reflection, which is around 2%, and also eliminating it by transmittance (Yoshimura et al., 2010). Dense canopies can reduce UV to negligible levels, but even thin and uneven canopies can filter UV from the sun and downward scattered UV.

Chlorophyll in plants is able to absorb UVA and UVB radiation. This absorbed radiation produced fluorescence and this mechanism works effectively to dispose of harmful UVB radiation. UV absorbing substances in plants, such as flavonoids, result it low leaf reflectance and zero transmittance of UVB radiation. In addition, photosynthetic pigments affect UB optical properties that can dissipate solar UV energy. “Only trees provide cool shade, and the cooling influence is due in a small part to the UV energy dissipation mechanism, which is peculiar to plants” (Yoshimura et al., 2010, p. 186).
Grant et al. (2002) developed a model to assess the UVB irradiance below tree canopies in given sky conditions and canopy structures. They found that increasing tree cover reduced exposure to UVB, although a greater sky view factor (a ratio of the amount of sky visible from a certain point on earth’s surface) results in more UVB from reflected sources resulting in less protection from UVB. In a study by Brown et al. (1994) UVB was measured at the earth’s surface under a mixed deciduous forest and results indicated that, under closed canopies, geometric mean UVB transmittance was only 1-2% of incident radiation; under disturbed canopies, geometric mean UVB transmittance was 8-17%. In the leafless season, UVB transmittance increased to 30%. The study concluded that canopy structure played an important role in UVB transmittance as shaded understory locations received less UVB than areas where there were gaps and that UVB transmittance did not depend on solar elevation (Brown et al., 1994).

Other elements in the landscape, such as buildings and shade devices, impact the amount of UVB a person receives in the landscape. A study looking at shade devices, including umbrellas, concluded that horizontal and vertical surfaces positioned under a shade device are not fully protected from UVB depending on the location beneath the shading device, the size of the shade device, proximity to the ground, and albedo of nearby surfaces (Kudish et al., 2011). A similar study by Utrillas et al., (2010) reveals that umbrellas absorb the majority of direct UVB, approximately 95%; however, a considerable amount of the diffuse radiation from the sky surrounding the umbrella was not intercepted and was able to reach the sensor beneath it. In order to mimic a person in an upright position beneath the umbrella, a vertical sensor was also used. Although the umbrella absorbed most of the direct UV radiation from the sun, about 34% of the diffuse radiation that was reflected off surfaces or scattered by air molecules from around the umbrella reached the area beneath it.

2.2.7 Additional Variables

In addition to the geophysical variable that impact the amount of UVB reaching the earth’s surface, skin type, dietary intake of vitamin D and genetics, amongst others, all play a role in how much UVB penetrates the human body. Skin pigmentation alters the exposure-
disease relationship for all UVR-induced diseases where the primary exposure of interest is via skin. Deeply pigmented skin provides more protection from UVB, although races/ethnic groups with darker skin colours living in the northern hemisphere are at particular risk as “melanin skin pigmentation absorbs UVB light reducing vitamin D synthesis” (Makariou et al., 2011, p. 355). Table 4 shows the Fitzpatrick Skin Type Categories.

Table 4: Fitzpatrick Skin Type Scale

<table>
<thead>
<tr>
<th>Skin Type</th>
<th>Skin Colour</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>White: very fair; red or blonde hair; blue eyes; freckles</td>
<td>Always burns, never tans</td>
</tr>
<tr>
<td>II</td>
<td>White: fair; red or blonde hair; blue, hazel, green eyes</td>
<td>Usually burns, tans with difficulty</td>
</tr>
<tr>
<td>III</td>
<td>Cream white; fair with any eye or hair colour; very common</td>
<td>Sometimes mild burn, gradually tans</td>
</tr>
<tr>
<td>IV</td>
<td>Brown; typical Mediterranean Caucasian skin</td>
<td>Rarely burns, tans with ease</td>
</tr>
<tr>
<td>V</td>
<td>Dark Brown; mid-eastern skin types</td>
<td>Very rarely burns, tans with ease</td>
</tr>
<tr>
<td>VI</td>
<td>Black</td>
<td>Never burns, tans very easily</td>
</tr>
</tbody>
</table>

2.3 A Meta-Analysis of Vitamin D and Skin Cancer

1 billion people world-wide are estimated to be vitamin D insufficient (Makario et al., 2011). People who are sufficient in vitamin D have adequate levels of physiologic calcium and phosphorous; these elements are important for normal bone mineralization, rickets prevention and reducing the risk osteomalacia and osteoporosis (Greenfield et al. 2012). Very recently, there have been numerous studies that show sufficient levels of vitamin D is associated in reducing the risk of various types of cancer including colon, prostate and breast cancer (Field & Bishop, 2011; Gandini et al. 2007; Greenfield et al. 2012). Additionally, in the past two decades, vitamin D deficiency has been identified as a possible new risk factor for many chronic diseases, such as the metabolic syndrome and its components, the whole spectrum of cardiovascular diseases, several auto-immune conditions, many types of cancer as well as all-cause mortality (Makariou et al., 2011). Many studies are currently underway to identify more concrete evidence that vitamin D deficiency is indeed a risk factor for detrimental health concerns as
listed above. As with many pioneering studies regarding causes of cancer, further investigation of the topic is necessary. A general guide was set by Holick in 2004 stating that “5-15 minutes of exposure between 10:00 and 3:00 during the spring, summer and autumn” is enough time outside to maintain healthy levels of vitamin D for those with type II or type III skin (Field & Newton-Bishop, p. 201, 2011). Many different researchers have discovered populations with sub-optimal levels, suggesting that more sun exposure than Holick suggested may be necessary (Field & Newton-Bishop, 2011). Although this may be the case, other studies have shown that, depending on the latitude, this number may be much too high, causing higher than acceptable amounts of skin erythema resulting in negative health consequences (Samanek et al., 2006). A massive study undertaken by the World Health Organization determined that, in the year 2000, 1.5 million people suffered disability while 60 000 people died due to over-exposure to UVR. However, if a situation was to arise which yielded zero exposure to UVR, 3.304 million people would develop a morbid disability due to vitamin D deficiency disease. Such diseases include rickets, osteoporosis and osteomalacia (Lucas et al., 2006).

Vitamin D can be obtained through certain foods like fortified milk, eggs, fish oils and oral supplements, but 90% of vitamin D is derived from the action of sunlight on the skin (Gandini et al. 2007). Estimates show that the values of vitamin D in food are quite low and that national fortification and supplementation practices vary amongst countries (Gandini et al. 2007). Oral vitamin D supplements have a bigger impact on health as a study concluded that infants given an oral dose of 2000 IU a day had an 80% reduction of developing type I diabetes later in life (Schwalfenberg, Genuis & Hiltz, 2010). An interesting observation discovered by researcher Richard Weller is that giving oral vitamin D supplements to people does not change that high rate of heart disease and evidence for preventing various forms of cancer is not yet concrete. Weller suggests that high levels of vitamin D are an indicator of sunlight exposure and that it is sunlight exposure that is beneficial to prevent heart disease. A chemical transmitter, nitric oxide, is found in the skin and dilates blood vessels which results in reduced blood pressure. Human skin produces nitric oxide and Weller discovered that through exposure to UVA (not UVB to separate this from vitamin D production) there are benefits including more blood flow within the cardiovascular system. The skin has very large stores of nitric oxide and
sunlight releases this, which has beneficial effects on cardiovascular health. Weller believes this accounts for the north-south health divide in Britain as those at lower latitudes have more exposure to sunlight and have less cardiovascular health problems. “Yes, sunlight is the major alterable risk factor for skin cancer, but deaths from heart disease are a hundred times higher than deaths from skin cancer. And I think that we need to be more aware, and we need to find the risk-benefit ratio” (Weller, 2010). This is an interesting perspective as Weller states that UVA is the wavelength responsible for improving cardiovascular health and many other studies directly associate UVB and vitamin D production with improved cardiovascular health. This study suggests that oral supplements cannot replace exposure to sunlight for certain health benefits.

