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Role of vegetation placement for temperature moderation in an urban microclimate

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ROLE OF VEGETATION PLACEMENT FOR TEMPERATURE MODERATION IN AN URBAN MICROCLIMATE

By

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ABSTRACT

Role of Vegetation Placement for Temperature Moderation in an Urban Microclimate

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Through optimal planning and site design, strategic selection and placement of vegetation is one approach to prevent warming in the urban core. To test this hypothesis, a paired sampling design using temperature loggers, was conducted in the City of Toronto to assess the overall effect that shading through vegetation had on moderating temperatures in the microclimate proximate to built structures. The role of vines, a single mature tree, and multiple trees growing at one site, was investigated to compare their temperature moderating benefits. Tree placement on the west facing aspect of built structures delivered the greatest overall benefits when compared to south and east facing building walls. Temperature differences between loggers reached a maximum of 11.7 °C during the month of August. A mixed model evaluated the longitudinal study data and revealed that temperatures were significantly cooler ($p < 0.05$) in the shade of both trees and vines compared to those recorded in the sun for all aspects throughout peak solar access periods.

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LIST OF ACRONYMS

AR(1) - First Order Autoregressive Structure

CBH - Crown Base Height

DBH - Diameter at Breast Height

GSIC -Gerstein Science Information Centre

HHs - Hart House (South)

HHw - Hart House (West)

KCe - Knox College (East)

KCw - Knox College (West)

kWh - Kilowatt Hour

LAI - Leaf Area Index

MCIS - Munk Centre for International Studies

SAS - Statistical Analysis System

SDWRe - Sir Daniel Wilson Residence (East)

SDWRw - Sir Daniel Wilson Residence (West)

Sh - Shading Coefficient

SP(POW) - Spatial Power Structure

TC(1) - Trinity College (Site 1)

TC(2) - Trinity College (Site 2)

TCe - Trinity College (East)

TOU - Time of Use

UC(1) -University College (Site 1)

UC(2) - University College (Site 2)

UCC - University College Courtyard

UHI -Urban Heat Island

UofT - University of Toronto, St. George Campus

WS - Warren Stevens

1.0 INTRODUCTION

1.1 Urban Forestry and Urbanization

The concept of urban forestry evolved in North America during the mid-1960s. Its evolution was coincident with the height of Dutch Elm disease, which decimated treed urban landscapes across much of the continent. The resulting elevation in public interest concerning the plight of city trees led to the forestry profession taking a more proactive role in the management and maintenance of the urban forest (Johnston, 1996; Jorgensen, 1970). Urban forestry was first defined by Jorgensen in 1965 as a "specialized branch of forestry and has as its objective the cultivation and management of trees for their present and potential contributions to the physiological, sociological and economic well-being of urban society" (Jorgensen, 1970; 44). This definition also includes the effects trees have on the environment, as well as their aesthetic value, which indicates urban forestry does not only consider street trees, but rather the management of trees in the entire area that is influenced by the urban population (Jorgensen, 1970). Since that time, however, the working definition of urban forestry has changed to include such things as the planning, protection and maintenance of trees, forests and greenspaces (Deneke, 1993). The incorporation of planning, protection and maintenance of trees and their growing medium will ensure that healthy forest cover is retained, as urban populations continue to expand into surrounding rural areas (Deneke, 1993). This is an important concept, as urban forests can provide an array of benefits to the communities in which they grow; benefits that are not only ecological or environmental, but also economical and social.

Urban forests are composed of both publically and privately owned trees, and are ecosystems characterized by their association with human development (Lohr et al., 2004). They are a significant natural resource in the urban environment, but due to shifts in population, changes in economic activity, and densification of built structures, extreme pressures for their alteration and removal represent consistent threats. Urbanization, now more than ever, is jeopardizing the ability of the urban forest to sustain basic ecological functions (Dwyer et al., 2003; Lohr et al., 2004). Like all forests, urban forests undergo considerable changes with the growth and development of their physical and biological components over time. However, the development of the urban forest and its resources occurs in a rapid changing anthropogenic environment, which can make management of these areas complex and challenging (Dwyer et al., 2003).

Both human population growth and urbanization are currently the dominant demographic trends (Akbari & Konopacki, 2004; Wu, 2008). World populations are continuing to grow exponentially, with the majority of people living in cities. It has been projected that 60 % of the world's population will reside in an urbanized area by 2025 (Wu, 2008). This is in stark contrast to the rural population globally, as the population living in urban areas is growing three times faster (Wu, 2008). Urbanization has altered many natural landscapes around the world, with impacts reaching far beyond city limits. Such impacts include: increased air, noise, and water pollution, loss of agricultural land, habitat fragmentation and degradation, enormous and concentrated consumption of energy, increased production of wastes, and changes to many ecological cycles needed for the survival of both terrestrial and aquatic flora and fauna (Nowak & Dwyer, 2000; Wu, 2008). Cities have transformed the natural environment so significantly, such that society now views urban areas as merely employment sites; this has caused a large number of people to relocate to suburbs and surrounding rural areas. The problem with this, however, is that it has increased commuter traffic as well as other environmental stresses; collectively, these pressures have resulted in even more damage to the natural environment (Heidt & Neef, 2008).

