

ABSTRACT

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UMBRELLAS

Nicholas R. Cloyd, Master of Science, 2017

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The living umbrella is resembling of a traditional patio umbrella but with a canopy made of a layer of plants rather than fabric or metal. It is thought to provide comfort and shade to users while increasing nature in hardscaped areas. The study aimed to compare the microclimates of metal canopy umbrella to that of living umbrellas. Metrics used were Wet Bulb Globe Temperature (WBGT), UV transmittance, solar transmittance, air temperature, canopy temperature, and humidity. Compared to ambient conditions, the living umbrella reduced WBGT by 1.5°C, and UV and solar radiation by 76% and 82% respectively and 88% and 91% by the metal. The metal umbrella reduced UV and solar transmittance more than the living umbrella, but not WBGT. A second aim was to determine whether there was a Biophilic connection between the living umbrella and its users, which was explored through surveys. The Biophilic connection is exemplified by people who experience feelings of comfort when they are close to nature. The majority of respondents felt strong positive emotions towards the living umbrella, while 81% preferred a living umbrella over a metal umbrella. The research showed that an innovative green technology can improve the microclimate experienced by people while making them feel better.

MICROCLIMATIC EFFECTS & BIOPHILIC PROPERTIES OF LIVING
UMBRELLAS

By

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Dedication

This work is dedicated to individuals who have provided love and support of my goals throughout my educational career. I would not be standing where I am today, having achieved what I have, without the unconditional support of my Mother and Father, Krys Renzi & William Cloyd. Their motivation and teachings throughout my childhood have moved me to work hard, see the good with the bad, treat others as I wish to be treated, and never forget to have fun. I will forever be grateful for everything they have given. This work is also dedicated to my amazing wife and best friend, Chelsea Cloyd. Your encouragement and understanding of what was required to complete my education was selfless and honest. From weekend sacrifices to calming my overworked emotions, you were always there to keep me going. Special thanks are due to my advisor, Dr. David Tilley. All of the opportunities you've provided me with have helped steer me to the next stages of my life. I hope that we can continue to achieve greatness in years to come.

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List of Symbols

T_g	Globe Temperature (°C)
T_a	Air Temperature (°C)
V_a	Mean Air Velocity (m/s)
ε	Globe Emissivity
D	Globe Diameter (mm)
WET	Wet Bulb Globe Temperature (°C)
I	Radiation through canopy (W/m ²)
I_o	Radiation exposed to canopy (W/m ²)
K	Light Extinction Coefficient
LAI	Leaf Area Index

1.0.0 Introduction

As the global human population continues to flourish, for the first time in history the majority of the population lives in cities (Buhaug et al. 2013). City residents often find themselves living without many of the functional and cultural ecosystem services provided by natural ecosystems (Chiesura 2004; Nordh et al. 2009). These services include resource provisioning, cleaning and purification, nutrient cycling, climate stabilization, intellectual stimulation, and aesthetic beauty among others (Daily 1997). Without sufficient ecosystem services, urban areas lack important benefits which aid in protecting human health and well-being (Dwyer et al. 2007; Van Den Berg et al. 2007).

A city's lack of green space is known to contribute to the phenomenon known as the Urban Heat Island effect (UHI), which is a process whereby manmade materials absorb shortwave solar radiation during the day and slowly release this heat as thermal radiation into the environment, which especially elevates nighttime temperatures (Armson et al. 2012; Chang et al. 2014; Jenerette et al. 2011; Rahman et al. 2015). This excess storage and delayed release of thermal energy creates "heat islands" over cities which become a significant source for dangerously high temperatures within city limits (Akbari et al. 2001). UHI can be as great as 6.5 to 9 °C warmer than their surrounding rural areas (Zhang et al. 2010). With over half of our world's population living in urban areas, this potentially deadly condition must be addressed (Mavrogianni et al. 2011). Using technologies that create local mitigation of city wide UHI effects may a solution for resident health concerns.

Shade is also important in its ability to protect individuals from both thermal stress and damaging Ultraviolet (UV) radiation. Emitted by the sun, UV radiation is common health concern for individuals in the outdoor environment. Known to cause damage to the DNA of skin cells which could lead to multiple medical conditions including photoaging and cancer (Almeida et al. 2015). This has become a serious public health concern as non-melanoma cancers have become the most common form of cancer worldwide. The threat of UV exposure is thought to increase as the depletion of the planet's protective ozone layer intensifies (Dinkova-Kostova 2008). Technologies that allow the public to protect themselves from these deleterious effects of UV exposure should be understood thoroughly.

Plant biomass is a major influence affecting the urban climate (Jonsson 2004). First, evapotranspiration by vegetation removes sensible heat by changing liquid water to water vapor becoming latent heat. Second, the shade produced by vegetation reduces amounts of longwave solar radiation reaching the ground, decreasing surface temperatures (Chang et al. 2014). Shade trees have been shown to decrease road temperatures by 24.5°C and ambient air temperatures by 5.6°C (Vailsherry 2013). Finally, natural materials have a lower heat capacity as compared to most manmade materials allowing for less heat to be stored locally (Stone et al. 2001). Research has been conducted proving the cooling effects of plant material on local ambient temperatures and UHI (Armson et al. 2012, 2013; Chang et al. 2014; Rahman et al. 2015). Similar research of innovative technologies will aid in creating a catalog of products that provide health benefits and are available to different locations or applications.

In efforts to increase the amount of green space in cities and improve resident health, many innovative technologies are being developed. Widely seen examples of these technologies include green roof and green wall systems. These innovative devices improve urban ecosystem services by allowing plants to grow in nontraditional locations in cities (Francis et al. 2011). In addition to climatic benefits, exposure to green spaces improves the health and well-being of city residents by inducing feelings of calmness and relaxation, and increasing rates of healing (Hartig et al. 2003; Pretty et al. 2005; Ulrich 1983). This type of stress relief, highlighted within the study of Biophilia, is elemental to maintaining a healthy lifestyle (Kellert et al. 1993). Biophilia is a philosophy based on an intrinsic connection between humans and nature (Wilson 1984). Assuming this health benefit of green space, its application in urban areas should be thoughtful. Although green roofs and green walls provide aesthetic benefits and ecosystem services, they fall short of creating shade and immersive environments for local residents (Oberndorfer et al. 2007). This research centers around an innovative green technology, the living umbrella (Figure 1), and two of its intended purposes of improving thermal comfort and increasing natural beauty of urban environments, which may lead to improved quality of life for its users.

The living umbrella (Figure 1) was designed to replace a traditional patio umbrella. It utilizes a center supporting pole and extended ribs to provide structure for a canopy of plants. The above-head vegetation acts as the shade provider rather than a fabric or metal canopy. Many functions of a small shade tree are mimicked by the living umbrella. The increased vegetation is intended to create cooler local environments and relaxing, immersive green areas for occupants. First developed in 2015, the living

umbrella is a patent pending technology (PCT IB2016/056440). Prior to this research, no scientific studies of any kind have been performed on this new invention.



Figure 1. A living umbrella on display during a campus event at CSPAC. This unit was later moved to a patio in close proximity during the sampling period.

A major aim of this research was to evaluate the living umbrella's ability to provide shade and thermal comfort. In doing so, the living umbrella's abilities were compared to the capabilities of a metal patio umbrella with an opaque canopy. This was addressed through an evaluation of the shaded region created by the canopy which is its microclimate. Seven living umbrella units were paired with metal umbrellas across the University of Maryland, College Park campus. They were evaluated for a series of microclimatic metrics that describe the quality of the microclimate produced.

Another aim was to determine if the living umbrella invoked a Biophilic connection with users, like has been shown for large urban green spaces. Two surveys were developed for completion by individuals that used or observed the living umbrella. The surveys gave insight on public opinion of the living umbrella's natural beauty and its effects on emotion.

1.1.0 Microclimatic Evaluation

Thermal comfort is an important consideration when planning outdoor spaces. It is well known that thermal stress can directly affect the well-being of humans by raising body temperature, causing dehydration, inducing heat stroke, and even becoming fatal (Enander et al. 1990). Technologies that reduce or mitigate the harms of heat stress are essential for ensuring health of our communities (Stone et al. 2001).

The American Society of Heating, Refrigeration & Air-Conditioning Engineers (ASHRAE) Standard for thermal comfort is defined as a condition when an individual is satisfied with the temperature of the surrounding environment (ASHRAE Standard 2004). An individual's ability to achieve a satisfied temperature is limited while outside. Interacting climatic stressors make it difficult to address all sources of discomfort. The most commonly addressed stressors are direct solar radiation and ambient air temperature. Decreasing exposure to direct shortwave radiation improves the individuals comfort by decreasing their skin temperatures and reduces other dangers such as sunburn and heat stroke (Armson et al. 2013; Saraiya 2004). Shade devices are effective in reducing the amount of direct solar radiation that an individual receives, thus allowing the skin, clothes and surrounding material surfaces to cool (Armson et al. 2012).

Measuring the incoming solar radiation and ambient temperature can help determine the risk level of the environmental conditions. Mean Radiant Temperature (MRT) is one metric used to gauge the thermal comfort of an environment (Armson et al. 2013; Matzarakas et al. 2002; Thorsson et al. 2007). MRT is also a variable in multiple calculations of heat indices such as Physiological Equivalent Temperature (PET) and Predicted Mean Vote (PMV) (Hoppe et al. 1999; Yau et al. 2014). These indices can be used to understand the interactive effects of the outside environment including the ambient temperature, solar radiation, wind and humidity have on an individual's thermal comfort.

To effectively gauge the MRT of an area, a study by Thorsson et al. 2007 validated Wet Bulb Globe Temperature (WBGT) as a suitable analog for the MRT metric. WBGT takes into account 3 variables to determine the heat-stress acting on an individual in a specific micro-climate. These variables are air temperature (TA), Wet Bulb temperature (WET), and black globe temperature (TG) (Equation 1).

$$WBGT = (0.7 \times WET) + (0.2 \times T_g) + (0.1 \times T_a) \quad \text{Equation 1}$$

WET=Wet Bulb Temperature(°C); T_g =Globe Temperature(°C); T_a =Air Temperature(°C)

Wet Bulb Temperature is a function of relative humidity and ambient air temperature (Stull 2011). The globe temperature is a function of the short wave solar radiation being absorbed by the black bulb of the instrument. When comparing the MRT and WBGT calculations, each account for one variable that the other is disregarding. MRT dismisses humidity specifically; although it can be argued it would have effect on the ambient temperature reading. WBGT does not measure air velocity; however,

advection or convection across the globe thermometer may result in cooling effects or lack thereof. The WBGT will be utilized as analog to the MRT measurements and calculations in this study. Further comparison of the two metrics can be found in the discussion (Equation 4). Similar to the interactive effects of MRT and WBGT, describing the microclimate requires a variety of metrics.

The shading quality of the microclimate will be of equal importance in determining the microclimates ability to create safe environments. UV radiation is broken into 3 classifications of UV light based on wavelength; UVA (400-320nm), UVB (320-290), UVC (290-200nm). The UVC range has been found to have the most detrimental health effects, but this wavelength is greatly reduced by the earth's ozone layer (Dinkova-Kostova 2008; Kerr et al. 1993). The meters utilized for this study will evaluate the sun's wavelength spectrum between 250-1100nm encompassing the large majority of the UV and visible light spectrum.

Contrast of the living umbrella with a metal patio umbrellas allows for direct comparison to conventional shade solution. Commonly, fabric and metal umbrellas are used as shade devices to create comfortable microclimates. Man-made materials such as fabrics, plastics, or metals make up the materials used on these inanimate structures. Traditional canvases require the use of synthetic polymer based materials. These plastics have a very slow rate of degradation which allows them to be persistent in our environment. Of the waste that accumulates on our land and seas, 80% is attributed to plastics (Barnes et al. 2009).

The living umbrella reduces the use of manmade materials for shade and looks towards the natural world's limitless pallet of living materials that can create shade. The

most historically well used is the canopy of a tree. A tree is an environmentally sustainable shade solution because it provides effective shade and a litany of ecological services (Armson et al. 2012). However, there are many limitations to planting trees in specific urban environments, like rooftop patios, small enclosed outdoor atria, parking lots, walkways, patios, and other concrete spaces. Trees need a substantial amount of soil, water, sunlight and nutrients. In addition, trees are rarely mobile unless planted in large moveable containers. The living umbrella has reduced resource requirements and less limitation in its application. The soil contained within the raised bucket is minimal, and its location above the heads of users allows floor space to remain available. A stand-alone, automatic irrigation system alleviates plant maintenance while eliminating the need to be in proximity to an electrical outlet or water spigot. The slender support pole gives the option to insert the umbrella into a table, further enhancing space efficiency in space-limited areas.

A human dilemma is solved through ecological design with the living umbrella's ability to support natural vegetation while having added benefits of the modular design of a traditional patio umbrella.

1.1.1 Aims

We expect to see the living umbrella to produce a microclimate of similar quality to that of the metal umbrella. Due to the spaces between leaves of the vegetation we expect more sunlight will pass through the living umbrella canopy resulting in decreased shade quality; however, we expect this difference to be negligible when compared to the metal umbrella's shade. Reduction from the ambient condition's UV and Solar Radiation

metrics is expected to be significant within both microclimates. We expect the WBGT to be significantly decreased beneath both observational units as compared to ambient conditions. We also expect the living umbrellas reduction of WBGT to be equivalent to that of the metal umbrellas. It is expected that the canopy temperature of the metal will be significantly hotter than that of the living.

1.2.0 Biophilia

The Biophilia philosophy, formalized by Edward O. Wilson, proposes that there is an intrinsic bond between humans and other living things (Wilson 1984). In a series of personal essays, Wilson argues that humans are more complexly connected to the natural environment than a simple, resource based relationship. Our ability to connect with nature on an emotional level, beyond that of just instinctively gathering resources, is a genetic trait we have evolved through time. Steven Kellert, Co-author to the Biophilia Hypothesis (1993), posits that humans are genetically predisposed to be attracted to spaces that provide diversity, complexity, and nature. It is argued that this predisposition was derived from our ancestor's preference of savanna-like environments which provided abundant food, topographic relief, and clumps of trees for safety (Butzer 1977). This savanna landscape proved ideal to support the evolution of our species. Thus, in turn, modern human cultures have a predisposition to favor savanna-like landscapes. A study by Falk and Balling (2010) found an affinity in young subjects towards a savanna-like setting as compared to resource rich forests which posed many dangers, or barren deserts in which food and shelter are extremely limited.

This supports the hypothesis of an early-human vestigial trait that is expressed in modern humans as an aesthetic preference. Today, over half of our world's population lives in urban areas (Mavrogianni et al. 2011), which eliminates the notion that living in a savanna is essential or optimal. However, humans do spend copious amounts of time and energy changing their environments to more closely resemble the savanna landscape (Balling et al. 1982; Falk 1977). Philosophies that the human mind is wired to find comfort in environments that simulate the elements of open green spaces, clumps of trees, and access to water have been discussed by Butzer (1977) and Falk (2010). Natural selection has resulted in traits that create appreciation for this type of landscape. Although many of us now live in hard, inanimate, urban environments, some people strive to achieve more comfort by providing natural elements that connect them to their ancestral lives on the savannas. This connection has been severed through mass urbanization. Communities have grown apart from the natural influences that shaped their evolution. Through development of large metropolitan areas, which exclude green space and limits residents' access to nature, individuals suffer from a lack of exposure to the natural world (Nordh et al. 2009).

The Biophilia Hypothesis was publicized in 1993 by Kellert and Wilson in an attempt to validate people's affinity and need for the natural world. What started as a collection of thoughts, has developed into a study that has spread across the fields of ecology, biology, philosophy, social studies, and architecture among others. Many seek to justify Biophilia because of a unified consensus in the idea that natural elements and connection to green space are beneficial to an individual's well-being and a community's progression (Kellert et al. 1993).