A researcher at the University of Calgary examined the literature related to vitamin D and its effects on pregnancy, selecting a total of 31 studies and performing a meta-analysis of the combined data (Aghajafari et al., 2013). Results indicated that low levels of vitamin D in pregnant women can result in an increased risk of the woman developing gestational diabetes, or high blood sugar levels that can lead to excessive levels of sugar reaching the developing fetus. Results also showed an increased chance of pre-eclampsia, or elevated blood pressure, a potentially life-threatening disorder during pregnancy. It was found that low vitamin D levels in the mom, below 75 nanomoles per litre of blood which is considered a mild deficiency in Canada, were fairly consistently associated with troubling outcomes. However, the latest research shows only an association, it does not prove that low vitamin D levels cause pregnancy complications. Further research is required to establish a more profound association between vitamin D levels and pregnancy (Aghajafari, 2013).

2.3.1 Measurement of Risk Factors

UV can be measured using physical units or weighted using an erythemal response function to give biologically effective UVR, expressed as joules per square metre (J/m²), minimal erythemal dose (MED) and standard erythemal dose (SED) (Lucas et al., 2006). As stated earlier, the ‘minimal erythema dose’ (MED) is defined as the quantity of UV radiation needed to cause slight erythema with clearly defined edges 16–24 h after exposure (Mahe et al., 2012). MED is
often used in studies; however, it is frequently applied to populations with varying skin types where the dose of UVR is not defined for each skin type, resulting in the lack of a consistent baseline (Lucas et al. 2006). The SED is independent of skin type and have been established as an erythemally weighted measure of radiant exposure, equivalent to 100 J/m². A specific dose of SED may cause erythema in fair skin but not in darker skin (Lucas et al., 2006). The value of 100 J/m² also approximates the standard vitamin D dose (SDD) with 25% skin exposure. This is equivalent to an oral dose of 1000 IU of vitamin D per day which is enough to maintain vitamin D sufficiency (Krzyscin, Jaroslawski & Sobolewski, 2011).

The UV index is another way to measure UVR and since its introduction in 1992, it is the most widely understood method to measure biologically affective UV (Lucas et al., 2006; Fioletov et al., 2010). The index is based on erythemal exposure for the reason that it has the most immediate impact on humans (Fioletov & Kerr, 2008). The UV index is defined by erythemally weighted global irradiance divided by 25 mW m⁻² (Fioletov & Kerr, 2008). This yields values that make up the UV index and are categorized into low (less than 2), moderate (3 to 5), high (6 and 7), very high (8 to 10) and extreme (11 and above). For each category, sun protective measures are suggested and UV Index values are currently widely available as a guide to the public (Fioletov & Kerr, 2008).

Vitamin D concentrations in the human body are often measured through 25(OH) serum levels. Data has suggested the serum levels in the range of 70-100 nmol/L is a reasonable target for maintaining vitamin D sufficiency (Field & Newton-Bishop, 2011). Makariou et al. (2011) determined that the most commonly used divisions for serum 25(OH) vitamin D levels in adults is as follows: >75 nmol/L for vitamin D sufficiency, 50-70 nmol/L for insufficiency and <50 nmol/L for deficiency. Although there is some controversy regarding the appropriate dosing required for optimal vitamin D status, the Vitamin D Action Consortium of Scientists is calling for a standard intake of 2000 IU/day, which will achieve 100-150 nmol/L (40-60 ng/ml) in most individuals (Schwalfenberg & Hiltz, 2010). The recommended dose for adults was 400 IU until recent research confirmed that this is an insufficient dose to optimize 25(OH) levels in most individuals and current research suggests that raising this daily intake to 1000 IU will bring concentrations up to 75 nmol/L in approximately 50% of the population (Schwalfenberg & Hiltz,
A Canadian study stated that daily intake of 2000 IU would result in 93% of patients achieving sufficient vitamin D status without risk of toxicity, although individuals with sun-seeking habits would have to reassess (Schwalfenberg & Hiltz, 2010).

2.3.2 Comparing Previous Studies

In a study done by (Fioletov et al., 2010) a gridded dataset was presented portraying hourly vitamin D action-spectrum weighted UV climatology for the USA and Canada on the basis of UV irradiance derived from global solar radiation, total ozone, dew point temperature and snow cover. This study was previously developed for erythemal UV and modified for the vitamin D action spectrum UV. The vitamin D action spectrum used in this study is the same one published by CIE and if hourly doses of vitamin D weighted UV are known, the time required to obtain 1 SDD from UV on unprotected skin can be calculated as a function of the skin sensitivity to UV. This study assumed that the effect of vitamin D weighted UV is attenuated to the same extent by skin type as that for erythemal UV and as a result the amount of time required to obtain 1 SDD can be estimated for different skin types. Holick (2004) recommends exposure of 25% of skin area to achieve 1 SDD. 1 SDD is defined as a dose that corresponds to the UV equivalent of an oral dose of 1000 IU vitamin D at 42°N in March. This assumption is based on Holick’s model (2004) and this assumption yields 1 SDD dose of 106 Jm² for skin type II. The study concluded that in January the 106 J/m² thresholds for skin type II can be reached with all day exposure near 54°N (latitude of Edmonton) and even farther north. UV exposure levels for sufficient vitamin D status depends on latitude and skin type, as a person with type I skin can produce the same amount of vitamin D in winter at 40-45°N as a person with type VI skin at 25-30°N at the same time of year. Figure 4 shows the borders of areas where 1 SDD can be obtained within one hour near noon for six different skin types during clear days. An important note is that the link between UV exposure and vitamin D production may be non-linear and the estimated times in the sun should be used with caution; it is suggested that estimated time be used as a relative scale as opposed to a literal scale. Some limitations of this study by Fioletov et al. (2010) include the fact that a horizontal surface was used and this does not reflect a completely accurate situation with a human.
Figure 4: The borders of the areas where 1 SDD can be obtained within 1 h near noon. The borders are shown for six different types of skin (I–VI), adapted from Fioletov et al., 2010, p. 6
A study completed by Samanek et al. (2006) concluded that for people with skin type II on the Fitzpatrick Scale, 1/6 to 1/3 MED would be sufficient to provide 200-600 IU. The study used UV data from several Australian cities to determine how long a person needed to stand in the sun to receive 1/6 to 1/3 MED of UV. Calculations were based on 15% of the body being exposed with Fitzpatrick type II skin. The results show times required for recommended vitamin D production and skin erythema. In all cities in January, approximately 2-14 minutes of sun at 12:00 was sufficient to produce 1/6 to 1/3 MED which would achieve recommended vitamin D production but since erythema can occurs in as little as 8 minutes, exposure at noon can also increase risk of skin cancer. Table 5 shows their recommendations for UV exposure. Although the study has many limitations including their optimal intake of vitamin D being too low, using only one year of data and applications to skin type II only, it seems inevitable that deliberately seeking sun exposure for vitamin D related benefits may result in squamous cell carcinoma risk. MED is defined as the minimal reddening of white skin and, for this reason, MED measurements decrease in value for comparing studies (Lucas et al., 2006). Diffey (2010) also suggests that the MED is a poorly defined unit of UV exposure and that SED is preferred.