To combat the negative ecological repercussions of urbanization, a new approach to creating "eco-cities" has begun in many places around the world (Carreiro, 2008). An eco-city is defined by well managed resources, and an incorporation of nature into urban design (Carreiro, 2008). Acknowledgement of the importance of mature trees in communities is increasing, as the potential for their ability to improve 'quality-of-life' becomes more evident (McPherson & Rowntree; 1993). Environmental concern about climate change, air pollution and the Urban Heat Island (UHI) effect have brought attention to the potential for trees to ameliorate these conditions. Planning and designing principles focused on sustainability are being incorporated in cities, with a large focus on urban forestry (Carreiro, 2008).

Nonetheless, management of the urban forest is still inadequate and thus the benefits that they currently provide are only a fraction of what they could be (Dwyer et al., 1992). A full understanding of the benefits and costs, as well as how management practices, programs and policies influence costs is essential for urban forest enhancement. This requires commitment from all levels of government as well as dedicated public education and outreach campaigns.

1.2 Urban Forestry Benefits

The following discussion begins with the influence of urban trees and forests on the physical and biological environment, as well as the social and economical benefits they provide.

1.2.1 Urban Forest Influence on Physical and Biological Processes

Urban trees and forests both influence, and are influenced by physical and biological components of the environment and its respective ecological processes. They have the ability to mitigate negative impacts of urbanization by improving air quality, moderating climate, ameliorating stormwater runoff, conserving energy, reducing noise pollution, and providing wildlife habitat (Chen & Jim, 2008; Dwyer et al., 1992; McPherson et al., 1997).

1.2.1.1 Air Quality

Air pollution is a serious problem in urban areas, especially as it relates to human health (Chen & Jim, 2008). Major air pollutants include sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3) and fine particulate matter (PM_{10}) (Chen & Jim, 2008). Trees exchange gases with the atmosphere through their inner leaf surfaces, a process that captures harmful particulates (Dwyer et al., 1992). This process removes gaseous air pollutants mainly through uptake by leaf stomata; however, some airborne contaminants are removed through interception by leaf and stem surfaces (Nowak, 2005). Once inside the plant, SO_2 and NO_x react with water on inner-leaf cells to form sulphuric, and nitric acid (Chen & Jim, 2008). These acids then react with other intra-cellular compounds to form new products that are redistributed to other parts of the plant (Chen & Jim, 2008). The rate at which trees remove gaseous pollutants such as ozone, carbon monoxide and SO_2 depends on foliage volume and the condition of the stomata (Dwyer et al., 1992). For example, one study showed that a mature urban tree could intercept up to 23 kg (20 to 40 times that of a newly planted tree) of particulates per year, which emphasizes the benefits of having large mature trees in the urban environment (Dwyer et al., 1992). However, it is important to note that when estimating the effectiveness of street trees to abate air pollution, factors such as atmospheric stability, pollutant concentration, solar radiation, temperature, turbulence, wind speeds, aerodynamics, atmospheric chemistry, particle size and vegetation characteristics must all be considered (Chen & Jim, 2008).

While having many benefits for urban environments, it is also important to note that trees have the ability to emit small amounts of volatile organic compounds (VOCs), which can contribute to the formation of pollutants such as ozone and carbon monoxide (Geron et al., 1994; Isebrands et al., 1999; Nowak, 2005). These emissions might be useful to the tree from the perspective of attracting pollinators or repelling predators (Nowak, 2005). VOC emissions vary among species, and are affected by air temperature, and other environmental factors (Isebrands et al., 1999). Trees that are high VOC emitters include Willow (*Salix* spp.), Spruce (*Picea* spp.), and Oak (*Quercus* spp.), each of which can have an impact on air quality in the immediate urban environment (Isebrands et al., 1999; Nowak, 2005). Unfortunately, this has been cited as one reason for not enhancing tree cover in urban areas (Nowak, 2000). In reality though, with proper selection and planning, the aggregate benefits trees provide through improving air quality far out-weigh the costs.

1.2.1.2 Temperature Reduction

Trees are capable of buffering extreme temperatures experienced in urban environments through the process of evapotranspiration and shading (Federer, 1976; Huang et at., 1987; McPherson, 1984). These two processes can affect air temperature, heat storage, and prevent ground and built structures from absorbing and re-radiating solar energy back into the atmosphere (Heisler, 1986a; McPherson, 1984; Nowak, 2005). The process of evapotranspiration involves the movement of water from the stomata into the atmosphere in the form of a vapour; through this state, changes in water (liquid to gas), energy is extracted from the surrounding environment resulting in cooling of ambient air (Nowak, 2005). It can also result in increased humidity, which has the effect of settling airborne particulates that may be present in the surrounding atmosphere (Chen & Jim, 2008). This reduction in temperature can help to reduce ozone formation and the overall production of smog in cities (Dwyer et al., 1992). For instance, computer simulations have shown that pine trees (*Pinus* spp.) in Los Angeles were found to remove 8 % of the ozone present in the atmosphere (Dwyer et al., 1992). Ozone concentrations have been shown to increase with a rise in temperature. For example, Dwyer et al. (1992) found that the occurrence of smog days increased by 1 % for each increase in temperature by 1 °C.