Green space is a broad term used to identify areas with vegetation large enough to allow groups to congregate and enjoy nature (Bertram et al. 2015; Des Vries et al. 2003; Kaplan et al. 1989; Kellert et al. 1993; Newton 2007; Peschardt et al. 2012; Tanako et al. 2002; Ulrich 1983). The benefits of green space on resident's wellbeing include stress reduction, positive self-emotions, and improved attention, have been well documented by Bertram (2015), Ulrich (1983, 1991) and Kaplan (1989). Physical benefits include improved longevity (Tanako et al. 2002) and positive self-reporting of health (Des Vries et al. 2003). Effects can also be seen through improved social cohesion and identity (Newton 2007). A benchmark study by Ulrich (1984) suggested that of the hospital patients who underwent similar surgery those who had views of natural landscapes from their beds were more likely to recover faster, experience less fear, and have less stress compared to patients who were placed in a room with a view of only a brick wall. This suggests that a simple view of plants had a healing and restorative effect on individuals.

The Biophilia hypothesis stipulates that a connection with nature is fundamental to psychological well-being and personal fulfillment (Kellert et al. 1993). Cities are realizing an increase in the use of green spaces for socializing and 'rest and restitution' (Peschardt et al. 2012). Access to green spaces and exposure to life-like processes, makes humans more aware of the role they can play in supporting healthy ecosystems (Kellert et al. 1993). Promoting green space in urban areas may improve environmental stewardship and allow for community cohesion when united with a purpose of environmental stewardship preservation. Biophilia may help explain the peoples' response to the living umbrella; in particular, why the living umbrella is or is not a preferred shade solution.

Although Biophilia provides a comprehensive platform to support an individual's connection with the natural world which, in-turn, provides physical and mental health benefits; it should be discussed how other ideologies may interact to influence how individuals use and perceive green space. Studies of environmental psychology have reviewed Biophilia's proposed intrinsic bond with nature and fallacies have been presented. An essay by Joye and Van Den Berg (2011), questions the conclusions gathered by many studies such as Ulrich (1984) and Kaplan (1989) that suggest scenes of unthreatening nature provide restorative effects. Their arguments begin by identifying the arbitrary categorization of "unthreatening nature" as an input into the research. Categorization of "unthreatening" could be variant based on the individual, thus hard to define for a population. Conclusions based on an undefinable variable should only be made case-to-case. Joye and Van Den Berg also challenge the evolutionary purpose that these restorative reactions may have had on our ancestors. Exposure to vegetation, which was abundant during early human evolution, may not have improved upon the ability to provide food or safety, which wouldn't create restorative effects like stress relief. Intrinsic feelings of stress relief would be more associated with having plentiful food or ensuring a safe place to sleep. An alternative article by Joye and De Block (2011) attacks the very foundation of the Biophilia hypothesis. Discrepancies includes identification of the variety of landscapes that humans evolved upon and a species wide genetic code for preference of solely the savanna is unlikely. The article continues to cite studies which question restorative effects towards vegetation. As debated by Lewis (2005) the majority of vegetation preference studies have limited ability in controlling for cultural or ethnic influences on an individual's response. Further, research by Hagerhill (2004) proposes

that fractal geometry common to both the natural and built environments could be the key to perceived preference of naturalness. As a consequence of these conflicting views surrounding why individuals react to their surroundings the way they do, it is important to understand more fully how the living umbrella affects its users. Ultimately, it is vital to understand all barriers and influences on implementing security and sustainability into our cities (Coaffee 2008).

1.2.1 Aim

The aim was to determine whether participants feel more comfortable and experience reduced stress in the presence of green space. The Biophilia hypothesis supports that people will be drawn to the green space and be more satisfied when shaded by green, living canopies. It is expected that the living umbrella will increase an individual's awareness of environmental stewardship.

2.0.0 Materials and Methods

2.1.0 Site Selection

The State of Maryland is located on the Eastern shore of the United States between longitudes 75° and 79° West & latitudes 30° to 49° North. Location in temperate latitudes aids its mild climate and four distinct seasons. Three major physiographic provinces spanning from East to West are; the Coastal Plain, Piedmont Province, and Appalachian province. Prevailing northwesterly winds during the winter bring in colder

norther air. During the summer, upper atmospheric air patterns change resulting in southeasterly winds bringing warmer, moist air. Mean annual temperatures range from 9° to 14°C. Mean annual precipitation ranges from 40 to 46in across the state. (Stratton n.d.)

The living umbrellas were placed across the University of Maryland, College Park campus (see Figure 2). Specific locations were determined through coordination with the University's Facilities Management, Director of the Arboretum, and interested 3rd party organizations on-campus. These locations and 3rd parties include; Stamp Student Union, Clarice Smith Performing Arts Center (CSPAC), South Campus Store (SCS), Eppley Recreation Center's Outdoor Pool (ERC), Ellicott Dining Hall, Tawes Plaza and Richie Coliseum. Site constraints included availability of seating, close proximity to metal umbrellas (less than 100 yards), exposure to direct sunlight for at least 2 hours per day, and availability to be utilized by the campus community. Due to constraints by the campus, fire code, arrangement and size of the areas, limitations were realized in the placement of the units. The researchers had little control over the final location of the treatments within the site because of these constraints. Additionally, the final decision on exact location within a site was made by the group volunteering the space.



Figure 2. Map of living umbrella site locations across the University of Maryland campus.

(Generated by Google Maps)

There was variation between sites because of the dissimilar furniture arrangements around buildings, surface materials, proximity to trees, walls and other urban features. Due to the possibility of shading by surrounding buildings, paired living and metal treatments were placed in similar paths of shadowing to mitigate influence on factors of interest. These sites have been championed because they provide opportunities for campus involvement, sufficient sunlight, and are populated with metal umbrellas.

2.2.0 Observational Unit Descriptions

2.2.1 Living Umbrella

Plant structure on individual living umbrellas was heterogeneous because of variation of plant species and plant density. Two pairs were placed at Richie Coliseum, one living umbrella with white Mandeville (*Mandevilla Sunmandeho*), one with red Mandeville (*Mandevilla Sunmandecrikin*). One unit at Stamp supported red Mandeville. One unit at the South Campus Common Store contained 3 panels of a non-fruiting grape (*Vitis vulpina*), and one panel of Passion Flower (*Passiflora incarnata*). One unit at ERC pool with yellow Mandeville (*Mandevilla sunpapri*). One unit at Tawes Plaza with 2 panels of pink Mandeville (*Mandevilla sunmandecripi*) and 2 panels of Red Mandeville. One unit at CSPAC with non-fruiting grape. Table 1 displays all sites and plant arrangements.

Site	Plant Arrangement
Richie Coliseum	<i>Mandevilla Sunmandeho</i>
Richie Coliseum	<i>Mandevilla Sunmandecrikin</i>
Stamp Student Union	<i>Mandevilla Sunmandecrikin</i>
South Campus Common Store	3 <i>Vitis vulpine</i> + 1 <i>Passiflora incarnata</i>
Epply Recreation Center Pool	<i>Mandevilla sunpapri</i>
Tawes Plaza	2 <i>Mandevilla sunmandecripi</i> + 2 <i>Mandevilla Sunmandecrikin</i>
Clarice Smith Performing Arts Center	<i>Vitis vulpine</i>

Table 1. Location and Plant Arrangement of the living umbrella units on the University of Maryland, College Park Campus.

The living umbrella was designed to resemble a traditional patio umbrella. A 24-in. square, steel base plate weighing approximately 120-lbs (54-kg) provides a low center of gravity. Attached to the base plates, via a supporting post, stands an 8-ft (2.4-m) tall,

2½-in (6.4-cm) diameter aluminum main pole. Atop the main pole at 7-ft (2.1-m), a 24-in (61-cm) wide aluminum bucket is centered and welded to provide a container for the plants. Four 3 ½-ft (1-m) long, extended ribs are pinned to guide channels which are welded to the container. A trellis system is created between the extended ribs using 3/16-in (0.5-cm) diameter steel cabling which is ferruled to remain permanent. The surface of area of the canopy is 40-ft² (3.7-m²). Housed by a 24x24x12-in (60x60x30-cm) metal enclosure, the irrigation system rest at the bottom of the living umbrella. A system including a water reservoir, solar panel, battery, pump, and controller allow the plants to be watered on a customizable schedule. The entire unit is powder-coated grey to resist rust and damage. A picture of a living umbrella unit during the sampling period is portrayed above (Figure 1).

2.2.2 Metal Umbrella

Two different metal umbrellas types were used in this study. Both Type 1 and Type 2 metal umbrellas are entirely of steel construction, powder coated black, and centered within a table. The tables are also metal, powder coated black, and surround by metal chairs.

The Type 1 canopy is made of 6 entire, flat, metal sheets with small 1½-in (3.8-cm) separations between the panels. This separation is open and allows sunlight to transmit through to the microclimate. The canopy is 7-ft (2.1-m) above the ground with an 8-ft (2.4-m) diameter. A visual of the table & umbrella unit can be viewed below (Figure 3). The Type 2 metal canopy is made of 6 perforated, domed, metal sheets. A 1½-in (3.8-cm) separation between the panels allows sunlight to transmit through to the

microclimate. The canopy sits 8-ft (2.4-m) above the ground with an 8-ft (2.4-m) diameter. The Type 2 umbrella can be seen in below (Figure 3).



Figure 3. Type 1 and Type 2 metal umbrellas

2.2.3 Umbrella Pairs

The living umbrellas were of new construction, made of aluminum, powder coated grey, and had recently been placed on location. The metal umbrellas have been on location for a number of years, are made entirely of steel and powder coated black. The locations are used by the campus community as meeting places, studying areas, lunch tables, and relaxation spaces. The living umbrellas will be placed within close proximity to the metal umbrellas so conditions are similar.

2.3.0 Microclimatic Evaluation

2.3.1 Design

The study was organized as a randomized complete block design. Each block contained one living umbrella and one metal umbrella. This study examined one treatment factor; the canopy type, with two levels; living or metal. Seven living umbrellas were placed across the campus, each paired with a metal umbrella resulting in 7 blocks, with 7 replications of the treatment levels. Some sites contained multiple pairs of observational units; paired units were treated as one block. The microclimate of the umbrellas served as the observational unit. Areas adjacent to the treatments microclimate, where the unfiltered, direct sunlight's effect on the macroclimate can be measured, served as the control (ambient) measurement. An ambient measurement was taken for each observational unit within the blocks. This resulted in 4 groups of datasets gathered from each block; 1) Control Living 2) Living 3) Control Metal 4) Metal (see Figure 4). The umbrellas are inherently independent, and paired units will be within a reasonable distance of each other to improve homogeneity of the environmental conditions.

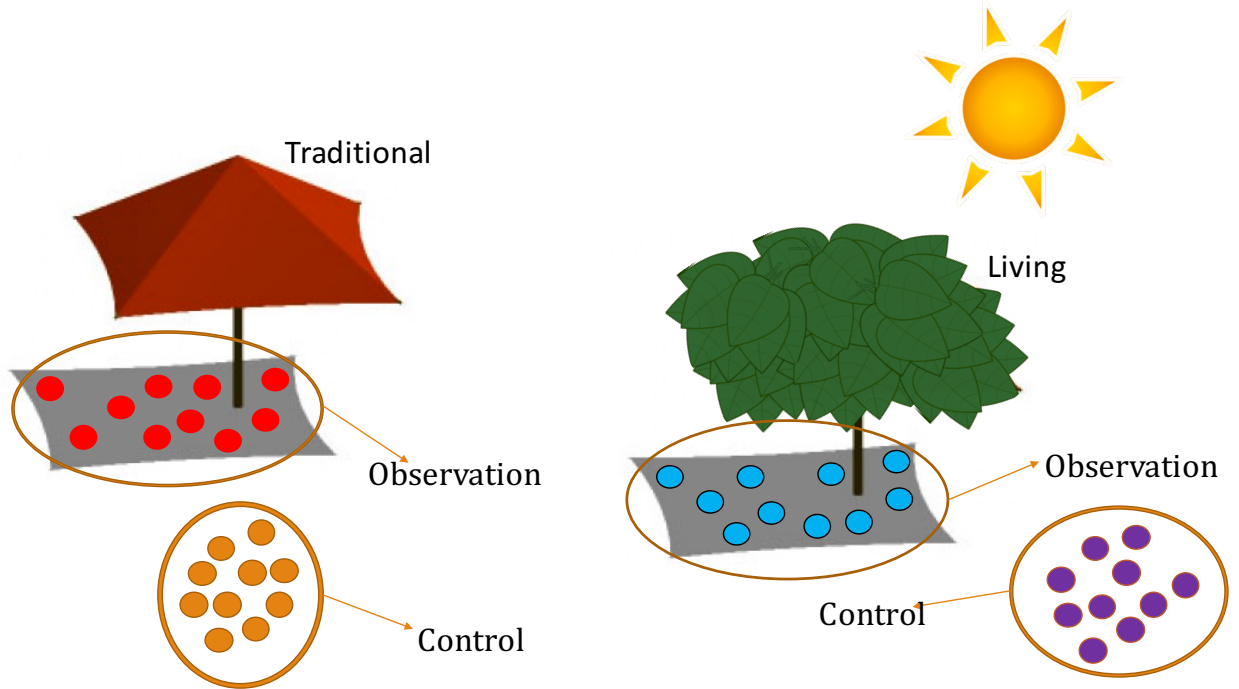


Figure 4. Visualization of the sampling procedure for WBGT, Air Temperature, UV Radiation, Solar Radiation, Humidity. Observational units were paired with ambient control measurements

2.3.2 Sampling

Sampling occurred between the hours of 10:00 AM and 3:00 PM over 4 days in the month of October. October was chosen because this was the first month the newly constructed living umbrella units were available. All experimental units were installed by the end of September. Days of sampling required clear sunny conditions to eliminate potential disruptive effects of clouds. Site sampling randomization was extremely limited in the study. Obstructions and the shading paths of buildings required that some locations be sampled at specific times to ensure direct exposure to the Sun. Some sites were exposed to direct sunlight only in morning hours while others only in the afternoon. Not all sites were sampled every day, the researcher sampled as many sites as possible during

the study period. Some sites were sampled more frequently due to the site attributes. These attributes included minimal shading influence due to local buildings or trees, multiple pairs on the same location, and amount of foot traffic on the site. Table 2 shows the sampling schedule on individual sample days.

Date	Site
October 3, 2016	South Campus Store
October 3, 2016	Richie Coliseum Red
October 3, 2016	Richie Coliseum White
October 4, 2016	South Campus Store
October 4, 2016	Eplley Recreation Center Pool
October 4, 2016	Clarice Smith Performing Arts Center
October 4, 2016	Stamp
October 4, 2016	Richie Coliseum Red
October 4, 2016	Richie Coliseum White
October 5, 2016	South Campus Store
October 5, 2016	Stamp
October 5, 2016	Richie Coliseum Red
October 5, 2016	Richie Coliseum White
October 5, 2016	Tawes Plaza
October 18, 2016	Stamp
October 18, 2016	Richie Coliseum Red
October 18, 2016	Richie Coliseum White

Table 2. Sampling Schedule during the study period. Not all sites were sampled each day. Some sites were sampled multiple times due to their ideal site attributes.

At each site the researcher measured five microclimatic metrics and two vegetation metrics;

- Wet Bulb Globe Temperature (WBGT)
- Solar Radiation
- UV Radiation
- Canopy Temperature
- Leaf Area Index (LAI)

- Percent Cover
- Air Temperature
- Humidity

2.3.3 Wet Bulb Globe Temperature & Humidity & Air Temperature

The Wet Bulb Globe Temperature was measured by a Wet Bulb Globe Thermometer. WBGT ambient measurements were recorded in direct, unfiltered sunlight and observational measurements recorded within the treatment's microclimate. The researcher used a Tenmar TM-188D Heat Stress Meter (Tiapei, Taiwan) to measure WBGT. This device recorded relative Wet Bulb Temperature, air temperature, and globe temperature to calculate the WBGT (Equation 2). Relative humidity and air movement are both integrated into the Wet Bulb Temperature. Their effects, although not shown in the calculations, influence the Wet Bulb Temperature and globe temperature. The accuracy for this meter is $\pm 1.5^{\circ}\text{C}$.