Table 5: Recommended UVR exposure, adapted from Samanek et al., 2006, p. 341

<table>
<thead>
<tr>
<th>Region</th>
<th>October to March</th>
<th>April to September</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 12:00 – Northern (Townsville and Cairns)</td>
<td>2-5 minutes with extreme care*</td>
<td>3-10 minutes with care^</td>
</tr>
<tr>
<td>At 12:00- Central (Brisbane and Perth)</td>
<td>2-6 minutes with extreme care*</td>
<td>4-17 minutes with care^</td>
</tr>
<tr>
<td>At 12:00 Southern (Adeliade, Sydney, Melbourne and Hobart)</td>
<td>2-10 minutes with extreme care*</td>
<td>5-34 minutes with care^</td>
</tr>
<tr>
<td>At 10:00 and 15:00 – Northern (Townsville and Cairns)</td>
<td>Less than 10 minutes with care^</td>
<td>Less than 16 minutes with care^</td>
</tr>
<tr>
<td>At 10:00 and 15:00 - Central (Brisbane and Perth)</td>
<td>Around 10 minutes with care^</td>
<td>14-44 minutes with care^ and extreme care* in Brisbane</td>
</tr>
<tr>
<td>At 10:00 and 15:00 – Southern (Adeliade, Sydney, Melbourne and Hobart)</td>
<td>Less than 15 minutes with extreme care*</td>
<td>21 min to less 60 minutes with care*</td>
</tr>
</tbody>
</table>

* Extreme Care: sun protection is highly recommended
^ Care: sun protection is recommended as exposure is likely to exceed the maximum recommended time
A study by Terushkin et al., (2010) sought to provide estimates of the equivalency of vitamin D production from natural sun exposure versus oral supplementation using a simulation tool, FastRT, and determined the sun exposure times needed to achieve serum vitamin D concentrations equivalent to 400 or 1000 IU vitamin D for individuals of various Fitzpatrick skin types living in Miami, Florida and Boston, Massachusetts, during the months of January, April, July, and October. The results show that in Boston from April to October at 12 PM EST, a person with skin type III and 25.5% of their body surface exposed would need to spend 3 to 8 minutes outside in the sun to synthesize 400 IU of vitamin D. During the winter, it is difficult to synthesize vitamin D in Boston because of the cold temperatures and less skin exposed, approximately 3.5% of the body if only the face is visible. If 23 minutes of sunlight exposure results in 400 IU of vitamin D around 12 PM EST in Boston during the winter by an individual with type III skin exposing 25.5% of their skin, then it would take more than 7 times longer (2 hours and 41 minutes) when exposing 3.5% of their skin. The study suggests people living in Boston take vitamin D supplements during the winter months. In Miami, a person with skin type III and would need to spend 3 to 6 minutes outside at 12 PM EST all year round to synthesize 400 IU. The study concluded that due to their study limitations, oral supplementation remains the safest way for increasing vitamin D status. This is an interesting study as Boston is a mid-latitude city and this study states that it is possible in the winter, with 3.5% of a person’s skin exposed to receive 400 IU of vitamin D in 2 hours and 41 minutes. To reach the 1000 IU, the current optimal amount of vitamin D to get on a daily basis as determined by researchers, a person would have to be outside for 6 hours and 43 minutes. This is assuming that the relationship between time and vitamin D exposure is linear, which may not actually be the case in a real life situation.

2.3.3 Identifying Missing Links

While Fioletov et al., (2010) argue that it is possible to achieve sufficient levels of vitamin D at higher latitudes, Lucas et al. (2006) states that there is insufficient UVB to produce vitamin D over the winter months. Lucas et al. argues that inhabitants of such areas would need to achieve higher levels of vitamin D synthesis in other seasons in order to rely on stored
vitamin D through the winter (2006). To summarize, although there have been many studies involving achieving sufficient vitamin D status while avoiding overexposure resulting in increased chances of negative health consequences, none have identified any absolute results. There has been an association found between high levels of vitamin D in the blood and lower levels of heart disease and cancer; such research suggests that vitamin D is very good for humans (Weller, 2010). A study by Schwalfenberg, Genuis & Hiltz, (2010) concludes that public health recommendations to abstain from the sun and to regularly use complete sunblock need to be re-evaluated as sun exposure is beneficial to human health. In addition, broad-based public awareness campaigns to increase the awareness of the vitamin D deficiency at mid to high latitudes will create an expectation of vitamin D assessment and intervention. “A counterfactual exposure distribution of minimum UVR exposure to allow adequate synthesis of vitamin D is likely to represent a minimum risk for diseases of both over- and under-exposure, that is, there should be no need to accept an increased risk of diseases of excessive exposure, in order to achieve minimal risk of diseases of underexposure” (Lucas et al., 2006, p. 9).

2.4 Computer Modeling of UVB in the Landscape

Mathematical models have been developed to estimate the amount of UVB reaching the earth’s surface as well as models that measure individual geophysical variables affecting UVB at the earth’s surface (Diffey, 2002; Fioletov et al., 2010; Krzyscin et al., 2011; Madronich et al., 1998). Although many of these mathematical models exist, there are very few models that show how much UVB a person is receiving on earth. Ola Engelsen and Ann R. Webb have developed a series of computer models that quantify how much UVB a person is receiving in the landscape and the equivalent dose of vitamin D in I.U. units. FastRT is a model that simulates UV doses, indices and irradiances at the earth’s surface. VitD_quartMED is a model that estimates the length of exposure time needed to obtain a desired vitamin D dose in I.U. units.
2.4.1 Field Testing the FastRT and VitD_quartMED Models

A field test at an elementary school with children will be carried out using the FastRT and VitD_quartMED. The reason for selecting elementary school students is that children are a key target group who are likely to spend longer periods of time outdoors and UV exposure during childhood is a leading factor in inducing melanoma later in life (Wright, Reeder, Bodeker, Gray & Cox, 2007). However, children living at mid to high latitudes only have this concern for half of the year. As of 2007, approximately 30 studies had measured or assessed UVR exposure among children and youth; however, these studies mainly explored total daily UVR exposure as a percentage of the total daily ambient UVR during summer months (Wright et al., 2007).

Additionally, Carol Moogk-Soulis completed a study in 2002 looking at school yards as heat islands. She looked at the temperatures of school yards in the summer months and came to the conclusion that school yards can be very hot, making them thermally uncomfortable for users and a health risk for school children (Moogk-Soulis, 2002). Similar studies have been completed since and such studies have been the driving cause behind southern Ontario municipalities creating shade guidelines to increase the shade in the landscape and targets to decrease the school yard heat island effect. Carrying out field tests using the FastRT and VitD_quartMED models will bring awareness to the low levels of UVB reaching mid at high latitudes in the fall and winter which can help inform the design of landscapes and also provide UVB quantities in the summer months to help people avoid sun over-exposure.
3.0 Methods and Materials

3.1 Integrated Research Review

The scholarship of integration is a term coined by Boyer (1999, 1996) that is defined by the synthesis of knowledge and interpretation of its significance (Deming and Swaffield, 2011). The scholarship of integration is a part of a framework “aimed at recognizing the intellectual values and contributions of teaching and practice” (Deming and Swaffield, 2011, p. 39). The integration of scholarship was the first step in this thesis, as an extensive integrated research review was completed. This involved organizing and summarizing key concepts related to UVB, humans and the landscape.