The urban forest's ability to prevent warming through shading can also help to decrease emissions from parked cars. Un-shaded parking lots act as miniature heat islands, and are sources of motor vehicle pollutants. Results presented in the work of Klaus et al. (1999), indicate that afternoon maximum temperatures in a shaded parking lot were 1 °C cooler, on average, than an un-shaded parking lot, where the shaded lot was determined to have an 80 % reduction in solar radiation. These findings are important when considering the coverage of parking lots present in urban, and increasingly suburban areas.

1.2.1.3 Reduction in Stormwater Runoff

Stormwater runoff attenuation represents another very important benefit of the urban forest, especially because cities have such a large proportion of impervious surfaces. High runoff volumes can increase erosion and dispersal of harmful pollutants into important water sources. This occurs, as accumulated pollutants on roadways and in parking lots flow uninhibited into nearby sewers (Nowak & Dwyer, 2000). The presence of trees, and their pervious growing medium, causes rainfall interception, slows overland transport, and facilitates both storage and evaporation of precipitation. Nowak & Dwyer (2000) have shown that trees can help moderate high amounts of rain during intense storm periods by functioning like retention-detention structures. These mitigation measures posed by treed areas can help reduce municipal costs (Chen & Jim, 2008). The amount of water retention is based on tree species, leaf density and size; coniferous species are able to hold more water than deciduous species, due to their larger leafy exterior (Nowak & Dwyer, 2000). For example, runoff estimates taken from a study done in Dayton, Ohio after an extreme storm event, found that the existing canopy reduced surface runoff by 7 %, and a small increase in canopy would reduce runoff by almost 12 % (Chen & Jim, 2008; Sanders, 1984).

Through the process of evapotranspiration, trees draw moisture from the soil and increase soil water storage potential (Ward & Robinson, 2000). Root growth and decomposition help to increase the rate of soil infiltration and reduce subsurface overland flows (Ward & Robinson, 2000). Tree canopies also have the ability to reduce erosion by diminishing the impact (kinetic energy) of raindrops on bare soil (Ward & Robinson, 2000). Rainwater retention can reduce the size and density of drains needed in a city, which has the positive impact of reducing construction and maintenance costs (Chen & Jim, 2008). In cities located in very dry climatic zones (semi-arid or arid regions), water usage for landscape maintenance may be costly, as water resources are scarce; however, the savings in energy use from power plants often offsets water costs in these areas (Nowak & Dwyer, 2000).

1.2.1.4 Energy Conservation

A well maintained urban forest can contribute significantly to energy conservation. Achieving energy conservation with trees is dependent on local climate, location in relation to built structures, tree size, leaf density, and the age of construction materials. According to Heisler (1986b), tree impact on energy use is greatest for smaller buildings, particularly single-detached homes. However, older buildings stand to benefit more from the urban forest because they were made using less insulation and limited energy saving technologies compared with newer buildings (Dwyer et al., 1992). Studies done in

California and Florida have shown that appropriately placed trees can provide energy saving benefits by shading in the summer, which can reduce air conditioning costs, and by providing wind breaks in the winter to minimize heat loss to buildings (McPherson, 1984; McPherson & Rowntree, 1993; Nowak & Dwyer, 2000; Parker, 1983). For example, annual energy savings in California with properly placed trees were about 4 % over having no trees, and 13 % greater than improperly placed trees (Nowak & Dwyer, 2000). Improperly placed trees may alter wind patterns and can result in increased heating costs, which reduces the overall annual savings; this effect is most prominent during winter months in northern climates.

Trees can be used as windbreaks to help conserve energy, by either blocking cold winter, or warm summer air. The optimal location for windbreaks depends heavily on the wind speed and direction in the surrounding microclimate of a given area, the house-to-windbreak distance for minimal air infiltration, convective heat loss, and the maintenance of solar access during winter months (McPherson, 1984; McPherson et al., 2006). Solar access refers to the amount of sun that is not being blocked by an object; therefore, in order to conserve energy it is important to buffer and or intercept the sun's solar rays from reaching the built structures. A reduction in wind speed can reduce the amount of air infiltration into interior spaces; for some buildings (less well insulated) this may be up to 50 % (Heisler 1986a). Cool winter winds blowing against highly conductive material, such as windows, can significantly increase the heating load in built structures. Trees that are optimally planted to block such winds can help reduce energy usage associated with the increased heating load