The device was positioned on a tripod 1.1 m above the ground and given a five-minute acclimation period before a five-minute data gathering period. Subsamples were recorded every five seconds during this sampling period to replicate optimal data gathering methods suggested by Thorsson (2007). The direct sunlight (ambient) measurements were taken 2 meters from the southern edge of the shaded area, ensuring to be in direct, unfiltered sunlight. The observational measurements were taken within the shaded region, ensuring to be in an area of complete shade (Figure 4).

The researcher was careful to not record entirely in the shaded area cause by the chassis/bucket of the living umbrella as this may overestimate the shade quality of the

treatment. The WBGT will be a major factor in evaluating the ability for the treatments to alter the macroclimate conditions into comfortable microclimates. The WBGT measurement is a direct analog to the mean radiant temperature (MRT) measurement utilized by popular thermal comfort metrics such as physiological equivalent temperature (PET) (Hoppe 1999).

The WBGT metric is expected to be influenced by the amount of solar radiation removed by the canopy and evapotranspiration of the plants. Decreasing the WBGT of the ambient environment during hot summer days will provide safety from thermal stress for users.

2.3.4 UV & Solar Radiation

UV and Solar radiation measurements were taken at 1.1 m above the ground, which was the assumed center of gravity of a typical standing person (Marzarakis et al. 2002). The researcher used an Apogee UV meter MU-100 (250 – 400 nm) (Logan, Utah) and Apogee Pyranometer MP-100 (350 – 1100 nm) (Logan, Utah) to measure UV and solar radiation, respectively. The wavelengths measured by this study encompass the entire UVA and UVB spectrum. Direct sunlight (ambient) was measured 2 meters from the southern edge of the treatments shaded region, ensuring to be in direct, unfiltered sunlight. Microclimate measurements were recorded randomly across the entire shaded area, ensuring to remain inside of the shaded region (Figure 4).

To account for the high variability of solar transmittance, 10 subsamples were taken with 5 second intervals between recordings. To record shading effects of the living umbrella chassis/bucket the researcher ensured to only take one subsample of the shade

caused by these opaque pieces. The data is seen as relevant because it contributes to the quality of the shaded region. Transmittance is calculated as the proportion of light that passes through the treatment and will be represented as a percentage.

Transmittance is expected have a direct effect on WBGT due to the increased or decreased shortwave radiation affecting the umbrella users. It also is important in providing shelter from harmful UV radiation.

2.3.5 Leaf Area Index (LAI)

Ten subsamples were taken from each living umbrella and averaged for the LAI metric. To create subsample locations LAI, the researcher walked two concentric paths around the umbrella canopy. The first path gathered 6 subsample points between the outer-edge of the canopy and 2 feet towards the center. The second path gathered 4 subsample points within the center of the canopy (Figure 5).

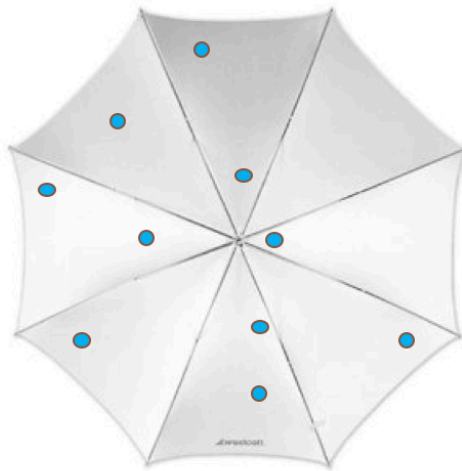


Figure 5. Example of randomized sample locations on umbrella unit. Six subsamples from the outer 2ft. Four subsamples within the center of the canopy

LAI was measured using point intercept method as described by Schumann (2007). A 1/2-in rod was inserted into the canopy, perpendicularly from the ground, all leaves touching the rod were counted, 10 subsamples were averaged for the LAI of the entire canopy. LAI is an appropriate metric to determine canopy light interception (Pearce et al. 1965; Wells 1991).

LAI is expected to have an influence on transmittance values as well as the WBGT of the microclimates. LAI will also be used to calculate light extinction coefficients which will help in forecasting effects of increased LAI. The light extinction equation (3) can be seen below (Jones 2015). This was applied to each dataset that was gathered through the sampling period.

$$I = I_0 e^{(-k \cdot LAI)} \quad \text{Equation 2}$$

$$I = \text{Radiation through canopy} \left(\frac{W}{m^2} \right); I_0 = \text{Radiation exposed to canopy} \left(\frac{W}{m^2} \right);$$

$$k = \text{light extinction coefficient}; LAI = \text{Leaf Area Index}$$

2.3.6 Canopy Temperature

Ten subsamples were gathered from each observational unit and averaged for the canopy temperature metric. An identical concentric walking procedure to that of the LAI method was used to gather the subsample data points. A circular path around the outer edge of the unit, followed by a path around the center of the canopy gathered 10-subsamples (Figure 5).

The researcher used an Apogee Infrared Radiometer MI-210 (Logan, Utah) to measure the canopy temperature of the observational units. The device was held 5-in

from the sample location and allowed an acclimation period of at least 3 seconds before a measurement was recorded. The treatment's canopy temperature is expected to have an influence on the WBGT of the microclimates. It is expected that higher canopy temperatures will increase the air temperature of the microclimate. This could potentially influence the individuals thermal comfort as represented by WBGT.

Thermal radiation exchange equations were utilized to understand the amount of longwave radiation the umbrellas were emitting. The heat flux equation (4) for thermal radiation utilizing the Stefan Boltzmann constant was applied (Cheng et al. 2011).

$$q = \varepsilon \sigma (T_h^4 - T_c^4) \quad \text{Equation 3}$$

$q = \text{Thermal Radiation } \left(\frac{W}{m^2}\right)$; $\varepsilon = \text{emissivity}$; $\sigma = \text{Stefan Boltzmann Constant}$;

$T_h = \text{Absolute Temperature Hot Object}$; $T_c = \text{Absolute Temperature Cold Surrounding}$

2.3.7 Percent Cover

For each of the living umbrella units, percent cover was calculated visually by the researcher. The researcher evaluated the amount of the quadrant covered by plant material to determine percent cover for individual quadrants. The 4 quadrants of each living umbrella were averaged to give an overall percent cover. Percent cover is expected to influence the transmittance values and WBGT metric. Figure 6 is a visual looking up through the canopy just as the researcher would have done to quantify percent cover. This quadrant would be valued at 75% covered.



Figure 6. Quadrant with 75% plant coverage. Researcher subjectively subtracted negative space from a value of 100% coverage to obtain percent coverage values. One researcher performed this task which limited variation of subjective analysis

2.3.8 Analysis

One-way Analysis of Variance (ANOVA) was used to determine within blocks, if the treatment types significantly decreased the macroclimate conditions within their respective microclimates for each metric. SAS statistical software was used with the PROC MIXED model to analyze the data. This was used over the GLM model because the same units were sampled multiple times fitting the repeated statement of MIXED more appropriately. A sample statistical code can be seen Appendix 1. The use of blocking aided in eliminating uncontrollable error due to site and plant heterogeneity. The ANOVA analysis determined if a significant block effect was present for each metric evaluated. If significant, the researcher was unable to make concrete conclusions on what may be causing this effect. The blocking is used to remove heterogeneity within the experiment that cannot otherwise be controlled for. The result of a significant blocking effect may be due to countless number of variables that had not been accounted for, thus

the variable responsible cannot be precisely determined. LAI and percent cover will be evaluated with regression to determine their effect on the microclimatic metrics.

2.4.0 Biophilic Connection

Two unique surveys were used in the completion of this study. The first survey, Survey of Users, was designed specifically for exploration of the Biophilia research. It was intended to be completed by individuals while exposed to one of the living umbrella units that were placed across the campus. These individuals would be randomly selected and assumed to have no prior knowledge of the living umbrella. The second survey, Survey of Curious Inquirers, was designed to be completed by individuals who actively approached the living umbrella unit that was on display during Maryland Day event. This survey was created with similar questions in mind, but was completed by individuals who expressed interest in the living umbrella technology.

Similar questions across the two surveys allowed the responses to be combined and evaluated with descriptive statistics and qualitative measures. Likert-scale questions on both surveys asked participants to rate how plants made them feel, and their preference between living or traditional umbrellas. A 1-5 scale with 5 representing “Strongly Agree”, 1 representing “Strongly Disagree” was used across both surveys. Each survey ended with an open-ended question allowing the participant to describe how the living umbrella made them feel. Responses to this question were gathered together and entered into a word frequency table. Phrases were shortened to a single representative word. The number of times participants used individual words were totaled and entered

into the table. The frequency table quantifies the qualitative responses of the sample population.

Both surveys presented the participant with a question probing their preference of the living umbrella or traditional umbrella. The word “traditional” umbrella was used as to not limit by categorization of metal, canvas, etc. The Survey of Users blankly asked the question and allowed the participant to select either the living or traditional umbrella. The Survey of Curious Inquirers presented the participant with a statement, “I would prefer a green umbrella rather than a fabric patio umbrella” with the Likert-scale response framework. All participants that selected 4 or 5, “agree or strongly agree” were deemed to have preferred the living umbrella over the traditional. Those that selected 3 or below were deemed to have not preferred the living. The results of these two questions were combined to provide an overall preference for the living umbrella.

The Curious Inquirer Survey was evaluated against its demographic information to determine if age had effect on the response scores. The Likert-scale responses were totaled for each participant and averaged across the designated age groups. ANOVA analysis was used to determine if age had effect on the totaled scores (Table 4).

2.4.1 Survey of Users

A primary goal of the study was to evaluate the Biophilic effects of the living umbrella. The primary means of evaluation was through in-person and app/web-based cross-sectional Knowledge, Attitude, and Practice (KAP) surveys. The survey remains unbiased in supporting one umbrella over the other, allowing the participant to express themselves truthfully. The survey contains both short demographic information, Likert-

scale, and True/False based responses. Primary goals of the survey include identification of;

- Participant's knowledge of green area benefits
- Participant's attitudes towards green areas
- Participant's attitudes towards urban areas
- Knowledge of ecosystem services provided by living umbrella
- Effects of living umbrella on mental well-being
- Effects of living umbrella on environmental stewardship
- Preference for the living umbrella or traditional umbrella

The Biophilia philosophy helped shape the survey and its questions. The surveys were administered in the same location as the living umbrella units. It was deemed important that the participants be able to experience the living umbrellas as this is a new technology that the public has never seen. Both living umbrella site and which 2-hour block between 9AM and 5PM for active surveying were randomly selected. Participation was not required from users of the living umbrella. The survey was available online for participants to complete when active surveying was not being performed. Online surveying utilized the QR barcode reader application on smartphones. Scanning the QR barcode located on the living or metal umbrella allowed the participant to open the survey using the University's Qualtrics platform. The survey was completed by individuals, not groups, to remove group biases. The survey was developed based on similar surveys that had been used previously to evaluate public effects of green space (Grahn et al. 2010; Nielsen et al. 2007; Schipperjn et al. 2010). The survey can be viewed in Appendix 1.

2.4.2 Knowledge

The survey contains 8 questions to identify the participant's knowledge of the benefits of green space and plants. The questions are closed answer questions with "agree, disagree or don't know" choices. The knowledge questions are all presented as statements. Understanding the participant's knowledge will aid in support of continued education of green spaces if deemed necessary.

2.4.3 Attitude

The survey contains 9 questions related to the participant's attitude towards green spaces. These questions are on a Likert-scale and do not have a correct answer. This effectively allows the researcher to quantify the participant's thoughts on green spaces and the environment. The strongly disagree, strongly agree scale will be given a numerical value from 1 to 5 respectively. Strongly agree means the participants were strongly influenced, attached, and appreciative of green space. Specific questions of the attitude section will relate to the participant's feelings on Biophilia. This aids in identifying those that have a strong Biophilic connection with green spaces. Questions will also allow us to make associations between benefits of large green space and how small green space provides similar benefits.

2.4.4 Practice

The survey presents one question evaluating the participant's preference between a living umbrella or a traditional umbrella. This is a yes/no question, allowing binary evaluation of the practice criteria. This is followed with a qualitative question asking the

participants to freely express their opinions of the living umbrella. Here the participant gives value statements that help us further identify the individual's personal beliefs and opinions towards the living umbrella.

2.4.5 Survey of Curious Inquirers

The researcher made available a web-based survey for participants of the University of Maryland's Maryland Day event to supplement the KAP survey. The Maryland Day event is a day for the entire campus community to showcase projects and research. The researcher displayed a living umbrella unit next to a fabric patio umbrella. A poster with information on the living umbrella was provided for participants. Without requiring participation, individuals who approached the living umbrella were asked to fill out the 10-question survey. The survey was made of Likert Scale statements, close ended multiple choice questions, and open ended responses. Questions similar to the KAP survey were presented. Determining the participant's emotional response to natural structures and the living umbrella were probed. The survey of curious inquirers can be found in Appendix 1.

4.0.0 Results

The four-day research period gathered 17 microclimatic datasets. The average air temperature during the sampling periods was 23.1°C. The mean ambient UV and solar radiation was 40.53 W/m² and 884 W/m² respectively. The average macroclimate WBGT was 21.5°C. Historically the average high temperature of Beltsville, MD during the study

period is 28.3°C (National Center for Environmental Information, n.d.) thus our sample period was of mild conditions for the area during the early Fall. Average LAI of the living umbrella units was 3.7 and a percent cover of 62.4%. Metrics evaluated in this study were UV transmittance, Solar Transmittance, Wet Bulb Globe Temperature, Air Temperature, Humidity, and Canopy Temperature. Plant density measurements, LAI and Percent Cover, were also recorded to correlate with transmittance data. Table 3 presents the complete list of all statistical analysis performed. A table of metric averages by block can be found in Appendix 1.

Significant (Y/N)	Description	Degrees of Freedom	P-value
Y	UV Radiation	26	<0.05
Y	UV Transmittance	26	<0.05
Y	Solar Radiation	26	<0.05
Y	Solar Transmittance	26	<0.05
Y	WBGT	26	<0.05
N	Reduction in WBGT	26	0.17
N	Air Temperatures	25	0.80
N	Humidity	25	0.80
Y	Surface Temperature	19	<0.05
N	Average Totalized Scores	3	0.15

Table 3. List of ANOVA tests performed. Identifying Significance, Test Description, Denominator Degrees of Freedom, P-Value

4.1.0 UV Radiation

UV measurements were taken under exposed conditions and within the units' microclimate for comparison. UV transmittance is the ratio of UV radiation passing through the treatment to the total amount of UV radiation applied to the treatment. Average transmittance was calculated for each control & treatment pair for comparison.

The two treatments were compared first in their ability to reduce UV radiation from ambient conditions.

The living umbrella treatment averaged 9.98 W/m^2 while the control averaged 41.1 W/m^2 . ANOVA analysis revealed that this 31.12 W/m^2 reduction was significant ($p < 0.05$). A significant block effect was found ($p < 0.05$). The metal umbrella averaged 4.45 W/m^2 while the control averaged 40 W/m^2 . ANOVA testing revealed that this 35.55 W/m^2 was significant ($p < 0.05$). A block effect was found ($p < 0.05$) (Figure 7). The significant blocking effect validates the use of this statistical model to account for uncontrollable factors that may have placed effects on individual sites. The identification of what specifically may have caused the blocking effect cannot be concluded.