3.2 Controlled Testing

Controlled testing was carried out through the use of the solarmeter and dosimeter badges. These controlled tests included placing all three dosimeters side-by-side on a horizontal plate in various conditions. Tests with the solarmeter included pointing it directly at the sun and blocking its sensor and ability to receive direct radiation. Other tests include being in the shade of trees and buildings. Field testing was carried out through the use of three personal UVB dosimeter badges worn by elementary school students during their time spent outside on a regular school day. The following section will outline the methods developed to test the FastRT model (http://nadir.nilu.no/~olaeng/fastrt/fastrt.html) and VitD_quartMED model (http://nadir.nilu.no/~olaeng/fastrt/VitD_quartMED.html) against the readings obtained through controlled testing and field testing with personal UVB dosimeter badges.

3.2.1 Materials and Tools

Three personal UVB dosimeter badges, developed by Sciencterra Limited in Oamaru, North Otago, New Zealand, were used to collect data. The Personal UV Dosimeter Badge: Mark II was designed to allow researchers to monitor the UV exposure of individuals. The dosimeter badges used in this study only record UVB wavelengths, meaning wavelengths between 280 – 320 nm. The dosimeter badges were the primary method of data collection. The dosimeter badges were first tested in controlled conditions and then worn by elementary school students in various weather conditions in February during their recess breaks outside. The badges were
strapped on the arm of the students over their winter jackets. A UVB solarmeter by SOLARTECH INC was also used to take readings for calibration purposes, to ensure consistency and a low percentage of error.

The FastRT and VitD_quartMED models developed by Ann Webb and Ola Engelsen were used to calculate UVB values to compare to the values obtained by the students during their time outside in the school year. FastRT inputs included the date, latitude and longitude, cloud conditions, total column ozone and surface altitude, surface albedo and surface type. VitD_quartMED inputs included date, latitude, longitude, skin type, timing of exposure, percent of body exposed, desired dietary equivalent dose of vitamin D in I.U. units, cloud conditions, total column ozone and surface altitude, surface albedo and surface type. The models have been validated against measurements and other models, although under cloudy conditions the accuracy level is uncertain and may be imprecise due to the lack of information on the cloud properties (Webb & Engelsen, 2006; Engelsen et al., 2005; Engelsen & Kylling, 2005).

3.2.2 Calibration of Instruments

To calibrate the dosimeters, the data from the controlled dosimeter tests were analyzed. In these controlled tests, the dosimeter badges were set outside in various conditions on a horizontal surface, as can be seen in Figure 5, and worn on the arm of the researcher’s assistant in a vertical position as can be seen in Figure 6. The solarmeter was also used to record values during the dosimeter testing to ensure precision of the dosimeters. All of the results were within 10% of the solarmeter values, and also within 10% of what FastRT estimated would be received on a horizontal flat plate. It is very difficult for UVB meters to measure a precision higher than 10%, therefore we are in an acceptable range (Webb, 1998). The ratios of dosimeter reading over FastRT values are as follows, dosimeter 2084 = 0.91, dosimeter 2085 = 1.07 and dosimeter 2086 = 0.97. The calibration data can be found in Appendix A.
3.2.3 Selection of Location and Subjects

Millen Woods Elementary School was opportunistically selected to participate in the study. The research protocol regarding the participation of human subjects was approved by the University of Guelph Research Ethics Board and the Waterloo Region District School Board as can be seen in Appendix B. The teacher of a split grade 3 and grade 4 class agreed to participate in the study and consent forms were sent home to students’ parents. Students with permission to partake in the study completed child assent forms. These forms can also be seen in Appendix B. Students who agreed to partake in the study were randomly selected to wear the dosimeters on test days.

Millen Woods is a newly constructed school that opened in September of 2011. The entire site is a total of 2.09 hectares of land and has a very open school yard facing north and west. Several deciduous trees have been planted as shown in Figure 7; however, they are very young and quite small with a trunk calliper of 60 – 70 mm. A public pathway surrounds the school yard and there is a dense forest surrounding the school yard to the north and west. Figures 8 through 13 are photographs taken on site and correspond with the map in Figure 7.
Figure 7: Plan view of Millen Woods School, Google maps photo used as background. Source: “Waterloo, Ontario.” +43° 30’ 47.70", -80° 30’ 18.41". Google Maps. March 2013.
Figure 8 & 9: Section A of the school yard, photo credits to Laura Hilliard

Figure 10 & 11: Section B of the school yard, photo credits to Laura Hilliard

Figure 12 & 13: Section C of the school yard, photo credits to Laura Hilliard
3.2.4. Data Collection and Comparison

UVB data was collected over four days in February 2013 with varying weather conditions. Personal UVB dosimeter badges were worn by 3 students at Millen Woods Elementary School in Waterloo, Ontario. The students were in grade 3 and wore the badges on their arms when they went outside for their morning break, from 10:50 am to 11:10 am and their afternoon break, from 1:30 pm to 1:50 pm. Data was collected on February 12th, 15th and 21st. February 12th and 15th were overcast days and February 21st was a clear, sunny day. The dosimeters took a UVB reading every minute for the duration that the students were outside. All of the students were wearing full snow attire with only their faces exposed, which is the equivalent of 3.5% body exposure, and were of type II Caucasian skin. For all days of testing there was snow on the ground of the school yard.

The data collected on these selected days will be analyzed and compared against readings from the FastRT model and the VitD_quartMED model. FastRT will provide a UVB value directly comparable with the dosimeter data using model inputs as closely matched to the conditions as possible; however, FastRT gives a value for a horizontal flat plate and the dosimeters were a vertical flat plate. VitD_quartMED will estimate the length of exposure time needed to obtain a desired vitamin D does in I.U. units. 200 I.U. and 1000 I.U. were selected as current research suggests that 1000 I.U. is an appropriate daily intake of vitamin D to achieve vitamin D sufficiency (Schwalfenberg & Hiltz, 2010).
4.0 Results and Analysis

4.1 Field Testing of Dosimeters and Computer Models

Table 6 shows the average UVB values calculated from the collected data during the field tests at Millen Woods. Table 6 also contains FastRT values and VitD_quartMED values. FastRT values and VitD_quartMED have been calculated using inputs as close as possible to the actual conditions including the date, latitude and longitude, cloud conditions, total column ozone and surface altitude, surface albedo and surface type, skin type, timing of exposure, percent of body exposed and desired dietary equivalent dose of vitamin D in I.U. units. The actual inputs for the models can be found in Appendix A.

<table>
<thead>
<tr>
<th>Date</th>
<th>Dosimeter 2084 Average W/m²</th>
<th>Dosimeter 2085 Average W/m²</th>
<th>Dosimeter 2086 Average W/m²</th>
<th>Average Of All 3 Dosimeters W/m²</th>
<th>FastRT UVB Values W/m²</th>
<th>Time to 200 I.U.</th>
<th>Time to 1000 I.U.</th>
<th>MED*</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.65</td>
<td>0.43</td>
<td>0.62</td>
<td>0.57</td>
<td>0.36</td>
<td>/</td>
<td>/</td>
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</tr>
<tr>
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<td>0.87</td>
<td>0.71</td>
<td>0.79</td>
<td>0.21</td>
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<td>/</td>
<td>0.26</td>
</tr>
<tr>
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<td>0.39</td>
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<td>0.37</td>
<td>/</td>
<td>/</td>
<td>0.26</td>
</tr>
<tr>
<td>February 21st AM</td>
<td>1.20</td>
<td>0.88</td>
<td>1.24</td>
<td>1.10</td>
<td>0.9</td>
<td>0:40</td>
<td>2:31</td>
<td>0.22</td>
</tr>
<tr>
<td>February 21st PM</td>
<td>1.30</td>
<td>0.91</td>
<td>/</td>
<td>1.10</td>
<td>1.15</td>
<td>0:26</td>
<td>/</td>
<td>0.22</td>
</tr>
</tbody>
</table>

*The fraction of a sunburn dose (MED) to obtain the desired amount of vitamin D

4.1.1 Data Collection

February 12th was an overcast day with light flurries and temperatures ranging between \(-0.1^\circ C\) and \(-2.7^\circ C\). Data was collected in the PM and this yielded the lowest average and maximum UVB readings as can be seen in Figure 14. The range of UVB on February 12th was 0.22 W/m².