Solar angles play an important role when identifying energy saving potential. Generally, in the summer in the Northern Hemisphere, solar angles are low in the east and west (early morning and late afternoon respectively), and high in the south at mid-day solar noon (Baker & Taleb, 2002). This indicates that high levels of summer irradiance can heat interior spaces quickly, increasing demand for energy to cool interior spaces. To minimize this process, passive energy practices that use trees, shrubs and vines can be implemented. Passive energy systems are more sustainable than active energy systems (i.e., furnace and air conditioner), because passive energy uses fewer natural resources, is cheaper and less susceptible to fault as it relies completely on nature (Bansal & Pal, 2009). Passive systems do not use gas for heating, or coolants for air conditioning, but use energy from the sun for heating and design principles for cooling (e.g., strategic placement of shade trees) (Bansal & Pal, 2009). Since the sun's energy is effectively free, it is wise to maximize the benefits of solar energy before incorporating active technologies.

Energy savings are beneficial from both an environmental and economic standpoint; they reduce power-plant emissions, as well as save the city, local businesses, and homeowner's money (Dwyer et al., 1992). For example, computer simulation models have shown that increasing, by 100 million, the number of mature trees in US cities, (equivalent to approximately three trees for every other single home), a potential savings of 30 billion kWh of electricity could be achieved; this is equivalent to $2 billion in annual savings and a reduction of 9 million tons of CO_2 per year (Rowntree & Nowak, 1991).

1.2.1.5 Noise Reduction

Treed buffers (30 m wide or greater) nullify the effect of noise produced from industrial sites, highways, and downtown areas (Cook, 1978). These wide belts of tall dense trees can reduce noise pollution by approximately 50 % in a given environment (Cook, 1978).

1.2.1.6 Ecological Benefits

Trees in the city encourage ecological diversity. They offer essential food and shelter for a variety of city animals, from microorganisms to larger mammals such as foxes and squirrels. The urban forest can also provide stop over points for migratory birds and shelter during rain or windstorms (Nowak & Dwyer, 2000). Riparian habitats, woodlots, wetlands and other greenspaces help connect the city with its surrounding bio-region, and sustain biodiversity (McPherson et al., 2006).

1.2.2 Socio-economic Importance

All of the urban forest benefits associated with the physical and biological environment discussed previously have implications for people who live in urban areas. The following relate to the less tangible, and often subjective ways in which humans perceive the environment.

1.2.2.1 Real Estate Value & Desirable Environment

Urban forests and parks can have a positive outcome on the economic value of a proximate property. Several studies have indicated that properties adjacent to parks can experience a 5 % increase in property value, while others suggest an even higher percentage (Dwyer et al., 1992; McPherson & Rowntree, 1993; McPherson et al., 2006; Nowak & Dwyer, 2000). Not only does the urban forest provide economic value in terms of real estate, progressive shopping malls have used them in their landscape design to attract customers (More et al., 1988; Nowak & Dwyer, 2000).

1.2.2.2 Physical and Physiological Health of Humans

Reduced stress and improved physical health for urban residents has been shown to be correlated with the presence of urban trees (Dwyer et al., 1992; McPherson et al., 2006; Ulrich, 1984). One study indicated that hospital patients recover more quickly with a window view of a green canopy than without (Ulrich, 1984). The urban forest can affect the day-to-day lives of everyday people; its presence has directly related to increased physical activity in parks (Nowak & Dwyer, 2000). Both physical and emotional stress can have short and long term effects. Studies have shown that stress related to the urban built environment (i.e., commuting) can be decreased with views of natural treed landscapes (Ulrich, 1984). Minimizing the UHI effect and amelioration of smog can lower risks of heat stroke, as well as issues associated with dehydration (Ulrich, 1984). The ability of the urban forest to improve air quality within a city is of further benefit to those citizens with respiratory illnesses (Dwyer et al., 1992).

1.2.2.3 Local Economic Development

Sustaining, and where possible enhancing, the urban forest can also benefit the greater public good by providing employment. To uphold a healthy urban forest there is a requirement for regular maintenance by various practitioners, some of which include: arborists, tree-wardens, commissioners, by-law inspectors, and city workers. These individuals aid in the pruning, watering, planting, protection, and removal of dead or dying trees. Overall, employment gain associated with the creation of a healthy sustainable urban forest is largely dependent on the public and the governments' perception, as well as the general understanding of benefits the urban forest provides (Dwyer et al., 1992; McPherson et al., 2006).

It is clear from the preceding discussion that urban forests are a significant and valuable component of a city. Benefits and costs associated with urban trees vary, and are not always translated into monetary values. One must be aware of the interconnectedness and limitations that surround them as some benefits experienced by one homeowner may not be the same for other homeowners (Anderson & Cordell, 1985; Nowak & Dwyer, 2000). Overall, with effective planning and management, urban trees and forests can provide a great number of benefits to cities.