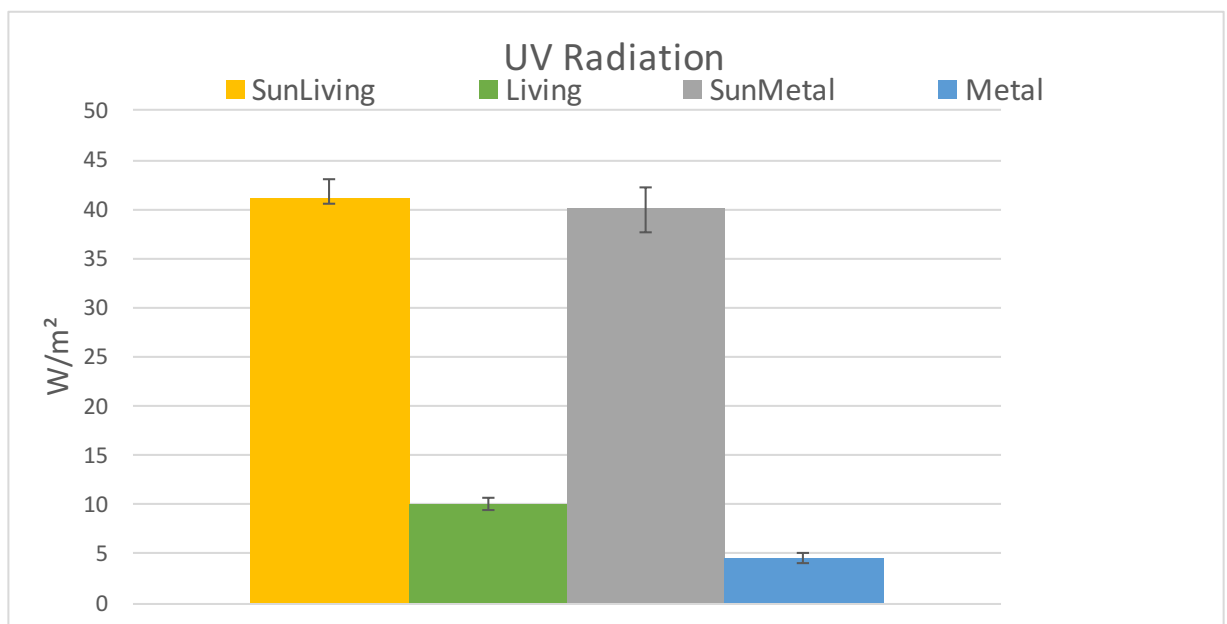


Figure 7. Living & Metal Umbrella's ability to reduce UV Radiation ($p < 0.05$). Averages generated across all sampling days. Ambient measurements compared to paired observational units.

The two treatment effects were compared against each other to find that the average UV transmittance of the living umbrella, 24.2%, was more than the average UV transmittance of the metal umbrella, 11% ($p < 0.05$) (Figure 8).

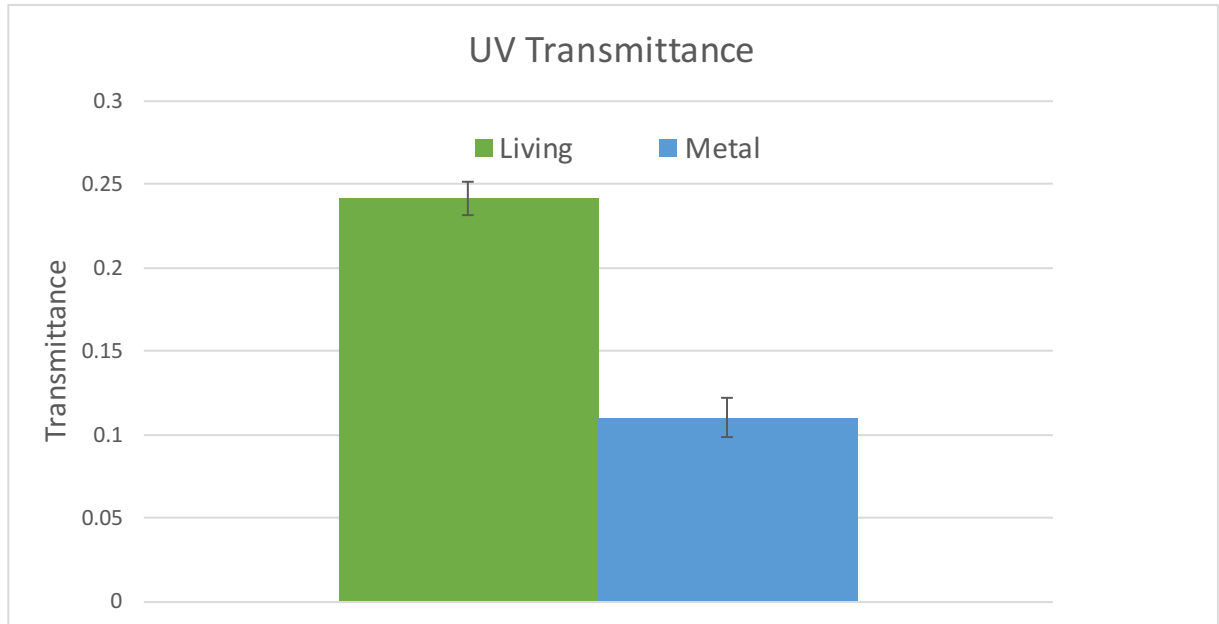


Figure 8. Mean UV Transmittance of living & metal umbrella ($p < 0.05$). Averages generated across all sampling days. Averages generated across all sampling days. Ambient measurements compared to paired observational units.

The light extinction coefficient was empirically found utilizing Equation 3 above. K-values ranged from 0.54 to 0.29. The mean K-value was 0.4. This produced a negative correlation ($R^2 = .73$) (Figure 9).

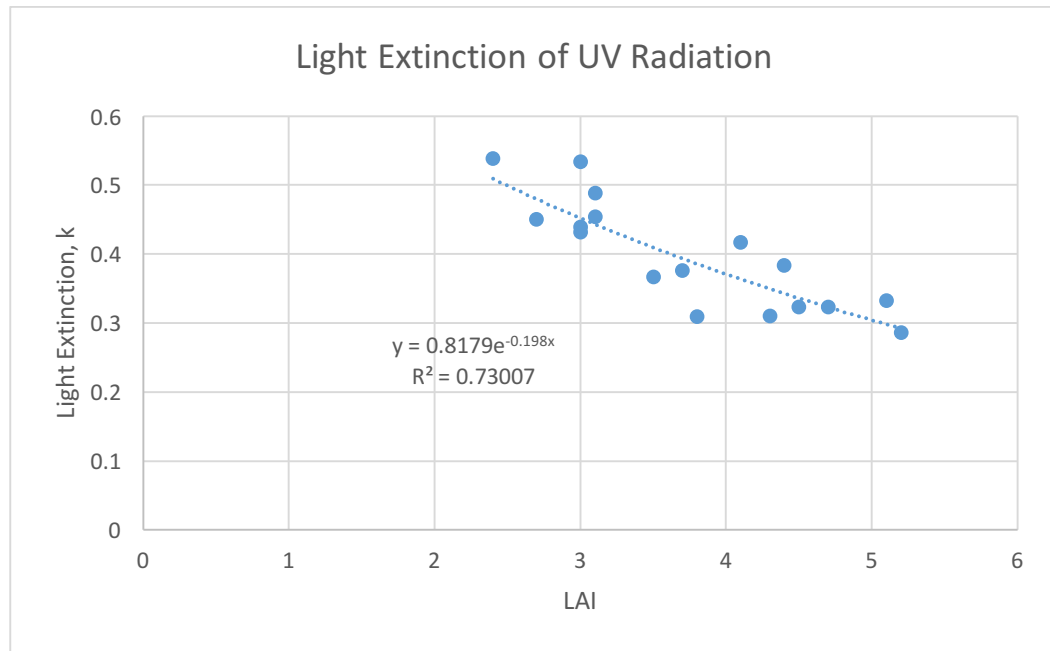


Figure 9. Light Extinction Coefficient (k) of UV Radiation ($n=17$). Values created for individual subsamples of observational units.

Living umbrellas with more plant cover had less UV transmittance ($R^2=0.4$)

(Figure 10).

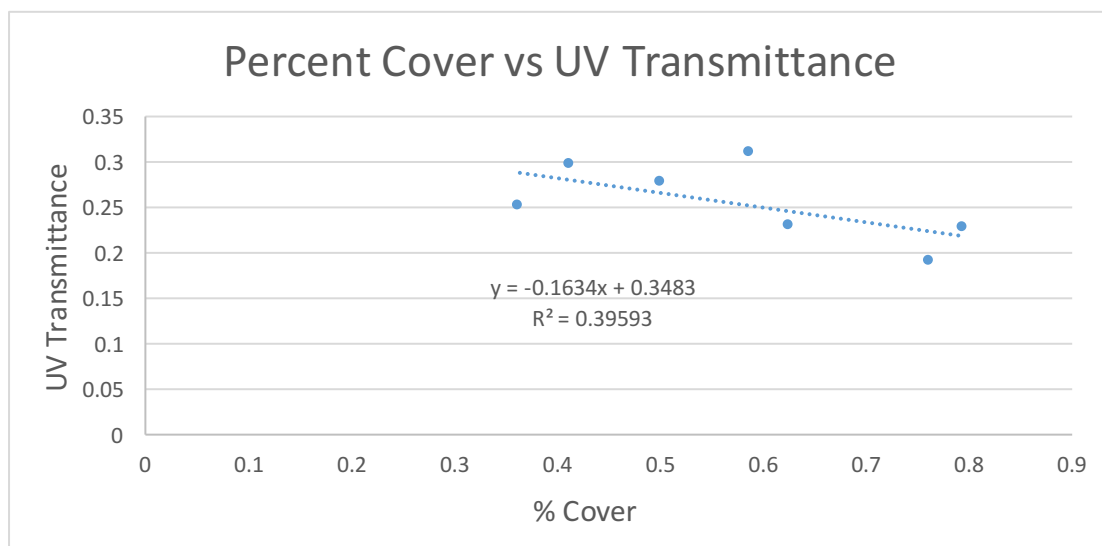


Figure 10. Correlation of % Cover & UV transmittance ($n=7$). Averages generated for individual observational units across all sampling days.

4.2.0 Solar Radiation

Solar radiation measurements were taken under exposed conditions and within the treatments microclimate to allow for comparison. Solar transmittance is a ratio of radiation allowed through the treatment to the total amount of radiation being applied to the treatment. Average transmittance was calculated for each control & treatment pair to allow for direct comparison. The two treatments were compared first in their ability to reduce solar radiation from exposed conditions. The living umbrella treatment averaged 161W/m^2 , while control conditions averaged 899.1W/m^2 . No significant block effect was found. The 738.1W/m^2 reduction due to the living treatment proved significant ($p<0.05$). The metal treatment averaged 76.5W/m^2 , while control conditions averaged 868.9W/m^2 . ANOVA testing across blocks revealed there was no significant blocking effect. The metal's 792.4W/m^2 treatment effect proved significant ($p<0.05$) (Figure 11). The difference between the living and the metal umbrellas microclimate was 84.5W/m^2 .

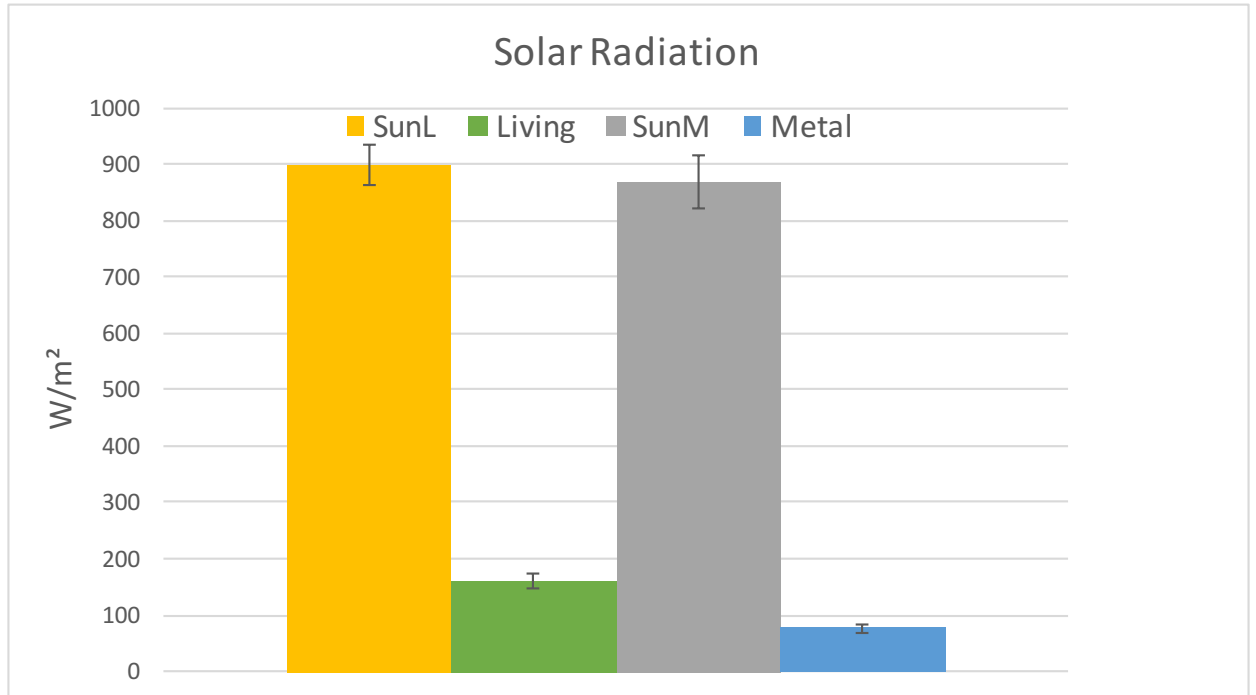


Figure 11. Living & Metal Umbrella's ability to reduce Solar Radiation ($p < 0.05$). Averages generated across all sampling days. Ambient measurements compared to paired observational units.

Solar transmittance means of the living treatment, 18%, compared to the Solar transmittance means of the metal treatment, 8.9%, result in a significant difference ($p < 0.05$) (Figure 12).

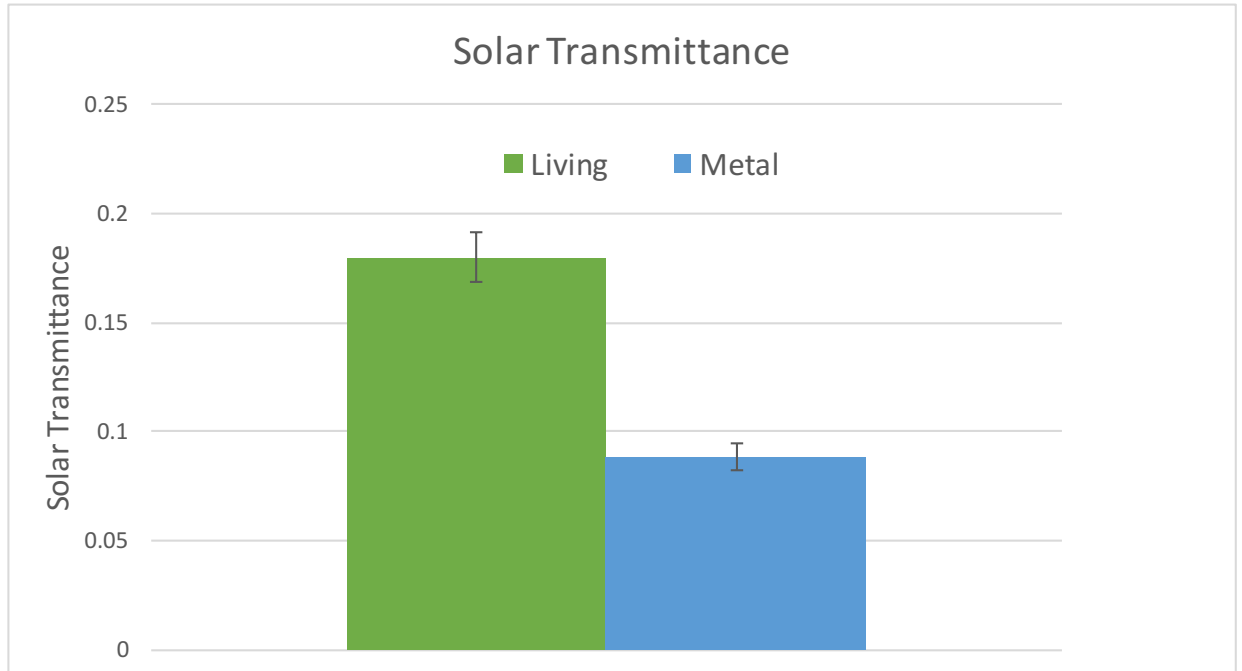


Figure 12. Living vs Metal Umbrella Solar Transmittance ($p < 0.05$). Averages generated across all sampling days.