February 15th was also an overcast day with light flurries and temperatures ranging between 1°C and \(-13.7^\circ C\). Data was collected in the AM and PM and results show higher
average and maximum UVB than on February 12th. The range of UVB in the AM was the smallest on this day with a maximum of 0.87 W/m² and minimum of 0.71 W/m², respectively resulting in a difference of 0.16 W/m². The data was collected before and after 12:00 noon and the range in UVB in the AM is much smaller than in the PM. The maximum values in the AM and PM differ by 0.04 W/m²; the average values in the AM and PM differ by 0.18 W/m²; and the minimum values in the AM and PM were within 0.32 W/m².

February 21st was a clear sunny day with temperatures ranging between -7.5°C and -13.7°C. The highest average, maximum and minimum UVB values were recorded on February 21st. The ranges for February 21st in the AM and PM were 0.36 W/m² and 0.39 W/m², respectively. Although the ranges are very close from AM to PM, the maximum and minimum values in the PM are higher amounts of UVB than in the AM. Maximum values in the AM and PM were within 0.06 W/m²; the average values in the AM and PM are the same at 1.10 0.06 W/m²; and the minimum values in the AM and PM were within 0.03 W/m².

![Average UVB Values Determined from Test Days at Millen Woods School](image)

**Figure 14:** Test days at Millen Woods
4.1.2 Data Comparison against Computer Models

The FastRT model was used to calculate UVB values over the same time periods, at the same location and the same conditions. The inputs were matched as closely as possible to the actual conditions on the three test days. Average FastRT values were all lower than the average dosimeter UVB values with the exception of February 21st in the afternoon. The VitD_quartMED model was also used to calculate the amount of vitamin D that the students would receive during their time outside and results indicate that on the overcast days, February 12th and 15th it is not possible for the kids to get even the equivalent of 200 I.U. of Vitamin D, even if they spend the whole day outside. However, the MED values for these days are 0.26 and 0.27, meaning that whatever amount of time the students spend getting outside synthesizing vitamin D in the skin, it is 27% of the time it would take to get sunburn. Therefore, about 4 times as long to get sunburn as to get your vitamin D on February 12th and 15th.

On February 21st in the morning, the clear and sunny day, it would take 40 minutes for the students to get the equivalent of 200 I.U. of vitamin D and it would take 2 hours and 31 minutes to get the equivalent of 1000 I.U. of vitamin D. On February 21st in the afternoon it would take 26 minutes to get the equivalent of 200 I.U. but the sun would set before the students could get the equivalent of 1000 I.U. The MED value for this day is 0.22, so in sunny conditions on February 21st it would have taken almost five times as long to get sunburn as it would to get ample vitamin D synthesis in the skin.

4.1.3 Interpreting the Results

A very interesting finding was that the students were able to get enough exposure to sunshine on February 21st in the morning, when the conditions were sunny and clear, to obtain the equivalent of 1000 I.U. of vitamin D as calculated by the FastRT model. This confirms that it is possible to get 1000 I.U. in the winter time in Waterloo according to the FastRT model, even with as little as 3.5% body exposure. Additionally, in general it takes 4 to 5 times as long to get sunburn as it does to get vitamin D in such conditions. Higher than expected values of UVB were recorded on overcast days and these numbers were likely enhanced by the snow laden ground.
The dosimeter average values for each day the students wore the badges outside were almost all higher than FastRT calculated values, with exception of February 21st in the afternoon. The modeled values were lower because the model only estimated the amount of UVB coming directly from the sky and the diffuse radiation reflected from the snow was not accounted for. The dosimeters recorded both direct and diffuse radiation. An interesting test with the solarmeters revealed that almost all of the UVB was diffuse. The solarmeter readings were still quite high, even when an object was placed in front of the sensor blocking any direct radiation from reaching it. Thus, that the solarmeter was receiving radiation from scattering and reflection by the atmosphere and other objects in the landscape.

4.1.4 Modeling in All Seasons

The VitD_quartMED model was used to calculate an estimate of the length of exposure time to obtain the equivalent of 1000 I.U. of vitamin D in Waterloo, Ontario under cloudy and clear, sunny sky conditions. In mid spring, on May 5th, with 25% exposure it would take 7 minutes for a person with type II skin to obtain the equivalent of 1000 I.U. of vitamin D under clear, sunny conditions. It would take a person with type V skin 17 minutes with 25% body exposure in the same conditions. In mid spring, on May 5, with 25% exposure it would take 48 minutes for a person with type II skin to obtain the equivalent of 1000 I.U. of vitamin D under cloudy conditions. It would take a person with type V skin 1 hour and 47 minutes with 25% body exposure in the same conditions. 25% of body exposure is the equivalent of exposing the face 3.5%, neck 2%, hands 6%, and arms 14% according to the Lund and Browder Chart (Webb & Engelsen, 2006).

In mid-summer, on August 5th, with 50% exposure it would take 3 minutes for a person with type II skin to obtain the equivalent of 1000 I.U. of vitamin D in Waterloo, Ontario under clear, sunny conditions. It would take a person with type V skin 8 minutes with 50% body exposure in the same conditions. In mid-summer, on August 5th, with 50% exposure it would take 25 minutes for a person with type II skin to obtain the equivalent of 1000 I.U. of vitamin D under cloudy conditions. It would take a person with type V skin 57 minutes with 50% body exposure in the same conditions. 50% of body exposure is the equivalent of exposing the face
3.5%, neck 2%, hands 6%, arms 14%, legs 14% and thighs 18% according to the Lund and Browder Chart (Webb & Engelsen, 2006).

In mid-fall, on November 5th, with 10% exposure it would take 1 hour and 50 minutes for a person with type II skin to obtain the equivalent of 1000 I.U. of vitamin D in Waterloo, Ontario under clear, sunny conditions. Cloudy conditions will not allow 1000 I.U. to be achieved for any skin type. 10% of body exposure is the equivalent of exposing the face 3.5%, neck 2% and hands 6%, according to the Lund and Browder Chart (Webb & Engelsen, 2006).

MED values were also calculated in mid-summer conditions with a ratio of 0.17, and a mid-winter ratio of 0.30. There is variability depending on the season, however the amount of time to get sufficient vitamin D status is somewhere between 17% and 30% of the amount of time to get a sunburn throughout the year. Results can be seen in Table 7.