1.3 Current State and Management of the Urban Forests: Case Study City of Toronto

While physical conditions clearly influence urban trees, social and policy factors appear to be a major component in how urban vegetation is laid out in the city (Conway & Urbani, 2007). Surveys conducted by municipalities across Canada in the study by Conway and Urbani (2007) indicate that the current existence of policy, tree-protection by-laws and tree planting and removal programs vary greatly among municipalities. Where programs and policies do exist, they are limited to publicly owned trees. Since the majority of all trees present in cities are located on private property, policy amendments addressing private tree populations will undoubtedly have a greater influence on the overall benefits that trees can provide to a city (Conway & Urbani, 2007).

Creating a healthy urban forest requires routine maintenance not just planting, a fact often overlooked by our politicians. For example, the City of Toronto is one such city that is trying to improve its urban forest; however, to sustain a healthy urban forest can cost a city a large amount of money (Toronto City Council, 2006). The demands associated with the care and maintenance of the urban forest are substantially increased as a result of drought, pest infestation and frequent storms (Toronto City Council, 2006). In addition to maintenance costs, the City of Toronto has proposed the goal of increasing its canopy cover from the current 18 % to 34 % by 2050. To ensure sound investments in this goal, and to make certain its success, existing and newly planted trees must be regularly maintained for the first 10 yrs after planting (Irvine, 2007; Toronto City Council, 2006). Toronto's chief forester, Richard Ubbens, states that it has taken 100 yrs to achieve what the urban forest is today in the City of Toronto, and realistically it will take another 100 years to get to the goal David Miller has proposed as a means to fight climate change (Porter, 2007).

With that as context, it is important to understand the issues facing Toronto's urban forests today. First, there is no contingency fund to pay for storm damage; clean up costs after storms have been taken out of the capital budget, which has diverted funds from planting, maintenance, and other activities that could otherwise be used to expand canopy and improve tree health (CAP, 2007). For example, the intense rainstorm of August 19, 2005 cost the city of Toronto's Urban Forestry department \$600,000 for the clean-up of fallen trees and branches - money that could have be allotted to back-logged maintenance issues (CAP, 2007). Second, there is inadequate knowledge about the value and state of urban trees. Many residents do not know how to properly care for trees, and most do not know the value that trees can provide (Irvine, 2007). In addition, most municipalities do not have a comprehensive inventory of street trees, which makes it difficult to assess and manage the urban forest efficiently (CAP, 2007).

Another major problem facing the urban forest is generally poor growing conditions. Trees planted along streets and sidewalks do not normally have enough room (soil volume) below ground for root growth. A large portion of a tree is below ground (40 %), with the majority of a tree's root system growing in the top 60 cm of soil (Irvine, 2007). Tree roots can extend twice as far as the canopy dripline, therefore, finding adequate growing space to accommodate roots of a mature tree is a difficult task. Stressors such as salt and construction activities also curtail growth well before maturity. The failure of a city tree to attain mature stature represents an important loss from the perspective of maximizing ecological benefits. Large mature trees provide benefits that far out-weigh those of smaller, newly planted ones. It has been reported that to get the full benefit from a tree, its crown has to stretch at least 6m, which may take up to 20 yrs for some species (CAP, 2007).

It is also worth considering that it can take up to five years for a city tree to absorb all the carbon dioxide that went into putting it there in the first place (Porter, 2007). Therefore, to off-set this cost, it is imperative that trees are able to grow to maturity to ensure they are providing benefits to their fullest potential. If we continue to lose larger trees as a result of inadequate protection and general neglect, only to replace them with small trees, there won't be much of a gain in per cent canopy coverage; an example of what occurred in the City of Toronto, that had 22 % canopy coverage in 1992 (Porter, 2007). Better maintenance strategies need to be implemented to ensure larger tree stature. Trees require a considerable amount of care such as watering, pruning, and disease and pest control. In addition to this, many tree planting programs help resident's plant trees, but they do not provide maintenance information or resources. It is only with proper knowledge that, residents can learn to care for newly planted trees.

A general lack of biodiversity is also an underlying issue for many urban forests (CAP, 2007). The City of Toronto has many tree species; however, only a small number of species account for majority of the urban forest population (CAP, 2007). Norway Maple (*Acer platanoides*), Green Ash (*Fraxinus pennsylvanica var. subintegerrima*), and Honey Locust (*Gleditsia triacanthos*) are the most common; this lack in species richness, creates a situation of vulnerability concerning invasive insect pests and other problems (CAP, 2007). At present, the City of Toronto opts to buy new trees from commercial nurseries, which restricts the choice of tree species, where choice is largely based on the market demand and not diversity or attention to native species (CAP, 2007). Without proper selection, the maintenance cost associated with those specific trees may be far higher than if a native species were chosen.