The light extinction coefficient was empirically found utilizing Equation 3 above. K values ranged from 0.81 to 0.30. The mean K-value was found to be 0.5. As LAI of the living umbrella increased the light extinction coefficient decreased. This can be seen in the nominal negative correlation ($R^2 = .56$) (Figure 13).

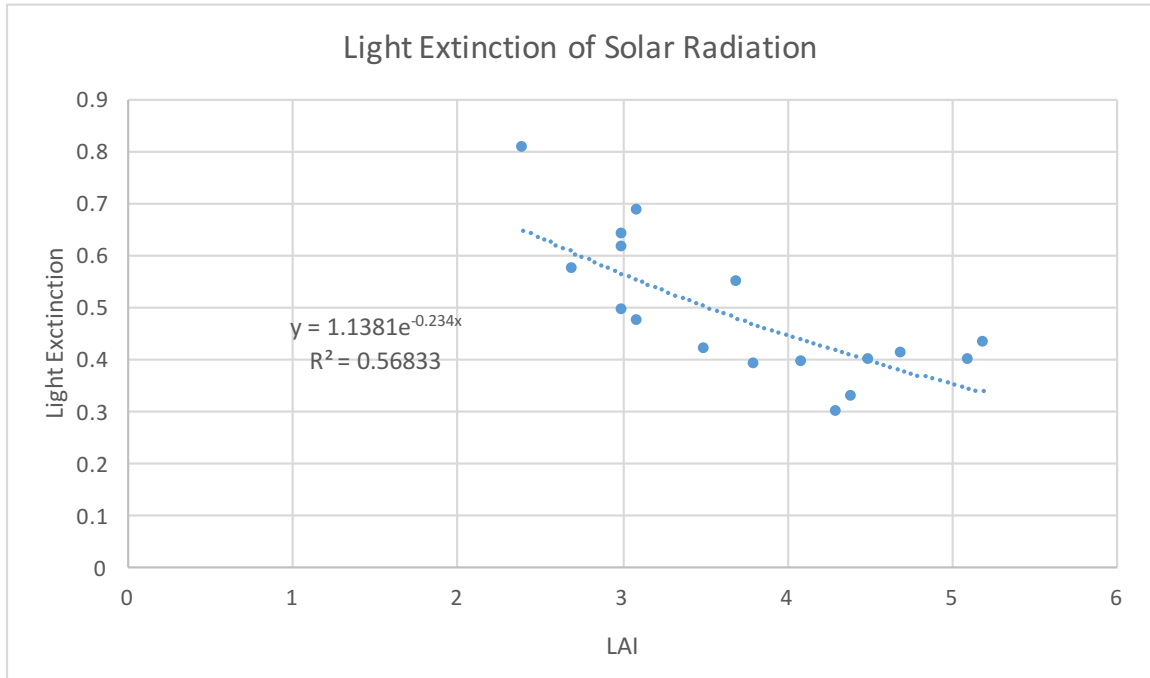


Figure 13. Solar Radiation Light Extinction coefficients as a function of LAI (n=17). Values generated using individual subsamples of observational units.

There was little information to suggest that as percent cover increased, Solar transmittance decreased ($R^2 = 0.07$) (Figure 14).

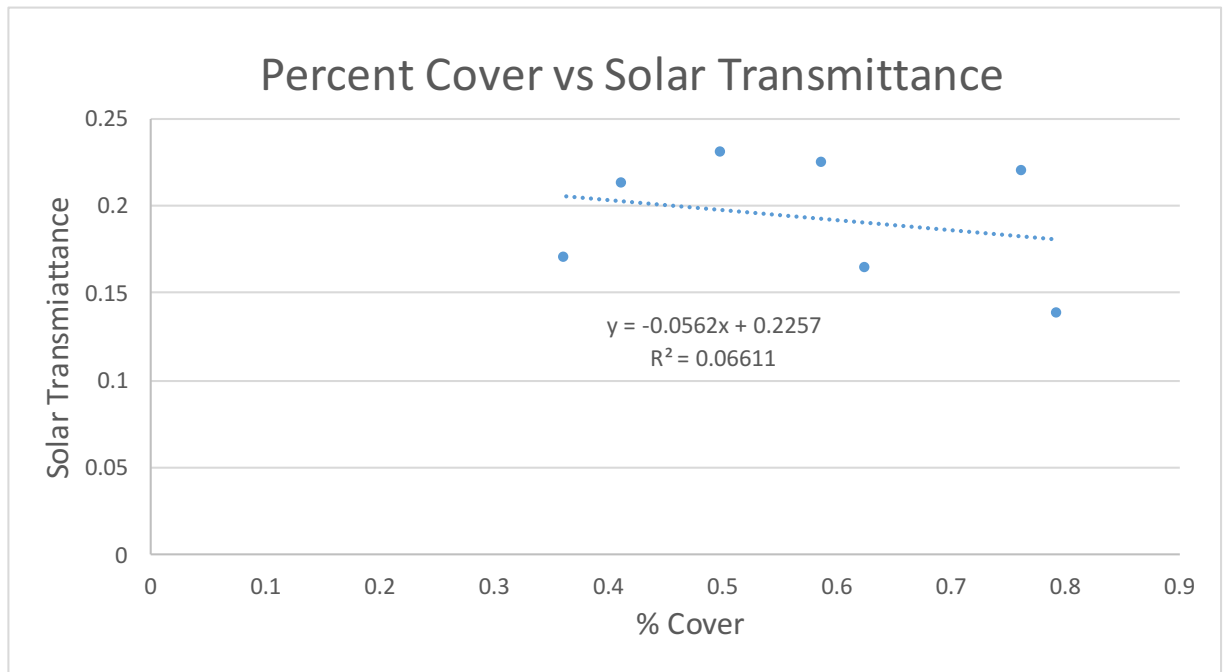


Figure 14. Correlation of Percent Cover & Solar Radiation (n=7). Averages generated for individual observational units across all sampling days.

4.3.0 Wet Bulb Globe Temperature

WBGT measurements were recorded in pairs to evaluate the change between the ambient conditions and treatment effects. The living treatment averaged 20 °C while its ambient averaged 21.5 °C. This 1.5 °C reduction was found to be significant ($p < 0.05$). There was no blocking effect found. The metal treatment averaged 19.8°C while the ambient averaged 21.6°C. This 1.8 °C reduction was found to be significant ($p < 0.05$). A significant blocking effect was found (Figure 15).

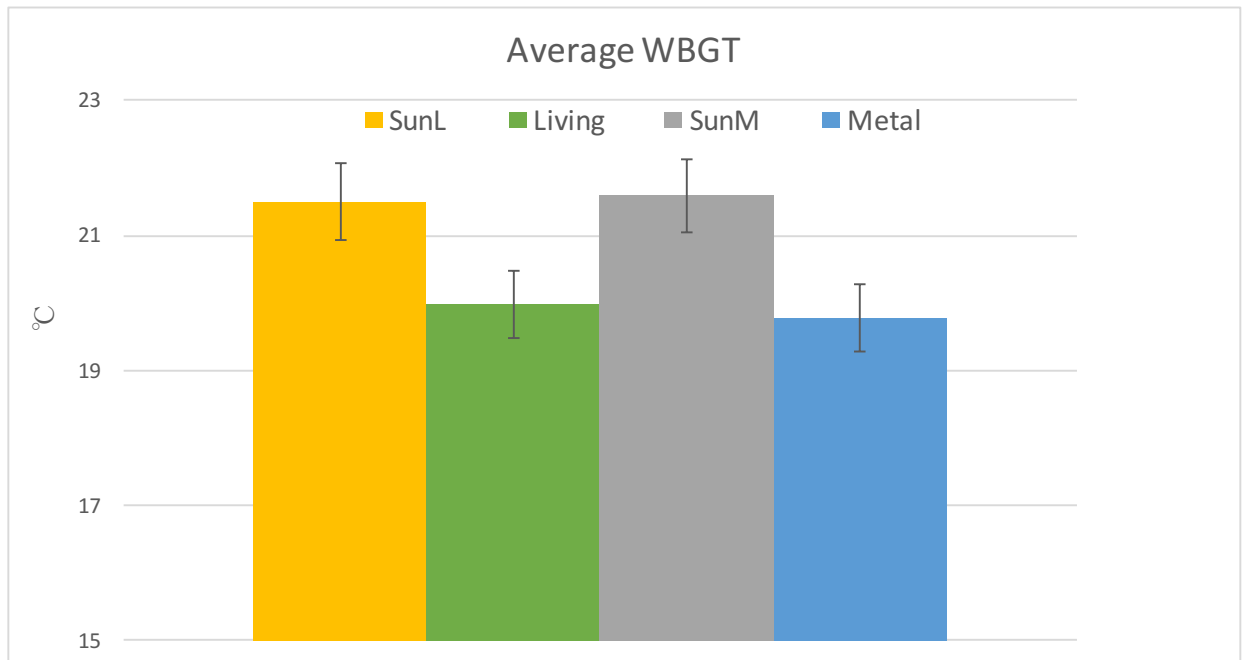


Figure 15. Living & Metal Umbrella's ability to reduce WBGT ($p < 0.05$) & ($p < 0.05$). Averages generated from all sampling days. Ambient temperatures compared only against paired observational unit.

The living treatment reduction, 1.5°C, was not significantly different from the metal treatment reduction, 1.8°C ($p > 0.05$). There was no significant blocking effect found. (Figure 16)

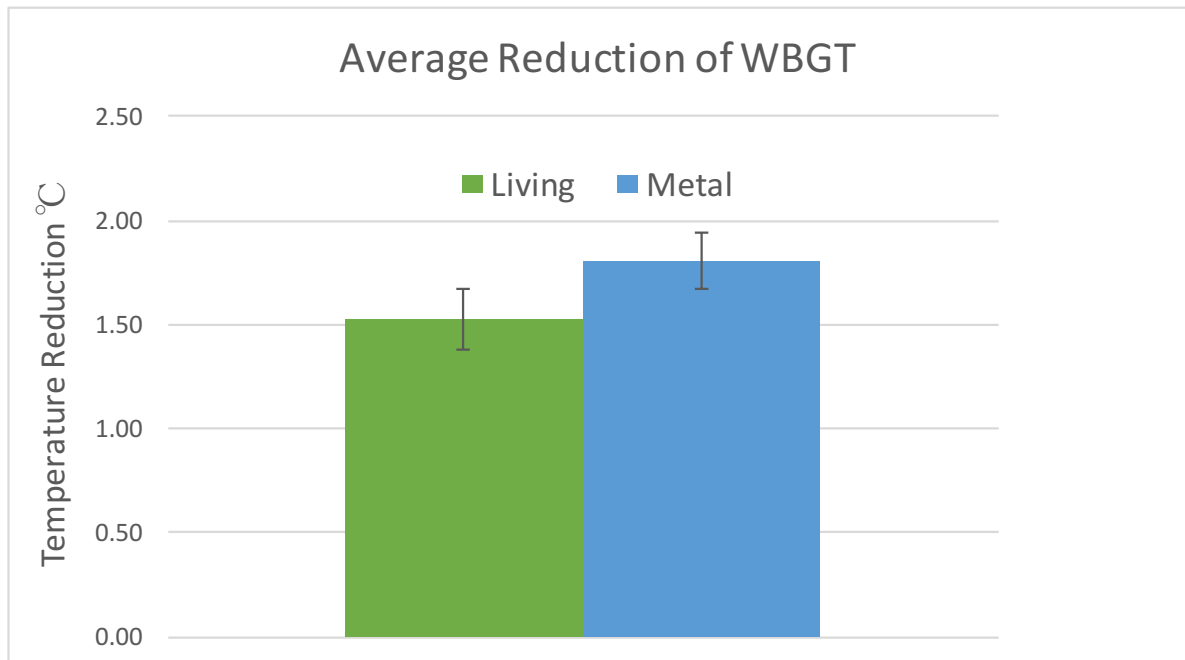


Figure 16. Living vs Metal Umbrella's reduction of WBGT ($p>0.05$). Temperature reduction from Ambient Conditions. Average created from all sampling days.

Air temperature reductions within the treatments shaded regions were compared. The living umbrella treatment averaged 23.0°C while the control measurements averaged 23.2°C. This .2 °C reduction produced no significant difference ($p>0.05$). No significant blocking effect was found. The metal umbrella treatment averaged 23.1°C while the control measurement averaged 23.5°C. This .4 °C reduction produced no significant difference ($p>0.05$). No significant blocking effect was found. (Figure 17)

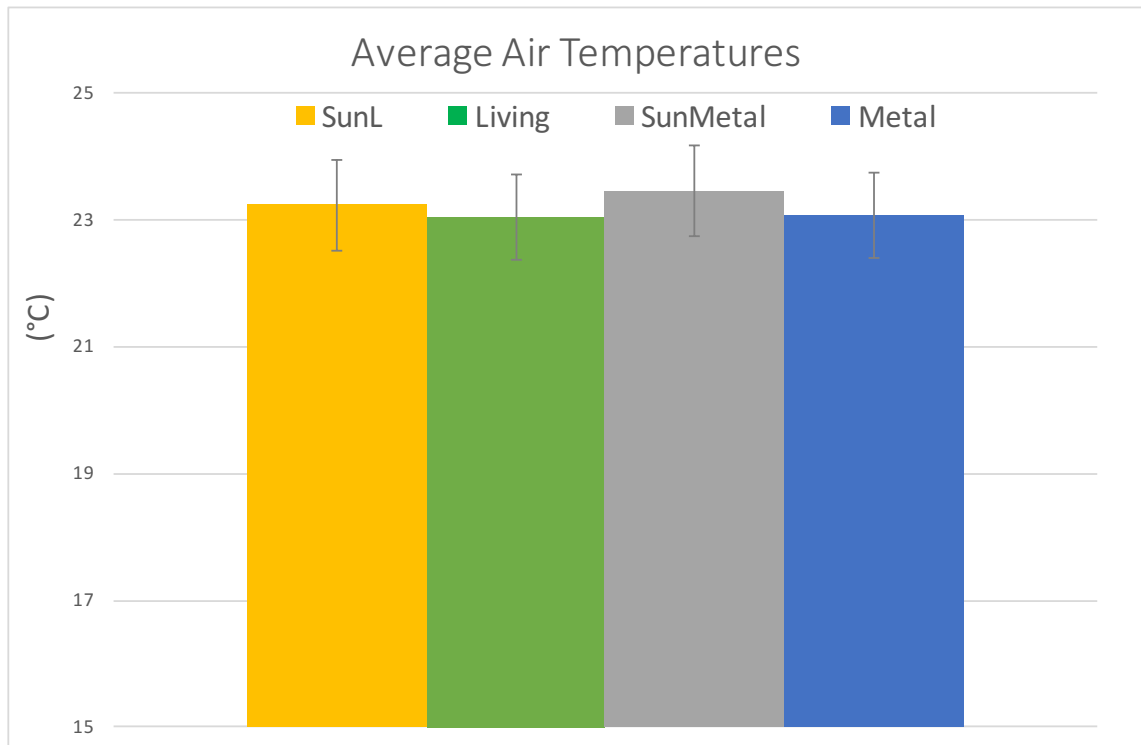


Figure 17. Average Air Temperatures. Averages generated from all sampling days

No significant air temperature reduction was found; thus, the two treatment effects were not compared against each other.