Table 7: Summary of Model Results

<table>
<thead>
<tr>
<th></th>
<th>Mid-spring 25% body exposure</th>
<th>Mid-summer 50% body exposure</th>
<th>Mid-fall 10% body exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear sky, time to 1000 I.U. Type II Skin</td>
<td>7 min</td>
<td>3 min</td>
<td>1 hour 50 min</td>
</tr>
<tr>
<td>Clear sky, time to 1000 I.U. Type V Skin</td>
<td>17 min</td>
<td>8 min</td>
<td>/</td>
</tr>
<tr>
<td>Overcast sky, time to 1000 I.U. Type II Skin</td>
<td>48 min</td>
<td>25 min</td>
<td>/</td>
</tr>
<tr>
<td>Overcast sky, time to 1000 I.U. Type V Skin</td>
<td>1 hour 47 min</td>
<td>57 min</td>
<td>/</td>
</tr>
</tbody>
</table>

/ not possible to obtain 1000 I.U. in these conditions
5.0 Discussion

5.1 Climate Responsive Landscape Architecture

Landscape architects and scholars have researched and implemented designs that respond to the changing climate and recently the term ‘climate responsive landscape architecture’ has become more widely recognized. Climate responsive landscape architecture “involves the translation of climate knowledge into design directives and designing on various scale levels for climate adaptation” (Lenzholzer, 2010, p. 1). Thus, climate responsive landscape architecture aims to provide interventions that can improve outdoor climate and provide thermal comfort for humans in various conditions while also contributing to energy saving indoors and lowering CO₂ emissions (Lenzholzer & Brown, 2013). “Landscape architecture is well positioned to ameliorate these effects through climate appropriate landscape, urban planning and site design, as it is clear that the orientation of buildings, composition and color of surface materials, and types and locations of vegetation have major effects on the urban heat islands and on microclimates” (Lenzholzer & Brown, 2013, p. 2).

5.1.1 Existing Climate Responsive Design Guidelines

Lenzholzer and Brown (2013) reviewed the previous literature related to climate responsive landscape architecture and found that there is information on climate responsive design but very little could be used by non-specialists. There is a missing link between scientific jargon and practical application, a subject that had been previously identified by Eliasson (2000) in the field of climate knowledge and design. Through this literature review, Brown and Lenzholzer (2013) found some more general design guidelines that could be used at all scales of design in the field of landscape architecture (Robinette and McClennon, 1983; Brown and Gillespie, 1995; Brown, 2010) and had evolved from the literature. In the book, Design with Microclimate: The Secret to Comfortable Outdoor Space, Brown (2010) stressed that the most effective way to modify human thermal comfort in the summer is through modification of the sun, and in the winter through modification of the wind. In addition, orientation of buildings, shading devices and surface materials can have a big impact on increasing or reducing the urban heat island effect. There have been general guidelines created in other places, like
Beijing, China and most of these guidelines are very similar to Brown’s (2010) guidelines in *Design with Microclimate* involving the modification of the sun and wind in summer and winter.

More detailed design guidelines addressing a specific climate responsive issue have started to become available. An example would be shade guidelines for specific cities, with the aim of increasing the shade in the landscape in order to decrease UVR reaching humans and prevent the increasing rates of skin cancer. Shade audits have been increasing in popularity throughout municipalities in Ontario as a process for measuring the UVR exposure of an outdoor site and an assessment tool to aid in the identification of shade sources (The Waterloo Region Shade Working Group, 201). Australia was a pioneer for developing shade guidelines due to their high incidences of skin cancer (Greenwood, Soulos & Thomas, 1998) and some cities in Canada have followed suit in creating shade guidelines to increase shade in the landscape (Toronto Cancer Prevention Coalition, 2010; The Waterloo Region Shade Work Group, 2012; Durham Region Health Department, 2008). This could be in response to the Ontario Adaption Strategy and Action Plan, published in 2011, though the Ministry of the Environment that is effective from 2011 – 2014. This plan specifies how Ontario is taking responsibility to mitigate climate change and reduce greenhouse gas emissions. It provides government grants for programs that aim to reduce greenhouse emissions and it acts as a catalyst for these kinds of initiatives.

The Region of Waterloo Shade Information Guide and Toolkit (http://chd.region.waterloo.on.ca/en/healthyLivingHealthProtection/resources/ShadeAudit_GuideTool.pdf) explains six co-benefits of shade including: providing thermally comfortable spaces for humans (microclimates), mitigating the urban heat island effect, improving air quality, preventing climate change, providing energy savings and helping to increase physical activity in humans. It discusses the effectiveness of natural versus built shade, orientation of buildings, orientation of objects in the landscape, tree species for optimal shade and surface materials (Waterloo Region Shade Work Group, 2012). The toolkit allows for individuals to assess how much shade is on their property through five simple steps of preparing for the shade audit, considering the site context, observing and evaluation the site, envisioning a solution and planning for shade.
5.1.2 UVB and Climate Responsive Landscape Architecture

To review, the variables that affect how much UVB a person is exposed to on the earth’s surface include: solar zenith angle, distance from the sun, stratospheric ozone, other ozone, gases and aerosols in the troposphere, clouds, surface albedo and altitude, trees and other objects in the landscape. There are also other factors at the human scale including skin type, diet, skin area exposure and individual behavioural trends. Behaviour is a key factor in determining how much UVB radiation a person receives in the landscape. A person cannot change their skin type and although they have control over their diet, skin exposure and behaviour, some do not have a thorough understanding of the positive and negative effects of UVB, children especially. Moreover, aids to help achieve vitamin D sufficiency, like oral supplements and sunscreen, are often not an affordable or viable option. The following section will focus on geophysical variables affecting the amount of UVB radiation a person receives in the landscape.

While some of the geophysical variables are not modifiable through landscape design, such as solar zenith angle, clouds and altitude, some variables could be modified with large scale initiatives. These are the variables considered modifiable at a regional scale. There are also variables that can be readily modified through landscape design at the site scale including surface albedo and the location and orientation of trees and other objects in the landscape. Table 8 summarizes the geophysical and human scale variables that affect the amount of UVB radiation a person receives in the landscape. Although some of these geophysical variables are not modifiable by humans, understanding their influence on the landscape is important for landscape architects to take into consideration. Solar zenith angle, distance from the sun, clouds and altitude are very important to understand for site design.
### Table 8: Geophysical Variable Modifiable by Humans

<table>
<thead>
<tr>
<th>Geophysical Variables</th>
<th>Modifiable by Humans at the Regional Scale</th>
<th>Modifiable by Humans at the Site Scale</th>
<th>Non-Modifiable by Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Zenith Angle</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Distance from the Sun</td>
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<td>X</td>
<td></td>
</tr>
<tr>
<td>Stratospheric Ozone</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropospheric Ozone, Gases and Aerosols</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clouds</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Altitude</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Surface Albedo</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Objects in the Landscape</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

#### 5.1.3 Designing for Optimal UVB in Northern Latitudes through all Seasons

The results of the current study can be used to augment and extend existing guidelines like the Region of Waterloo Shade Information Guide and Toolkit. Although the results indicate that under ideal conditions a student could get the equivalent of 1000 I.U. of Vitamin D, the daily dosage needed for vitamin D sufficiency, in almost every case students would not receive sufficient Vitamin D by playing in a typical school playground in February. The students would not be exposed to enough UVB to cause erythema; therefore, the goal of school yard design should be to maximize UVB exposure in February and throughout the winter months. With evidence-based landscape architectural design, school grounds can be designed so that children can receive adequate amounts of vitamin D, even in midwinter in northern latitudes. Additionally, there is no possibility of them receiving too much UVB so as to be dangerous. However, designs that do not take this into consideration leave children with no opportunity to receive adequate vitamin D.

A design guide, shown in Figure 15, has been created as a tool to provide information and suggestions for designing to optimize UVB in all seasons at northern latitudes. Below is a summary of the most important considerations, determined through the integrative research.
review and further confirmed through the field testing, while designing for optimal UVB at the site scale:

1. **If you can see the sky, you are being exposed to UVB radiation.** Under human-fabricated structures like umbrellas, or under the shade of a tree, you are not receiving direct UVB, but if you can see the sky, you are receiving diffuse radiation.

2. **The leaves of trees intercept and absorb all direct UVB.** There is zero transmittance through a single leaf directly from the sun, but if you are under a tree canopy and can see the sky, you are receiving diffuse radiation via many different sources.

3. **Dense canopies can reduce UV to negligible levels.** Even thin and uneven canopies can filter UV from the sun and downward scattered UVB. UVB is filtered differently depending on the structure of a single tree or group of trees.