Lastly, there is insufficient policy protection, as most trees are on private property (CAP, 2007; Conway & Urbani, 2007). Municipal zoning by-laws regulate what can be built in these areas. They, however, do not regulate the minimum requirements for green space and do not have any measures outlining natural processes (CAP, 2007). In many cities, as much as 90 % of all trees are on private property; therefore, policies that were designed to address these areas will likely play a larger role in maintaining the urban forest (Conway & Urbani, 2007).

In Ontario there has been an increase in the number of cities adopting single tree bylaws rather than just woodlot protection (Conway & Urbani, 2007). At present, there is a wide range of regulations and programs across provincial municipalities in terms of what should be considered as a protected tree (i.e., based mostly upon diameter, health and species). This apparent discrepancy is problematic concerning sustainability and enhancement of urban forests.

Recently, the City of Toronto boosted the forestry budget to $20.3 million, prohibited the destruction or damage of trees on private property without a permit, and introduced new building standards asking developers to cover 40 % of residential gardens with trees and shrubs (Porter, 2007). It has also implemented a new streetscape manual calling for eight to 15 times the amount of soil per street, which will greatly assist in improving their longevity (Porter, 2007). The City is also moving away from planting Norway Maple, now considered an invasive species in many of Toronto's ravines, and which currently makes up 30 % of the urban forest population. Alternative trees recommended for planting include Oak, Red Bud, and Honey Locust (Porter, 2007). The City of Toronto is beginning to understand that city trees are an important component to urban ecosystems and that long-term management strategies and research are needed to fully understand the specifics regarding how policies may affect the urban forest.

1.4 Tree Influence on Pathways of Heat Transfer

In order to manage trees for energy saving strategies, it is essential to understand the pathways of heat transfer. Two things must be known: 1) how heat moves in an out of buildings in relation to the local environment; and, 2) how trees influence these proximate microclimates (Heisler, 1986b; Meier, 1991). Air exchange, heat conduction, and solar radiation transmission and reflectivity are mechanisms affecting the microclimate in a given area that can manipulate the rate of heat loss or gain within buildings. It is important to recognize that trees have the ability to influence these three mechanisms, and thus the overall energy usage of buildings (Heisler, 1986b; Meier, 1991, Miller, 1997).

Air exchange, defined as the ability of air to move in and out of the building structure through cracks, commonly in and around windows and doors, is a process driven by a pressure gradient that develops when interior and exterior building temperatures vary (Heisler, 1986b). In summer months, infiltration of air results when the outside air is warmer than the inside air. As the air hits the building, a pressure gradient establishes, that causes cool dense air inside the building to leak out through lower cracks or openings. In the winter, the reverse effect occurs, whereby the warmer, less dense air, inside the house rises and flows out through upper level openings. Air exchange is further influenced by wind pressure; buildings exposed to windier climates will tend to have a higher rate of exchange (Heisler, 1986b; McPherson, 1984; Miller, 1997).

Heat conduction through the various surfaces of the house (roof, wall, and windows) is influenced by temperature differences, sun characteristics, and wind effects; all of which are dependent on building surface types (brick, stone, and cement) (Heisler, 1986b; Miller 1997). As the sun acts to increase outside building surface temperatures, heat conduction into the house will occur. This can be described by R-values, which relate heat flow through conduction, driven by the temperature gradient between building materials inside and outside a structure (Heisler, 1986b). Windows have the greatest heat loss and gain because of their low R-values, which can be especially problematic during high wind periods (Heisler, 1986b). Windbreaks can help mitigate this effect, as Heisler (1986b) notes a 2/3 reduction in wind-speed can reduce conduction by 9 % for double-pane windows and by 13 % for single-pane windows. Heat can also transfer in and out of building surfaces through thermal and long-wave radiation emitted from hot driveways and sidewalks, all things to consider when developing proper site design strategies to prevent warming (McPherson et al., 2006).

Solar radiation can heat homes through various means, which include heating the walls and roof surfaces, with the main source being directly through windows. In the Northern hemisphere, during winter months, solar radiation is most important when the sun is low in the sky as it directly hits windows and walls on south facing surfaces (Heisler, 1986b). In summer months solar penetration is important on east and west, as well as south facing surfaces of building structures. In early mornings, when the sun is low in the sky, it is incident on east facing surfaces. At solar noon, sun penetration is strongest on south facing surfaces, and in late afternoon, when the sun is high in the sky, solar radiation is most important on west facing surfaces (Heisler, 1986b). For example, a study conducted by Simpson & McPherson (1996) found that residential buildings that had mature trees situated immediately to their west could experience as much as a 9 % reduction in peak electrical usage because the home was shaded during the warmest times of the day (1:00 to 4:00 pm). The shade from a southwest tree became more important for earlier peak times, and shade present on northwest surfaces for later peak times (Simpson & McPherson, 1996). In a study conducted by McPherson (1984), it was reported that a single 5 m tree shading an east wall between 9:00 am and 12:00 am decreased the average temperature of the wall by 13.5 °C.