4.5.0 Humidity

The living umbrella treatments averaged 57.9% while the ambient conditions averaged 57.3%. This .6% increase resulted in no significant difference ($p>0.05$). A significant blocking effect was found ($p<0.05$). The metal umbrella averaged 57.2% while the ambient conditions averaged 56.1%. This 1.1% increase proved no significant difference ($p>0.05$). A significant blocking effect was found ($p<0.05$) (Figure 18) .

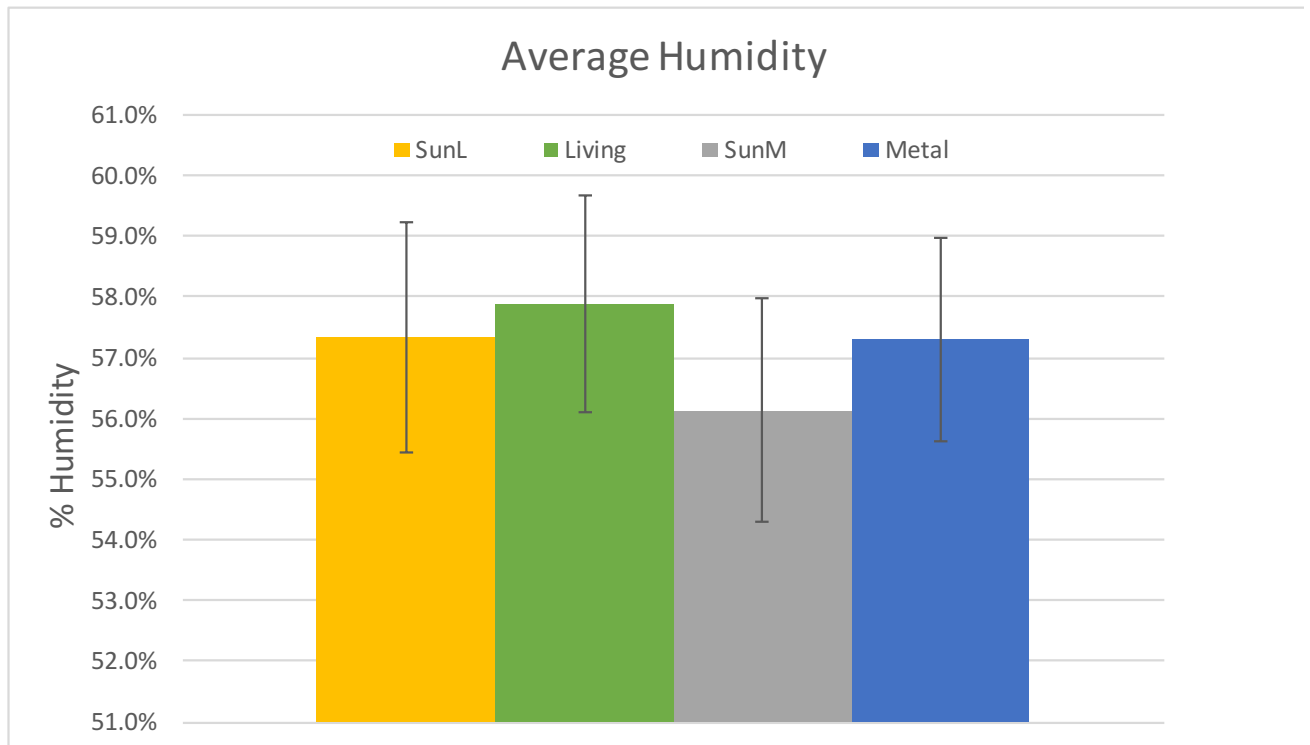


Figure 18. Average Relative Humidity. Averages generated from all sampling days.

No significant effect on humidity was found; thus, the two treatment effects were not compared against each other.

4.6.0 Canopy Temperature

The average canopy temperature for the living umbrella was 21°C while the average for the metal umbrella was 37°C. No significant blocking effect on the canopy temperature was found. The 16 °C cooler temperature of the living umbrella was found to be a significant difference ($p < 0.05$) (Figure 19).

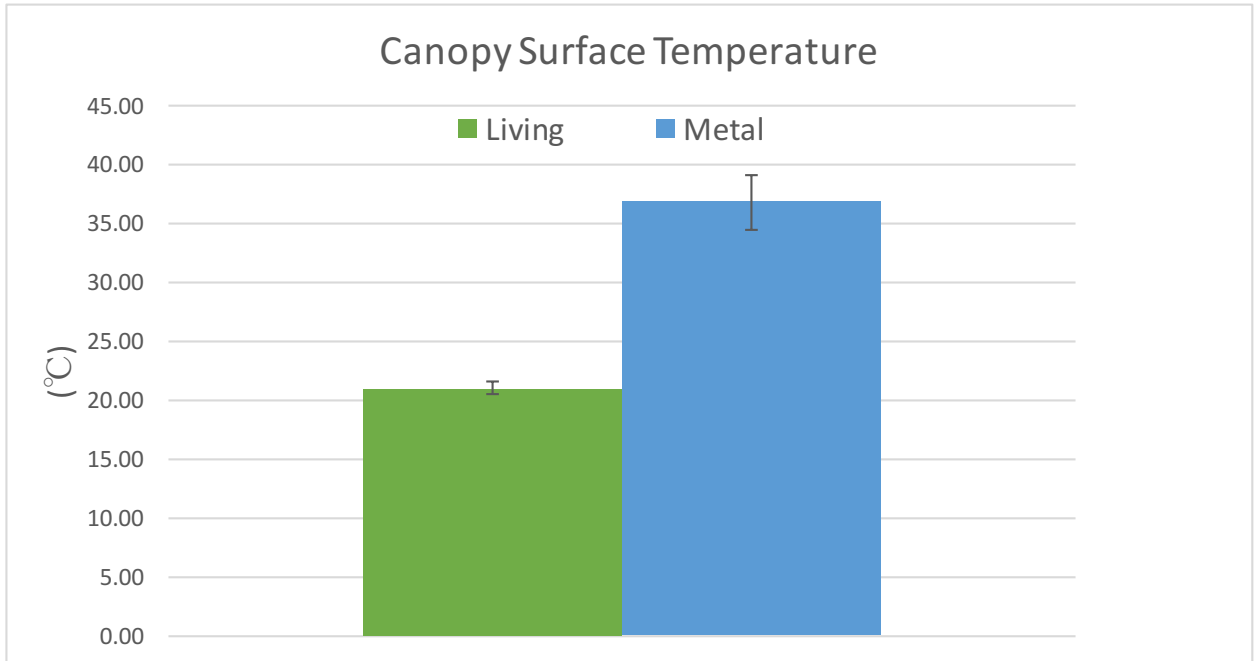


Figure 19. Mean canopy temperature of the living and metal umbrellas ($p < 0.05$). Averages generated from all sampling days.

The amount of thermal radiation released between each treatment type was compared. The Net Radiation Flux formula (Equation 4), was used to determined how much energy was being emitted back into the surrounding environment from the umbrella treatments.

The emissivity of living umbrella vegetation was found from Hatfield (1979) to be .96. Values used for the living umbrella were as follows;

$$\varepsilon = .96; \sigma = 5.67e - 8; T_h = 294.15; T_c = 296.49$$

The mean ambient temperature of the area was hotter than that of the living umbrella canopy. Thermal energy in the amount of 13.1 W/m^2 was absorbed by the living umbrella. Emissivity of the metal umbrella was found to be .875 (“Emissivity Coefficients” n.d.). The metal umbrella’s net radiation flux was calculated using the following values

$$\varepsilon = .875; \sigma = 5.67e - 8; T_h = 310.15; T_c = 296.49$$

The metal umbrella was emitting 75.7W/m² of thermal energy back into the surrounding area. On average, the metal umbrella emitted 88.9W/m² more thermal energy back into the surround environment than the living umbrella.

4.7.0 Biophilia

During the course of the study 14 Survey of Users were completed, which allowed for basic descriptive statistics. The Survey of Curious Inquirers survey captured 80 responses. The data was collected from ages under 21 to 56+, various backgrounds and ethnicities, men and women. The demographic and average totalized response rate for the Curious Inquirer Survey can be found in Table 4. ANOVA analysis of the Average Totalized Score resulted in no significant effect of age demographics on the totalized scores (p=0.15).

# of Participants	Age Group	Average Totalized Score	Average Single Response Score
19	21 or younger	21.4	4.3
24	22-35	20.4	4.1
17	36-55	22.1	4.4
9	56+	23.2	4.6

Table 4. Response Averages viewed against Age Demographics. Totalized Score found by summing all response values for individual and averaged within age group. Average single response score divides totalized score by number of statements, 5.

A representative sample of the campus community provided information for this study. The two surveys were combined to conduct a qualitative analysis. In total 94 questionnaire responses were recorded and evaluated.

All questionnaires provided the participants an opportunity to respond to an open-ended question to describe their feelings towards the living umbrella. Both positive and negative concerns were acceptable. As seen in the word frequency table (Table 5), the frequency of the word is influenced by the number of times it was recorded on the questionnaires.

Word Frequency Table			
26	happy	1	refreshed
7	calm	1	nice
6	peaceful	1	nature
5	relaxed	1	joy
5	happiness	1	intrigued
3	peace	1	interesting
3	content	1	interested
2	wow	1	impressed
2	relaxing	1	freshness
2	relaxation	1	free
2	pretty	1	excited
2	green	1	earth
2	cool	1	curious
1	wonderful	1	curiosity
1	wonder	1	complete
1	tranquility	1	cleanliness
1	soothing	1	beautiful
1	smile	1	awesome
1	serene	1	relax

Table 5. Word Frequency Table. Words generated from both Curious Inquirer Survey and User Survey. One key word was selected from each response.

The User Survey and Curious Inquirer Survey both contained similar questions on the participant's feelings towards green space, and their feelings towards the living umbrella. These questions were associated with a value between 1 and 5, 1 representing a strong disagreement and 5 representing a strong agreement. When asked to choose between the living umbrella or a traditional umbrella 81% of respondents between both

surveys said they would prefer the living umbrella. Table 6 gives the statements and average score from the surveys.

Survey	Statement	Average	# of Agree Responses
S	I would like to see more shade structures in public places.	4.5	12/13
S	I would like to see more green spaces in public places.	4.8	13/13
S	I would consider the living umbrella green space.	4.7	12/12
S	I feel the living umbrella could provide some of the same benefits as green space	4.6	13/13
S	I feel stress release when I am in green spaces	4.4	12/13
S	I feel the living umbrella could help me relieve stress	4.2	11/13
S	I feel a connection with nature	4.7	12/13
S	I feel responsible for the health of our Environment	4.6	12/13
S	I feel increased green spaces would increase environmental stewardship	4.4	12/13
CI	I would prefer a green umbrella rather than a fabric patio umbrella	4.3	62/77
CI	Plants and Green Space make me happy	4.9	79/80
CI	Having shade when sitting outdoors is important for me and my family	4.7	75/80
CI	I would be willing to pay more for a green umbrella than a fabric umbrella	4.0	57/77
CI	I would be willing to pay more for a green umbrella than the plants on my patio	3.9	54/80

Table 6. Statement and Averaged Score from Surveys. Results gathered from both Curious Inquirer Survey and Survey of Users. (S) indicates Survey of User question. (CI) indicates Curious Inquirer. # of Agree Responses totals responses that were a 4 or 5, Somewhat agree or Strongly agree.

All eight statement received values that scored above the agree category on the 1-5 scale. The average response to these statements is 4.5, falling between agree and strongly agree.

5.0.0 Discussion

Both living and metal umbrellas were able to significantly reduce UV Radiation, Solar Radiation, and WBGT. The living umbrella shaded its users by blocking 82% of the solar radiation, which was slightly less than the metal umbrella, 91% (Figure 12), but an appreciable amount that can keep users cool. The living umbrella was also able to block 76% of UV radiation, which was less than the metal umbrella, 89% (Figure 8), but an amount that reduces the risks of sunburn. Both treatments significantly reduced the WBGT within their microclimate. The living and metal treatments produced 1.5°C and 1.8°C reductions respectively. This 0.3°C difference of reductions was found not significant, which suggests the canopies have similar capabilities in producing comfortable microclimates. The living umbrellas plant canopy was 16°C (29°F) cooler than the metal, which greatly reduced the user's exposure to thermal radiation. and significantly hotter than that of the living umbrella, 21°C (Figure 19).

Survey respondents strongly expressed the living umbrella provided a comfortable and relaxing environment. An average of 81% of participants replied that they would prefer a living umbrella over a metal umbrella. When asked to agree-or-disagree with statements probing for personal stress release in nature and happiness in green space the average response value was 4.5, falling between the agree and strongly agree classifications. Examination of the word frequency table showed that the most used words were of positive such as, "happy, calm, relaxed, and peaceful". Statements that probed an individual's stewardship and connection with nature produced average response value of 4.6. The high agreement rate with these responses and preference of the

living umbrella over fabric/metal umbrellas, coupled with the positive emotions of the word frequency table supports that the living umbrella creates a positive, Biophilic connection for users.

5.1.0 Transmittance

The living umbrella reduced user's exposure to UV and Solar radiation by 31.1W/m^2 and 738.1W/m^2 , respectively (Figures 7 & 11). UV radiation is known to damage the DNA of skin cells. UV exposure can lead to photoaging and skin cancer (Almeida et al. 015; Armson et al. 2013). The innovation of new strategies for individuals to reduce their UV exposure is increasing with speculation that UV radiation is increasing as the depletion of the protective ozone layer intensifies (Dinkova-Kostova 2008; Kerr et al. 1993).

To combat the deleterious effects UV exposure can have on human skin, the American Academy of Dermatologists (AAD), has publicized general preventative measures. It is recommended that all individuals regardless of race, age, or sex wear sunscreen when outdoors. Sunscreen should be reapplied every 2 hours and a Solar Protection Factor (SPF) of 30 is suggested as the minimum. The SPF represents how well the sunscreen will protect your skin. An SPF 30 is capable of blocking 97% of the sun's UVB radiation while SPF 15 blocks 93% (Figure 20) ("Sunscreen FAQ's", n.d.). Every individual reacts differently to UV and should practice the protection methods they are most comfortable with. The living umbrella will not eliminate exposure to UV radiation. Even with significant reduction of UV light, radiant and reflected radiation from surrounding surfaces can be damaging to an individual's skin. Figure 20 displays the

percentage of UVB absorbed by sunscreen as function of SPF. The 24.2% transmittance through the living umbrella conversely means that 75.8% of the UV radiation was abated. Thus, the living umbrella produced an SPF 5 on average. The metal umbrella was able to achieve SPF closer to 10.