4. **Low shrubs and hedges can assist in absorbing and intercepting diffuse radiation.** Shrubs cannot prevent direct radiation from reaching you as trees can.

5. **Light ground surfaces or building facades reflect more diffuse radiation than darker colours.** Surface materials make a big difference in diffuse radiation being reflected or absorbed. Snow is especially effective at reflecting and scattering UVB as diffuse radiation.
Designing for Optimal Ultraviolet B Radiation in Northern Latitudes

Introduction:

Ultraviolet B (UVB) radiation from the sun is the chief cause of skin cancer and is also involved in the development of Vitamin D in humans (Field & Bishop, 2013). This poses an interesting challenge, especially for people living in northern climates as most Canadians are Vitamin D-deficient. Recent studies have compellingly concluded that the synthesis of Vitamin D in the skin is linked to improved musculoskeletal health and preventing certain cancers, cardiovascular disease and multiple sclerosis (Grant, 2010).

Background:

While there has been a rise in efforts to increase shade in the landscape due to high amounts of solar radiation leading to skin cancer in the summer months, the winter months have not been given fair consideration. As an example, school grounds are primarily used in the winter months and with evidence-based landscape architectural design, school grounds can be designed so that children can receive adequate amounts of vitamin D, even in midwinter in northern latitudes. Studies show that students would not be exposed to the dangers of sunburn even if they are exposed to the most UVB possible in midwinter. Geophysical variables, skin colour, amount of skin exposed and genetic factors all play a role in how much UVB a person can absorb into their skin.

Key Terms:

Direct UVB Radiation - unobstructed radiation directly from the sun
Diffuse UVB Radiation - radiation that has been scattered out of the direct sunlight beam

Key Concepts to understand before getting started:

1. If you can see the sky, you are being exposed to UVB radiation. Under human-fabricated structures like umbrellas, or under the shade of a tree, you are not receiving direct UVB, but if you can see the sky, you are receiving diffuse radiation.
2. The leaves of trees and other plants intercept and absorb all direct UVB. There is zero transmission through a single leaf directly from the sun, but if you are under a tree canopy and can see the sky, you are receiving diffuse radiation from many different sources.
3. Dense tree canopies can reduce UV to negligible levels. Even thin and sunlit canopies can filter UV from the sun and downward scattered UVB. UVB is filtered differently depending on the structure of a single tree or group of trees.
4. Low shrubs and hedges can assist in absorbing and intercepting diffuse radiation. Shrubs cannot prevent direct radiation from reaching you as trees can.
5. Light ground surfaces or building facades reflect more diffuse radiation than darker colours. Surface materials make a big difference in diffuse radiation being reflected or absorbed. Snow is especially effective at reflecting and scattering UVB as diffuse radiation.

Geophysical variables affecting UVB at the earth's surface:

Variables that can be modified at the site scale through design:

Design for optimal UVB in all seasons:

1. Deciduous trees, shrubs and vines are natural elements that optimize UVB in all seasons.
2. Movable and/or removable shade structures are built structures that can provide shade in summer but provide exposure to UVB in the winter.

References:

5.2 Limitations of the Study and Avenues for Future Research

One of the biggest limitations to the study is that the students were not observed during their time outside to connect their behaviour to the amount of UVB that they received. The students were asked to draw on a base map of the school and show where they played at recess, but ultimately these maps were not reliable enough to use. Ideally, the researcher could observe the students or the students could wear some sort of personal tracking system, like a GPS, so that the dosimeter time stamped data could be matched up to their location in the landscape. This study reported on total daily UVB exposure and although knowing total daily UVB exposure is beneficial, it would be more useful to measure the real-time exposure patterns linked to parallel activities to help assist with preventative strategies (Wright et al., 2007). Launching a larger scale study involving more students of different age groups would provide more information related to age, behaviour, skin type, gender, etc. Also, testing in a wider variety of weather conditions and looking at snow that is 1 day old versus 5 days old would be valuable. It would also be very beneficial to use the dosimeters in all seasons.

Future research in the area of improving human health by exploring optimal levels of UVB to achieve vitamin D sufficiency while avoiding sun over-exposure would help to give the existing models more importance. While there is a lot of information and recent studies discussing the benefits of vitamin D, there needs to be more concrete evidence showing the positive correlation between human health and sunlight exposure. Research is needed in the area of translating scientific knowledge into usable design guidelines for specific variables and populations that are more detailed, ever changing and evolving. A study, similar to this which focuses on another wavelength of ultraviolet radiation would help to increase the understanding of elements in the landscape. Computer models are also very valuable tools for landscape architects to use and although FastRT is available and user friendly it could be improved by adding landscape elements. FastRT gives a value for a horizontal flat plate and the dosimeters find values for either a horizontal flat plate or vertical plate, depending on its position. While most of the UVB would be the same, as it is mostly diffuse, components could be added to FastRT that would account for the switch in orientation and also the effect of
landscape elements like trees. Going even one step farther, specific tree species and their abilities to absorb UVB could offer a very reliable model.
6.0 Conclusion

This research has achieved its initial objectives. Variables that affect how much UVB a person is exposed to on the earth’s surface were reviewed and these include: solar zenith angle and distance from the sun, stratospheric ozone, other ozone, gasses and aerosols in the troposphere, clouds, surface albedo and altitude, trees and other objects in the landscape. There are also other factors at the human scale including skin type, diet, how much skin area may be exposed and individual behavioural trends. Results from the FastRT and Vit_quartMED models revealed that it is possible to get the equivalent of 1000 I.U. of vitamin D in February in Waterloo under sunny, clear weather conditions with snow on the ground, but not possible in most conditions. The fact that almost all of the UVB was diffuse radiation has vast implications for landscape architecture.

The results from the tests and information synthesized from the integrated research review helped to shape the guide for modifying UVB in the landscape for outdoor spaces that children may use in northern climates. This guide can be used by landscape architects, planners and even the general public. The guide effectively translates scientific knowledge to a practical application. Although there have been shade guides and tool kits issued by different cities in Ontario, such as the Region of Waterloo, an interesting note is that they tend to follow similar information that the Australian guidelines contain, but northern climates are much different and this has not been made obvious. Although the purpose of such shade guidelines responds solely to the issue of elevated skin cancer rates, vitamin D deficiency in Canada is a huge issue causing major health problems as well. Existing guidelines could be modified to also include more information regarding the importance of sunlight and vitamin D in the winter months and how to design outdoor spaces for optimal UVB in all seasons. Including information about the importance of vitamin D and the fact that many Canadians are deficient in the winter would be very beneficial for human health.
This research is very important as it aids in the development of the profession of landscape architecture. Landscape architects have the ability to improve human health through design and should use the guide provided in this study when designing school grounds, parks and outdoor public spaces in northern latitudes to optimize UVB.
References


Appendix A – Corresponding Data
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<tr>
<td>Longitude</td>
<td>-80.0</td>
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<tr>
<td>Sky Conditions</td>
<td>Overcast Sky</td>
</tr>
<tr>
<td>Ozone Column</td>
<td>350</td>
</tr>
<tr>
<td>Surface Altitude</td>
<td>0.35 m</td>
</tr>
<tr>
<td>Surface Type</td>
<td>Snow (5cm)</td>
</tr>
<tr>
<td>Compute Irradiances</td>
<td>290 – 320 (1mm range)</td>
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<td>Longitude</td>
<td>-80.0</td>
</tr>
<tr>
<td>Sky Conditions</td>
<td>Cloudless Sky</td>
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<td>Ozone Column</td>
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<td>0.35 m</td>
</tr>
<tr>
<td>Surface Type</td>
<td>Snow (5cm)</td>
</tr>
<tr>
<td>Compute Irradiances</td>
<td>290 – 320 (1mm range)</td>
</tr>
</tbody>
</table>
Appendix B – Ethics and Consent Forms
February 28, 2013

To Whom It May Concern:

This notice confirms that the following research project was approved by the WRDSB Research Committee.