Building surface albedo is another factor that is highly correlated with how warm a surface will get when exposed to solar radiation. Surface albedo can be defined as the proportion of incoming radiation which is reflected back into the atmosphere (Ward & Robinson, 2000). Actual values of albedo change over time, and vary with sun angle (time of day), season and latitude. Lighter surfaces such as snow or ice have high albedo values; this means that most incoming solar radiation is reflected back into the atmosphere. Darker surfaces such as pavement and asphalt, have lower albedo values; this results in their comparatively high absorption of solar radiation, causing their surface temperatures to be warmer. Taller (mature) vegetation, as well as species with deeper canopies and contiguous forests, have higher albedo values than shorter stature vegetation (newly planted trees) because their larger canopy volume provides for more reflection / adsorption opportunity (Ward & Robinson, 2000).

1.5 Trees and the Urban Microclimate

The urban microclimate differs from the general climate of a specific region. It encompasses the variation in climate within a narrowly restricted area, which is influenced by temperature, topography, built structures, as well as nearby water sources (LEAF, 2009). Trees and other vegetation have the ability to modify the urban microclimate by various means which include: 1) shading effects, which reduce the conversion of radiant energy to sensible heat, by preventing these surfaces from heating; 2) absorption and reflection of solar radiation; 3) moderation of wind speed; 4) interception of rain and snow; and, 5) cooling of the ambient air through evapotranspiration (exchange of latent heat), which may sometimes increase humidity (Federer, 1976; McPherson, 1984; Parker, 1983). All of these vegetation-induced microclimatic adjustments affect human comfort, building energy budgets, and the general climate of a specific region (Miller, 1997).

Trees and other vegetation intercept solar energy by blocking radiation from striking underlying surfaces, whereby some of this intercepted energy is converted into chemical bonds through the process of photosynthesis (Figure 1.1) (Miller, 1997).

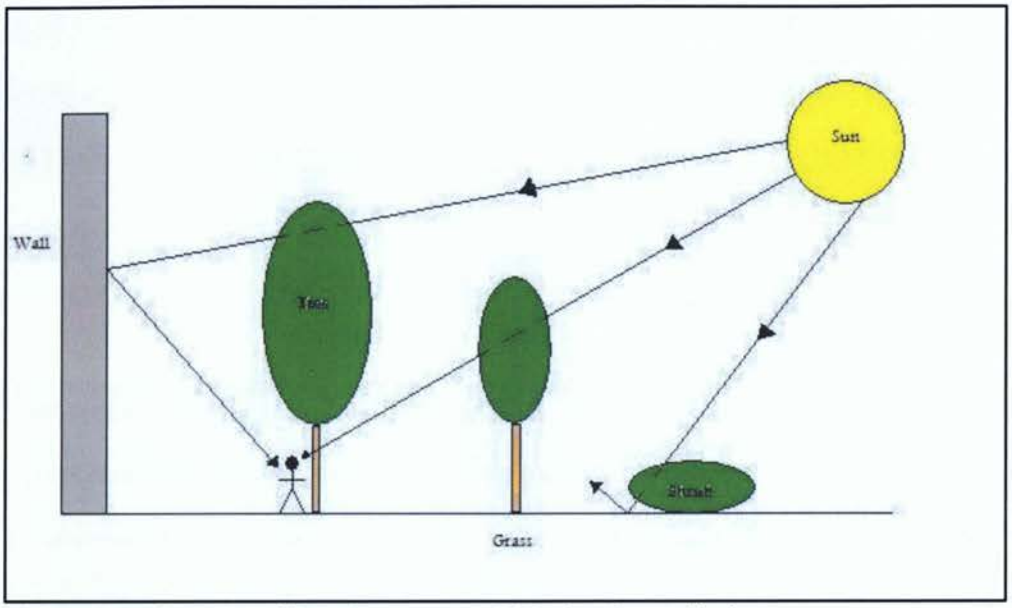

Figure 1.1: Plants can filter, intercept and block solar radiation.

The impact of individual trees on human comfort is not necessarily affected by lowering the air temperature from shade, but rather due to blocking solar radiation (Federer, 1976; Heisler, 1986a). A person will generally feel cooler in the shade of a tree, even though the air temperature may be the same in the sun only a few feet away. Controlling for radiation transmission is the most important function trees can perform when it comes to temperature and human comfort (Federer, 1976; Miller, 1997).