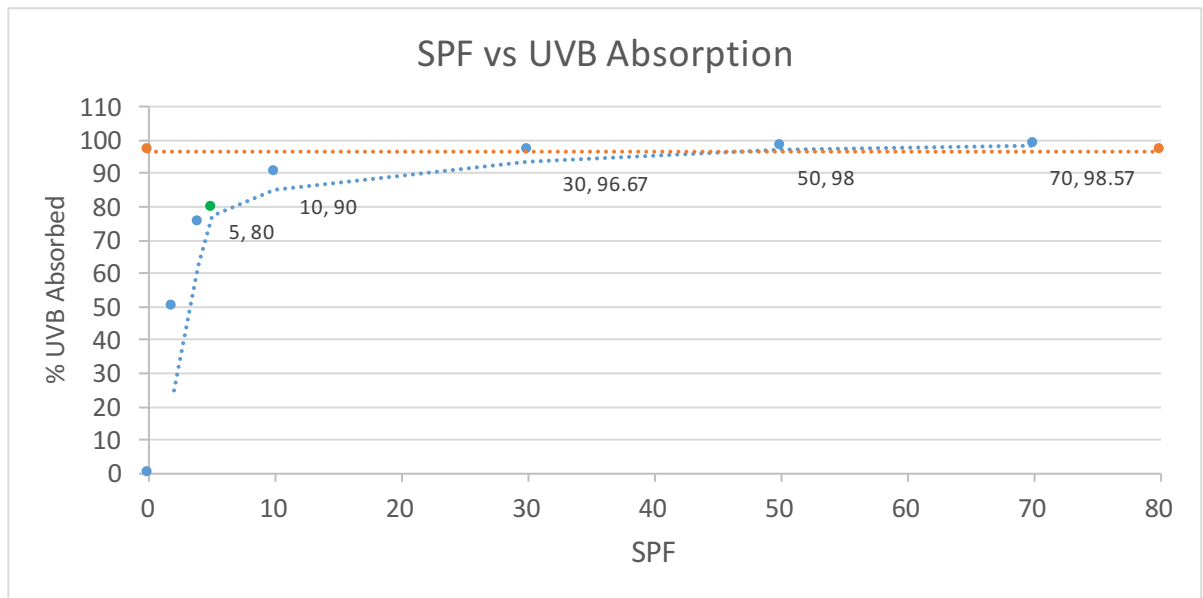


Figure 20. UVB absorption as function of SPF. Green icon indicates living umbrella SPF. Red Line is the AAD recommended SPF application

(data gathered from <http://modernaesthetics.com/>)

Although both treatments produced SPF lower than the AAD recommended SPF 30, it can be considered as an aid to reduce UV exposure. Research has identified that commonly inadequate application of sunscreen results in sunburn (Diffey et al. 2004, Russak et al. 2010). For this reason, the AAD suggests the use of shade as an effective way to avoid UV exposure. In the case of shade structures, the protection is not directly applied to the skin; therefore, it does not wash off, thus not requiring reapplication. As

long as the individual remains within the shaded region of the living umbrella, they can assume to have continuous application of at least SPF 5.

A comparative study by Hoyano (1988) evaluated the solar transmittance beneath a pergola cover with wisteria “sunscreens”. This canopy is 60m² in size and located 2.5m above the ground. No LAI was identified in the study; however, images show that the canopy was robust and prolific, suggesting old growth. The study produced that the canopy’s solar transmittance values fell between 5% and 15%. These values are slightly improved from the 18% solar transmittance found within the living umbrella study. Images of the canopy suggest that its density was much greater than that of the living umbrella. The Hoyano (1998) study also evaluated the ability of vertical screens made of Japanese Ivy to reduce sunlight on an adjacent wall. It was concluded that reduced solar transmittance had high inverse correlation with plant density. These complementary findings suggest that increased LAI and percent cover of the living umbrella will continue to improve its shading quality. The light extinction coefficient can be utilized to forecast the LAI at which transmittance will become similar to that of the metal umbrella. The light extinction coefficient, k , is the ratio of the area of the shadow cast by a leaf to the leaf’s surface area. On average the k -value of solar radiation for the living umbrella was 0.5. The living umbrella would need an LAI of 5 or more to achieve, on average, 76.5W/m² of solar radiation within its microclimate.

The high variation in the canopies percent cover and LAI metrics has strong influence on producing the low average of SPF 5 compared to the metal’s SPF 10 and weak transmittance values compared to prior studies. Through perfecting the growing methods of the plant canopies and requiring a minimum LAI qualification, the living

umbrella canopies can be expected to perform at a higher range of SPF and transmittance performance.

Future studies should compare the LU to fabric canopies, often made of nylon and other artificial materials, because they are more frequently found in commercial applications. Fabric canopies would be expected to have higher UV and solar transmittance than the metal because they are not opaque. The question for a future study would be to determine how the living umbrella compares to a commercial fabric umbrella.

The living umbrella can reduce the amount of UV and total solar radiation that an individual receives when sitting within the microclimate. This supports claims that the living umbrella will make an individual more comfortable by reducing the amount of shortwave and UV radiation they receive, and lessening their chance for skin damage.

5.2.0 Wet Bulb Globe Temperature

During the experiment, the air temperatures were mild, often near 22°C, which is considered room temperature. The skies were mostly clear which allowed for the maximum amount of sunlight and UV to reach the site. Under these conditions, the living umbrella decreased the WBGT from the ambient site conditions by 1.5°C. This validates that an individual within the microclimate of a living umbrella is exposed to less heat stress than if they were exposed to full sun. The reduction in heat stress helps an individual feel more comfortable, enjoy the outdoors for a longer period of time, and ultimately reduces the risk of heat exhaustion (Armson et al. 2012, 2013).

In a study conducted by Sofia Thorrrson (2007), three methods of obtaining a reliable value for Mean Radiant Temperature (MRT) were contrasted. Their results produced an equation (4) in which air temperature and globe temperature where of most significance in determining a representative MRT.

$$T_{mrt} = \sqrt[4]{(T_g + 273.15)^4 + \frac{1.335 \times 10^8 \times V_a^{0.71}}{\epsilon D^{0.4}} \times (T_g - T_a)} - 273.15 \quad \text{Equation 4}$$

T_g =Globe Temperature(°C); T_a =Air Temperature (°C); V_a =Mean Air

Velocity(m/s); ϵ =Globe Emissivity; D = Globe Diameter (mm)

The study concluded that a 35mm low albedo globe thermometer was a successful and accessible way to determine MRT in the outdoor environment; thus, WBGT was used to evaluate MRT within the living umbrella research study and Armson (2012, 2013) studies. The Wet Blub Globe Thermometer methods, revealed 5-7 °C & 3.8-4.2 °C reduction within the microclimate of urban shade trees as compared to ambient conditions in the Armson (2012, 2013) studies respectively. The 1.5 °C reduction within the living umbrella research was a less significant than the findings of the Armson (2012, 2013) research. This weak reduction found by the living umbrella compared to the Armson studies may be due to either differences in LAI or ambient temperatures during the research period. The trees in both Armson's studies were a minimum of 4 years old and produced mean LAI between 1.5 and 3. These averages were lower than that of the living umbrella's, 3.7; thus, it can be suggested that living umbrella should have been able to perform in similar capacity to the findings of Armson's research. The ambient WBGT of the Armson research averaged 28°C while WBGT of this study averaged

22°C. This 6°C temperature difference would have allowed the trees in the Armson study the ability to provide more cooling. The mild ambient conditions of the living umbrella research gave little chance for large reductions to be observed. It would be valuable to observe the living umbrellas during periods of more extreme temperatures to understand its effect on WBGT when it would be of more importance on user's health. These values of WBGT can be expanded into a MRT value that is used as a variable in multiple thermal stress measurements.

MRT can be used as an estimation in a multitude of metrics including the Physiological Equivalent Temperature (PET) of a human in a specified area (Matzarakis et al. 1999). PET involves measurements in three dimensions and a series of equations involving multiple parameters which becomes arduous and unfeasible for many applications with limited sensing equipment. The MRT metric has been researched and validated as a supplemental analysis tool for thermal heat stress (Matzarakis et al. 1999; Thorsson et al. 2007). An investigation by Matzarakis et al. (1999) provided a range of values for the most comfortable PETs. These values fall between 19°C and 24°C. MRT values outside of this PET range were never measured during the course of this study. It was observed however, that the living and metal umbrella were not significantly different (Figure 16) in their ability to reduce WBGT, 1.52°C and 1.87°C respectively. As the WBGT reductions of the living umbrella and metal umbrella were not significantly different we can say they function in a similar capacity. The performance of the living umbrella pertaining to WBGT reduction was consistent with the performance of the traditional shade structure currently utilized across the University of Maryland campus.

This provides evidence for implementation of the living umbrella across the campus as it would provide at least equal benefits as the existing structures.

5.3.0 Air Temperature and Humidity

There was no effect of either living umbrellas or metal umbrellas on air temperature nor humidity (Figure 17 & 18). As mentioned above, the experiment took place while the air temperatures were mild, near room temperatures, and humidity levels were moderate (~50%), which is considered near optimum human comfort. In addition, it may be that advection and convection of air mass from the macroclimate has a dominant effect on the microclimate. Unfortunately, wind speeds were not recorded.

Since air temperature was not affected by either umbrella type, it is likely that reductions in the WBGTs were primarily caused by the reduction in solar radiation. The wet bulb globe thermometer (Equation 1) accounts for the air temperature, humidity, convection across the bulb thermometer, and solar radiation heating the globe thermometer. Observing that air temperature and humidity did not change during the study period, convection across the globe and solar radiation are the residual variables potentially effecting the WBGT value. As wind speeds were not recorded, we are unable to make conclusions on effects of advection and convection. The only quantifiable variable is the temperature gain due to solar radiation. Future studies would be advised to record wind speeds as Thorsson (2007) suggests that adjusting the wind speed coefficient of the MRT equation can dramatically improve results estimated by WBGT.

5.4.0 Canopy Temperature

The living umbrella's canopy temperature, 21°C, was found to be significantly cooler than that of the metal umbrella, 37°C (Figure 19). This was expected because of the high specific heat capacity of metal compared to vegetation. High specific heat capacity combined with the black powder-coating allowed the material to absorb and hold heat. On a large, urban scale, this property of manmade materials is the cause of the phenomenon known as Urban Heat Island Effect (UHI) (Mavrogianni et al. 2011; Oke 1982; Zhang et al. 2010).

The higher temperatures of the metal umbrellas were expected to influence the ambient temperature of the microclimate. Throughout the study, only mild ambient air temperatures were observed (Figure 17). It was not observed that either treatments surface temperature had any influence over the ambient air temperatures. However; the surface temperature was used to calculate the Net Thermal Flux (Equation 4) of each umbrella treatment and found that a measurable change in thermal radiation could have been observed.

The living umbrella was found to be absorbing 13.1W/m² of thermal radiation from the surrounding environment. The metal umbrella was found to be releasing 75.7W/m² of thermal energy back into the environment. The evaporative cooling effects of vegetation and their influence on the surrounding environment have been well documented (Akbari et al. 2001; Ali-Toudert 2014; Chang et al. 2014; Hwang et al. 2011; Oberndorfer et al. 2007). A study by Rahman (2014) showed that urban shade trees were able to produce cooling of up to 150 and 450 W/m² with LAI values of 1.5 to 3. The

living umbrella provided on average 13.1 W/m^2 of cooling per umbrella with an average LAI of 3.7. It is important to note that the canopies structure is dissimilar to that of a tree. In observation of the living umbrella, there are prolific areas with high LAI or leaf density; however, in neighboring areas, there are large spaces that lack any leaf coverage at all. This is represented in figures 9,10, 13 &14. High LAI averages, 3.7, with low percent cover averages, 62.4%, is representative of dense clusters of leaves neighboring large holes of open space. In practice the living umbrella was lacking ability to provide a complete canopy across the entire 40ft^2 umbrella. The deficit between these two cooling effects could be due to the size of the trees in the study and their age which on average was 10-years. Given sufficient time to grow and establish a prolific canopy the living umbrella may be able to perform at higher rates of cooling.

The metal umbrellas provided the area with no thermal benefits. Results show that on average the metal umbrella attributed 75.5W/m^2 of thermal energy back into the environment. The difference between the living and metal umbrella's solar transmittance, 84.5W/m^2 can be viewed as an aid in reducing thermal stress and UV exposure on a user within the microclimate of the metal umbrella. However, this 84.5W/m^2 of shortwave radiation is then directly converted into longwave thermal radiation, shown as part of the 88.8W/m^2 difference in longwave flux between the living and the metal umbrella. Unfortunately, the instruments in this study were unable to record this heat transfer empirically. Ability to model and understand this radiation of heat from manmade materials aids in design and development of public spaces. Providing empirical data that validates the living umbrellas ability to cool surrounding environments, similar to that of urban shade trees, could be a valuable future research effort.

These results support literature that beckons for the increased use of green space over manmade materials to combat the health hazards of UHI. Armson (2012) suggests the increased use of grassy areas and shade trees to reduce both surface temperatures and MRT. Chang (2014) suggests that business parks be designed with at most 50% paved areas and more than 30% green spaces. Wang (2015) validates that the use of trees in urban areas effectively reduces the predicted mean vote, a parallel to PET. The size, shape, and canopy cover of green spaces were determined by Feyisa (2014) to be the largest influencers of large scale cooling effects on a city. The living umbrellas add an additional 40ft² of green space to an area in an otherwise unachievable way. This technology could be used to accomplish some of the literatuer's suggestions which advocate for increased green space in areas. The living umbrella is unique in its ability to provide green space where the planting of trees is unavailable.

5.5.0 Biophilia

Through the surveys of the campus community, it was observed that the majority of individuals sampled responded with positive thoughts and emotions towards the living umbrella. The research aimed to test if individuals felt comfortable and relaxed when exposed to the living umbrella. Participants reacted to statements that evaluated their Knowledge, Attitude, and Practice of green space and the living umbrella. Results were interpreted to make claims regarding the communities Biophilic connection with the living umbrella. The results shown on tables 4, 5 & 6 suggest a high preference towards the living umbrella and an ability to perform restorative healing. Responses to statements regarding stress release in green space and connection with the living umbrella averaged

4.5, scoring within the “agree” to “strongly agree” categorization (Table 6). The Curious Inquirer survey revealed that 79/80 individuals agreed that plants and green space made them happy. The Survey of Users found 13/13 people agreed that the living umbrella could provide similar benefits to green space and 11/13 felt the living umbrella could help them relieve stress. These results support an ability for the living umbrella to create a connection with users that fosters restorative healing. When given the choice to select a living umbrella or traditional umbrella, 81% of participants chose the living umbrella. In statements that probed for environmental stewardship and a connection with nature, the average response was 4.6. These results provide support that the living umbrella creates comfortable, relaxing environments and has a Biophilic connection with its users.

The popular opinion of the living umbrella was that of beauty and attraction. The word frequency table (Table 6), illustrates that all words provided to the open-ended question revealed positive emotions. Words commonly related with relaxation or comfort. The most prominent word, “happy” or “happiness” was used by 31 different participants. Merriam-Webster’s Dictionary definition of happy states, “enjoying or characterized by well-being and contentment” (“Happy”, n.d.). This feeling of well-being and contentment suggests that the individuals are in a positive state-of-mind. The ability to encourage these emotions out of individuals is a value added to the living umbrella. Prior research has been centered around the effects that green space has on an individual’s mental and physical health. Neilsen (2007) conclude that proximity to green space lowers stress. Schipperjin (2010) found that 91.5% of participants surveyed, visit green space weekly, which corresponds closely with the 81% preference rate of the living umbrella over the traditional. Grahn (2003) suggest that more green spaces close to

apartment complexes will create more restorative environments. A later study by Grahn (2010) found that dimensions including Refuge and Nature are connected with the most restorative environments for stressed individuals. The results of this research could suggest that the living umbrella can provide a health benefit to users through the relaxing, restorative ability of green space. The majority of respondents expressed feelings of happiness and comfort, providing support that green space provides these benefits. Although the results suggest the living umbrella's ability to provide a restorative environment, it should be critically evaluated whether the living umbrella was the actual source of the participants' happiness.

The postulates proposed by Yannik Joye, suggest the drivers of this supposed Biophilic happiness may not be so unadulterated. Opponents to this study could argue that source of the participants' happiness could be resultant of uncontrolled factors. For example, Maryland Day is a festive, engaging, feel-good event that promotes happiness. Individuals sampled during this event may have had bias feelings of happiness and superimposed the living umbrella as the source of their happiness. Similarly, stress release that was suggested in the Survey of Users could not be quantified as there were no probes into understand the stress levels of the individuals before and after exposure to the living umbrella. This hints that the respondents' self-evaluated stress release may have been assumed or hypothesized.

Opponents to the Biophilic hypothesis disagree with the notion of an inherited trait that allows humans to have restorative health benefits from vegetation because of a lack of benefit regarding safety or food received by simple objects and images of greenery (Joye et al. 2011). Ultimately, this burdens the notion that the living umbrella

creates a connection and invokes restorative healing. This is not to say that individuals falsified their emotions and thoughts, but rather, there are alternative drivers which are being unaccounted for that invoke these feelings. Continuing to determine the motivations behind why people appreciate and respect green space is of growing importance as built environments are developed. Simple questions that remove motivational interpretation and allow simple, practical information may help in decision making.