- Title of Project: Sun vs. Shade: Exploring Sunshine Exposure in Southern Ontario School Yards
- Principal/Student Researcher or Investigator: Dr. Robert D. Brown/Victoria Cox
- Approved following the Research Committee held on: December 7, 2012

Please inform us at research.committee@wrdsb.on.ca as to which schools have agreed to be involved in this research project. Please be sure to include your research project title when communicating with us.

If you have any further questions regarding this research approval, please contact David Klassen, Psychologist, Learning Services, Special Education, 519-570-0003, ext. 4167.

Sincerely,

David Klassen, Chair
Research Committee
The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human subjects in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement.

The REB requires that you adhere to the protocol as last reviewed and approved by the REB. The REB must approve any modifications before they can be implemented. If you wish to modify your research project, please complete the Change Request Form. If there is a change in your source of funding, or a previously unfunded project receives funding, you must report this as a change to the protocol.

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Responsible Faculty, the safety of the participants, and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-council Policy Statement requires that ongoing research be monitored by, at a minimum, a final report and, if the approval period is longer than one year, annual reports. Continued approval is contingent on timely submission of reports.

Membership of the Research Ethics Board: B. Beresford, Ext.; F. Caldwell, Physician; C. Carstairs, COA; S. Chuang, FRAN (alt); K. Cooley, Alt. Health Care; J. Clark, PoliSci (alt); J. Devlin, OAC; J. Dwyer, FRAN; M. Dwyer, Legal; D. Dyck, CBS; D. Emslie, Physician (alt); B. Ferguson, CME (alt); H. Gilmour, Legal (alt); J. Goertz, CME; B. Gottlieb, Psychology; B. Giguere, Psychology (alt); S. Henson, OAC (alt); G. Holloway, CBS; L. Kuczynski, Chair; S. McEwen, OVC (alt); J. Minogue, EHS; A. Papadopoulos, OVC; B. Power, Ext.; V. Shalla, SOAN (alt); J. Srbely, CBS (alt); R. Stansfield, SOAN; K. Wendling, Ethics.

Approved: per Chair, Research Ethics Board

Date: December 2nd 2012
CONSENT TO PARTICIPATE IN RESEARCH

Sun vs. Shade: Exploring UVB Exposure in Southern Ontario School Yards

You are asked to give permission for your child to participate in a research study conducted by Victoria Cox, Master of Landscape Architecture candidate and Dr. Robert Brown, faculty advisor, from the School of Environmental Design and Rural Development at the University of Guelph. The data collected and results of the study will contribute towards a Master of Landscape Architecture thesis.

If you have any questions or concerns about the research, please feel free to contact Robert D. Brown, faculty advisor at 519-824-4120 x53619 or Victoria Cox, student investigator at 647-391-7068.

PURPOSE OF THE STUDY

The purpose of this study is to examine the amount of sunshine that children are exposed to throughout their school day. There is a need for research that explores how much sunshine is too much causing skin damage and how much is too little, resulting in Vitamin D deficiency. Very little information is available in the fall and winter months. The results will be used to help create design guidelines with the aim of safer and more enjoyable school yards for all seasons.

PROCEDURES

If you volunteer your child to participate in this study, we would ask your child to do the following things:

1. Students will wear a personal dosimeter badge, a small button-like device that measures and records the amount of sunshine they receive. The badges are simply a measurement tool; they are designed for children to wear and are not harmful to the student.
2. Students will pin the badge to the lapel of their usual outerwear when going outside at any point during a regular school day.
3. The badges will then be collected at the end of the day and the data will be uploaded to a computer and analyzed to understand how much sunshine they received.
4. Students will be issued a map of their school yard after each period outside and asked to sketch where they spent their time.
5. The information will remain anonymous; no names will be used in collecting the data.
6. The identity of the participant will remain confidential; no names will be stored in association with the data.

Each individual student participating in the study will wear the dosimeter badge a maximum of 3 times in a three month period (from January to March) for 3-5 times per day depending on how often they go outside (for gym, recess, lunch, etc.).

At the end of the study in April, a presentation will be given to the class to explain the results and a letter will be sent home to the parents.
POTENTIAL RISKS AND DISCOMFORTS

The badges pose no physical risk to the student; they do not contain any harmful elements. They are simply a tool for collecting information. Students may feel uncomfortable wearing the devices, in which case they will not be asked to partake in the study.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Students will not immediately benefit from the research. In the long term, the aim of this research is to aid in developing safer and more enjoyable school yards for students in Southern Ontario.

The potential benefits to science include more information about the exposure of children to UVB in the fall and winter months. An additional benefit is determining how to balance levels of UVB to avoid sun over exposure or under exposure.

PAYMENT FOR PARTICIPATION

The participants will not receive any payment for participation.

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.

1. Information will be treated in a respectful and confidential manner. Student names will not be recorded in collecting data as they will be assigned a number and categorized into groups.
2. Data collected from the dosimeter badges will be stored on a personal, password protected laptop computer. Data will be secure and only accessible to authorized individuals only. The laptop will be kept in a locked office.
3. Upon the conclusion of the study, the data will be destroyed.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer your child to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your child’s data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw your child from this research if circumstances arise that warrant doing so.

RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have questions regarding your rights as a research participant, contact:

Director, Research Ethics
University of Guelph
437 University Centre
Guelph, ON N1G 2W1

Telephone: (519) 824-4120, ext. 56606
E-mail: sauld@uoguelph.ca
Fax: (519) 821-5236
SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I have read the information provided for the study “Sun vs. Shade: Exploring UVB Exposure in Southern Ontario School Yards” as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant (please print)

___________________________________
Name of Legal Representative (if applicable)

______________________________
Signature of Participant or Legal Representative

[The name and signature of the legal representative is ONLY necessary if the participant is not competent to consent. If the participant is competent, please do not include these options.]

SIGNATURE OF WITNESS

______________________________
Name of Witness (please print)

______________________________
Signature of Witness

[The witness is ideally NOT the investigator, but if there is no readily available alternative, the investigator can act as witness.]
Sunshine in School Yards by Victoria Cox

Why you are here.
Victoria Cox and her teacher Robert Brown are researchers from the University of Guelph and want to tell you about a study that can help children stay healthy when they are outside. They want to see if you would like to be in this study.

Why are they doing this study?
They want to see how much sunshine you get when you are outside during lunch, recess and gym class.

What will happen to you?
If you want to be in the study two things will happen:
1. 1, 2 or 3 days in the winter you will wear a button on your coat when you go outside on the school yard that will see how much sunlight you get
2. After you wear the button you will draw on a map of the school yard where you played

Will there be any tests?
No, there will not be any tests and no marks will go on your report card.

Will the study help you?
No, this study will not help you right away but in the future it could help kids stay healthy when they play outside.

What if you have any questions?
You can ask questions anytime, now or later. You can talk to me, your teachers, family or someone else.

Do you have to be in the study?
You do not have to be in the study. No one will be mad at you if you don’t want to do this. If you don’t want to be in this study, just say so. Even if you say yes now, you can change your mind later. It’s up to you.

I want to be in this study

____________________________
Print name of Student

____________________________
Signature of Student Age Date

____________________________
Signature of Person Obtaining Consent Date