Preference of the living umbrella over the metal is quantitative measure of the participant's decision making tendencies. Regardless of a connection with the natural elements or microclimatic benefits, the survey results confidently show that 81% of individuals would prefer to use a living umbrella over a traditional umbrella. This 81% is in direct support that the public would prefer to have living umbrellas to replace traditional umbrellas to shade common areas. The motives and drivers behind this preference could be debated, yet the fact stands that the majority of the sample population prefers the living umbrella.

As suggested by Kellert and Wilson (1993), individuals have an intrinsic bond to nature and life-like process. The metal umbrellas across the University of Maryland are hard, modern, inanimate objects. There is no resemblance of nature or life-like processes within its shape, color, style, or texture. On the contrary, the living umbrella presents the users with abundant natural colors, shapes, and textures; while the metal umbrella is a monotone, rigid, dull structure. The living umbrella provides contrast between its flowers and leaves and its shape is fluid and dynamic. A manual developed by consulting company Terrapin Bright Green, *14 Patterns of Biophilic Design; Improving Health and*

Well-being in the Built Environment, highlights the influences of Biophilia in architecture and design. They present 14-Biophilic design aspects of nature that most impact our satisfaction with the built environment. These 14 design principles are as follows; 1) Visual Connection with Nature 2) Non-Visual Connection with Nature 3) Non-Rhythmic Sensory Stimuli 4) Thermal & Airflow Variability 5) Presence of Water 6) Dynamic & Diffuse Light 7) Connection with Natural Systems 8) Biomorphic Forms & Patterns 9) Materials Connection with Nature 10) Complexity & Order 11) Prospect 12) Refuge 13) Mystery 14) Risk/Peril. Of these 14, it could be argued the living umbrella satisfies 8 of the principles within one structure. The living umbrella realizes a visual connection with nature, airflow is variable as it flows through leaves, light diffuses through the canopy, it allows the user to be connected with nature, biomorphic patterns of the vines are visible, materials are natural, plants grow with complexity and order, and finally the microclimate provides a refuge. Supporting 8 of these 14 claims identifies the living umbrella as an ideal example of Biophilic design, able to reduce stress and create a connection with nature.

Although the living umbrella is an exemplar technology to visualize and portray these Biophilic design patterns, the reasons behind participant's decision to choose the living umbrella can be questioned. This research cannot conclude for certain that it was a Biophilic connection that drove individuals to prefer the living umbrella. More certain than a Biophilic connection, it could be presumed that the microclimatic benefits were the driver for preference. The research mathematically proves the microclimate was improved over the ambient conditions; thus, this physical benefit to the user is more quantifiable and verifiable than the intangible emotional connection. Some could suggest

that its simply the novelty and innovation of the living umbrella that drives preference (Bertarelli et al. 2000, Joye et al. 2011). Although it mimics a tree, and similar to other pergola or trellis systems, the living umbrella is a completely new product. Participants have never been exposed to this technology before; where as a traditional umbrella is unexciting and archaic. Excitement created by this newness could be the motivation behind the participant's preference. A paper by Ernstson (2013) reviews ecosystem services in urban places and the drivers behind why and why not they are championed. Relating to the living umbrella, the participants may have created an internal value to the living umbrella because of the perceived benefits it offers. These benefits may have been internalized by the individual and regarded as more valuable than the metal umbrella. Consequently, the major driving factor behind the popular preference of the living umbrella over the traditional cannot not be derived from this research. Influence and motivation of human decision-making is convoluted and uncontrolled for within this research. However, the data gathered does conclusively find that 81% of the individuals surveyed would rather use the living umbrella than a traditional. This is quantitative data supporting the use of this technology in the public space.

5.6.0 Experimental Limitations

5.6.1 Microclimatic

Limitations in the design and execution of the study were realized as a result of hosting the study on the University of Maryland campus. The experimental units were placed in distant locations, across the campus landscape, which created heterogeneous

sampling areas and conditions. Each observational unit was subject to unique wind and solar conditions which limits controlled replication. Although not conducive to a perfectly controlled scientific experiment, the variation between the study sites speaks to the consistent functionality of the living umbrella. No two spaces in the urban landscape are identical; therefore, having tested the living umbrella in a variety of conditions will bolster the understanding of its application in different locations.

It must be realized that each observational unit itself is unique. Just as in humans, no two plants are exactly alike. Some of the units were prolific, provided a dense canopy with high LAI and high percent cover; while others were not as expansive and did not provide a large shading canopy. Much of the variation could be attributed to the growing conditions of the plants.

The research team was unsure of how conducive the living umbrella would be to plant health. Positioned in a raised metal planter, utilizing a prototype irrigation system, and potential for public tampering did not provide a guaranteed platform for the plants to thrive. Although some plant failure occurred, all plants were healthy during the sampling period. It was gathered that some plants grew better atop the living umbrella than others. The researchers utilized a variety of plant species on the living umbrella units so that they may gain insight on which plants would succeed. This is important information for application of the living umbrella in the future. Variation in plant species created for more heterogeneity in the study than optimal, but did not limit the availability to perform the research. A Randomized Block Design appropriately accounted for this heterogeneity of observational units in the statistical analysis.

The methodology of sampling also placed limitations on the study. The researcher could only sample from one observational unit at a time, allowing for the possibility of change in macroclimate conditions between sampling. For this reason, the researcher compared reductions in the metrics from control & observed measurements before comparing data across paired treatments. This reduction would appropriately address the treatments ability to influence the macroclimate in an accurate temporal scale.

The time of year during sampling was a final limitation of the study. Sampling in the hottest time of year would have provided the best-case scenario for determining the treatments ability to create comfortable microclimates. Historically, the hottest month of the year is July (NCEI n.d.). The sample period occurred in October, which is 3 months past the hottest time of the year in College Park, MD. This mild weather may have muted the living umbrellas full potential to create comfortable microclimates in heat stressed conditions. Also expected is a dramatic increase of the surface temperature of the metal umbrellas during hotter months. Increased longwave radiation emitted from the metal canopy could raise the ambient temperatures of the microclimate. July may have created more pronounced effects between the treatment types. Without representative data, forecasting the influences of hotter conditions on how treatment effects may have changed cannot be supported. However, even with the mild sampling conditions and heterogeneity of the observational units and sampling locations, trends can be seen in the functionality of both canopy treatments. Attempting to run a controlled study in a public-urban landscape creates for unique complications. Nevertheless, this technology is designed for the urban environment therefor it is appropriate to be evaluated in such fashion.

5.6.2 Biophilic

It was found more difficult than expected to have passerby's on campus to complete the survey. There was no incentive provided to entice individuals into taking the survey. A small incentive such as a gift or opportunity to win a prize could increase the completion rate of the survey. The research also assumed that much of the campus community had access to a QR reader app in which they could access the survey from their phones. There was no validation of this assumption prior to developing and installing the QR codes on the observational units. A paper survey with drop-box may have increased the survey completion rate. Alternative methods of distributing the survey should be explored in the future to allow for a higher completion rate. The low completion rate eliminates the opportunity to analyze the information with analytic statistics which further limits the researcher's ability to make any mathematically qualified conclusions. Having accepted this limitation, the results gathered have been interpreted with support of descriptive statistics.

The use of a supplemental questionnaire, Curious Inquirer Survey, that was not specifically designed to evaluate the Biophilia hypothesis and its influence on the participants' emotions towards the living umbrella can complicate the results. This questionnaire was developed to assess individual's perceptions of the living umbrella and was designed with influence from the Biophilia hypothesis. The questionnaire was given to individuals in the presence of the living umbrella and allowed for both quantitative and qualitative assessment of the participants' feelings of the technology. It is for these reasons that the questionnaire was selected as a supplemental source of data to draw conclusions of the living umbrellas ability to create a Biophilic connection with its users.

6.0.0 Conclusion

The following is a list of the major findings of this study of the microclimatic effects and Biophilic properties of the living umbrella:

- The living umbrella reduced UV Radiation by 76% (31.1 W/m^2), Solar Radiation by 82% (738.1 W/m^2), and Wet Bulb Globe Temperature (WBGT, a measure of total personal comfort) by 1.5°C (2.7°F).
- The living umbrella's effect on microclimatic variables was comparable to patio umbrellas with metal canopies that were of similar size. The metal umbrellas reduced UV and Solar transmittance by 13.1% and 8% more, respectively.
- The Sun Protection Factor (SPF) of the living umbrella was 5, which corresponds to 80% reduction in UV transmission.
- The LU's canopy was 15.9 degrees C cooler than the metal umbrella.
- The LU was a net absorber of thermal radiation (-13 W/m^2), which was much less than the metal umbrella---a net exporter of thermal radiation ($+75 \text{ W/m}^2$).
- The mean light extinction coefficient of the living umbrellas was 0.5.
- The LAI of the living umbrellas were 3.7 in October.
- The Percent cover of the living umbrellas was 62.4 in October.
- The Survey of Users found that individuals 1) had positive feelings towards green space, 2) reported stress relief while immersed in green space, 3) considered the living umbrella green space, 4) felt the living umbrella would provide them with stress relief and 4) felt more responsibility toward the environment because of the

living umbrella. A vast majority of respondents (84.6%) would choose the living umbrella over a traditional patio umbrella.

- The Survey of Curious Inquirers found that the majority (80%) of respondents either agreed or strongly agreed that 1) plants and green space relieve stress, 2) they would pay more for a living umbrella than a comparable umbrella or plants, and 3) they preferred the living umbrella over the traditional patio umbrella.
- The Surveys found the most common, freely offered words from respondents that encountered the living umbrella were “happiness”, “peace”, and “calm”.
- The Surveys support the conjectures of the Bioiphilia Hypothesis that human connections with elements of the natural world can promote better mental well-being.
- The living umbrella, by offering people a tactile, functional experience with nature, increases peoples’ exposure to a type of green space that can relieve stress, connect people with nature, and increase their environmental stewardship.

Appendix 1

Sample Statistical Code for SAS. This code evaluated the Sun Living against Living Measurements of WBGT.

```
Code
options ls=180 ps=120;
data UVTRANS;
input Rdc Trt$ Blk;
datalines;
24.67833333333333 SM 1
26.2483870967742 SM 2
25.5305084745763 SM 3
18.4508474576271 SM 4
19.6898305084746 SM 1
18.8901639344262 SM 2
19.5603174603175 SM 3
19.5866666666667 SM 5
20.8587301587302 SM 4
19.9677419354839 SM 6
21.8966101694915 SM 7
22.9145454545455 SM 1
21.6425925925926 SM 2
21.3322033898305 SM 3
21.7180327868852 SM 4
21.7120689655172 SM 2
22.2962264150943 SM 3
23.055 M 1
23.6516666666667 M 2
23.7870967741935 M 3
17.3737704918033 M 4
17.25 M 1
17.1533333333333 M 2
18.3116666666667 M 3
18.315 M 5
19 M 4
19.5067796610169 M 6
19.8901639344262 M 7
20.1338709677419 M 1
19.5526315789474 M 2
19.8816666666666 M 3
20.1793103448276 M 4
19.2822580645161 M 2
19.9576923076923 M 3
;
run;
PROC PRINT;
proc mixed;
class Blk Trt;
```

Users Survey. Given to a random population of campus goers that were in proximity of the living umbrella. Completed digitally either on tablet or through QR Code reader app on smart phone.

Please indicate whether you believe to be true, false, or select don't know if you are unsure.

1. Plants help to clean the environment.
True False Don't Know
2. The plants on top of the Living Umbrella will provide environmental benefits.
True False Don't Know
3. Most plants and trees do not require daily maintenance.
True False Don't Know
4. Plants cool the environment around them.
True False Don't Know
5. Increased green spaces in cities will improve the condition of the environment.
True False Don't Know
6. Lack of green spaces in cities results in higher temperatures.
True False Don't Know
7. Green spaces can be used for stress relief.
True False Don't Know

Please make a mark on the scale based on your opinion of the statement.

8. I would like to see more shade structures in public places.
Strongly Disagree Neutral Strongly Agree
9. I would like to see more green spaces in public places.
Strongly Disagree Neutral Strongly Agree
10. I feel the Living Umbrella could be considered green space in public places.
Strongly Disagree Neutral Strongly Agree
11. I feel the Living Umbrella could provide the same benefits as larger green space.
Strongly Disagree Neutral Strongly Agree
12. I feel stress relief when I am in green spaces.
Strongly Disagree Neutral Strongly Agree
13. I feel the Living Umbrella would help me relieve stress.
Strongly Disagree Neutral Strongly Agree
14. I feel a connection with nature.
Strongly Disagree Neutral Strongly Agree
15. I feel responsible for the health of our environment.
Strongly Disagree Neutral Strongly Agree
16. I feel increased green spaces in public places will increase opportunity for environmental stewardship.
Strongly Disagree Neutral Strongly Agree
17. If given the choice, I would choose a Living Umbrella or a Traditional Umbrella. (Circle one)
18. How does the Living Umbrella make you feel?

Curious Inquirer Survey. Given to interested individuals that approached the living umbrella display at the Maryland Day even. Survey was completed digitally on a tablet.

10/12/2017

Living Canopy Maryland Day Questions

Living Canopy Maryland Day Questions

* Required

1. **Plants and green space make me happy (i.e. a park, wooded area, gardens).** *

Mark only one oval.

	1	2	3	4	5	
Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Agree

2. **Having shade when sitting outdoors is important for me and my family.** *

Mark only one oval.

	1	2	3	4	5	
Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Agree

3. **I would prefer a green umbrella rather than a fabric patio umbrella.**

Mark only one oval.

	1	2	3	4	5	
Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Agree

4. **I would be willing to pay more for a green umbrella than a fabric umbrella.** *

Mark only one oval.

	1	2	3	4	5	
Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Agree

5. **I would be willing to pay more for a green umbrella than the plants on my patio.**

Mark only one oval.

	1	2	3	4	5	
Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Agree

6. Check all that apply:*Check all that apply.*

- ☐ I am a homeowner
- ☐ I use a patio umbrella at my home
- ☐ I have plants at my home
- ☐ I purchase plants at least once a year
- ☐ I own my own business

7. I would expect to purchase this umbrella from (check all that apply):*Check all that apply.*

- ☐ A big-box store (Walmart, Target, etc.)
- ☐ A national home and garden center (Home Depot, Lowe's, etc.)
- ☐ A local plant and garden nursery (Behnke's, Johnson's Florist and Garden Center)
- ☐ An online retailer (Amazon, Ebay, Etsy)
- ☐ Other

8. What emotions do you feel when you are near this green umbrella?

9. Comments, questions or concerns? Leave an email and name if you would like your question answered or want to know more about our project!

10. What is your age?*Mark only one oval.*

- ☐ 21 or younger
- ☐ 22-35
- ☐ 36-55
- ☐ 56+
- ☐ Prefer not to answer

Table of Averaged Metrics by Blocks. All Subsample recorded within each block were used to calculate values. Differentiation between umbrella type was not separated out. Values for block 5 are missed due to lost data. These metrics showed little variance and were found to be insignificant thus loss is not critical.

Block	UV Radiation (W/m2)	UV Transmittance	Solar Radation (W/m2)	Solar Transmittance	WBGT (°C)
Stamp	26.74	0.17	531.37	0.10	21.30
Richie Red	25.35	0.17	513.87	0.12	21.16
Richie White	26.46	0.19	531.05	0.14	21.35
SCS	15.27	0.13	377.33	0.16	19.22
Tawes Plaza	21.84	0.26	546.88	0.16	18.90
ERC Pool	26.58	0.20	505.90	0.14	20.35
CSPAC	24.35	0.23	564.63	0.18	21.23
	WBGT Reduction (°C)	Surface Temperature (°C)	Air Temperature (°C)	Humidity	
Stamp	1.89	26.76	74.63	0.56	
Richie Red	2.04	28.17	74.88	0.55	
Richie White	1.70	32.12	75.76	0.53	
SCS	1.39	29.09	69.53	0.64	
Tawes Plaza	0.86	N/A	N/A	N/A	
ERC Pool	0.94	26.79	71.11	0.67	
CSPAC	1.67	27.69	73.82	0.60	

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