A tree's ability to influence temperature by removing heat from the air through the process of transpiration can significantly affect the cooling of the microclimate, whereby vegetation of all types can be used to manipulate air movement by obstruction, guidance, deflection, and filtration (Federer, 1976; McPherson, 2006). Research conducted by McPherson (1984) & Heisler (1986b) found that, the transpiration cooling effects of one tree may have little impact on the surrounding microclimate due to air movement in and around a single crown. However, the combination of a series of transpiring trees, growing throughout a neighbourhood, can have a collective impact on temperature reduction and, as a result, lower energy demand for summertime cooling. It is important to note that some studies have indicated that the addition of another tree adjacent to the first may not double the effect that trees have on the prevention of warming through shading, but will make an additional contribution in areas that are not affected by the first tree (Federer, 1976; Simpson & McPherson, 1996). Overall, the planting of urban trees is an inexpensive measure to reduce summertime temperatures, and by preventing solar radiation from reaching buildings, reduces heat storage and energy used for cooling (Akbari et al., 2001; Chen & Jim, 2008; Simpson & McPherson, 1996). Heisler (1986b) found that radiation reduction from trees is greater on clear summer days when compared with cloudy days. Clouds influence the amount of longwave radiation more so than clear skies; therefore, trees have much less of an effect on longwave radiation when skies are cloudy (Federer, 1976). Clouds also affect the amount of shortwave radiation penetrating the Earth's surface. This affect causes a lessening of night-time longwave cooling and daytime heating, which is why cloudy weather is associated with comparatively uniform temperatures (Oke, 2001).

1.6 Temperature Differences between City and Rural Areas

Urban areas have been shown to be warmer than surrounding rural areas by between 0.5 °C and 1.5 °C (Chen & Jim, 2008). This phenomenon has been labelled as the urban heat island (UHI) effect. Elevated urban temperatures are also accompanied by increased relative humidity, which can cause these built-up areas to be uncomfortably hot. To adjust for these increases in outdoor temperature, large amounts of energy (active cooling through air conditioning) are used indoors to achieve a level of human comfort (Chen & Jim, 2008). There are many reasons why this temperature variation exists. A city is a complex mosaic of many different natural and built structures: small and tall buildings, highways and streets, parking lots, parks, valleys, lakes, rivers and harbours. Each of these various locations has its own unique microclimate. No two areas are the same because each is influenced differently based upon its surroundings, built structures, and land cover characteristics (Federer, 1976; Miller, 1997). It is known that the main reason for temperature variation between city and rural areas is due to the absorption of solar radiation (shortwave) by built surfaces (buildings and pavement) during the day, and re-transmission of the energy back into the surrounding environs as thermal (longwave) energy. The UHI effect is further exacerbated by the internal combustion of fossil fuels in cars and other machines. Urban areas are comprised of materials that have different thermal and radiative properties when compared with a prevalence of vegetation found in rural areas (Federer, 1976). Commonly used building materials such as concrete, steel, asphalt and glass are poor insulators, have lower albedo, and have high thermal capacities (able to store large amounts of heat). Comparatively, vegetated surfaces only re-radiate a small percentage of incident solar energy back into the atmosphere in the form of thermal energy. Energy that is absorbed by plants for photosynthesis and respiration further assists in reducing the amount of re-radiated longwave radiation and in doing so helps to prevent the warming of cities (Chen & Jim, 2008). Although increased temperature in urbanized areas might be an advantage to residents in the winter months, in the summer, this effect can be quite uncomfortable. Urban areas are generally characterized by a scarcity of trees and other vegetation, which is highly correlated with a decrease in evapotranspiration-driven cooling (Federer, 1976). Vegetation cover in rural areas has the ability to insulate the ground, which helps prevent the storage of heat in soils. In cities, the lack of vegetation makes for larger energy storage in subsurface materials during the day, which results in higher night-time temperatures both indoor and outdoor (Chen & Jim, 2008; Federer, 1976). Energy that is stored throughout the day is then released back into the atmosphere at night once the sun sets, causing temperatures in the surrounding air to be warmer than adjacent treed natural spaces. For example, Federer (1976) found that rural-to-city differences are not as significant during the day, but are greatest in the early evening. This corresponds with periods when electrical utilities experience peak demand from their urban clientele; a situation that could be ameliorated with care and attention to the placement and maintenance of trees.

Dust, soot and other aerosols in urban areas can decrease the incoming solar radiation to between 80 and 85 % of that received by rural areas (Federer, 1976). However, these same particles act as an insulation layer such that net longwave radiation loss in late afternoon and evening is curtailed; instead of escaping back into the atmosphere, this energy is kept close to the surface lowering the rate of cooling when compared to an adjacent rural location. This difference in energy balance between urban and rural areas is based on different environmental factors, which explains why cities tend to warm more slowly in the morning, and why they are slower to cool at night. Federer (1976) further explains that the net radiant energy taken in by rural areas during the day is used up in three ways: 1) heating of the air; 2) heating of the soil and vegetation; and, 3) evaporating water. In situations where the soils are not too dry, transpiration from vegetation can remove significant amounts of the available heat. Comparatively, cities have less available water to evaporate; therefore, most of the incoming solar energy goes into heating the air and built materials (Federer, 1976).

The UHI effect increases the demand for summertime electricity; recent research indicates that for every C° increase in temperature, electricity generation rises by between 4 and 8 % (Heidt & Neef, 2008). Furthermore, for every C° increase in temperature, smog production increases by between 7 and 18 % (Heidt & Neef, 2008). Urban vegetation can mitigate the effects of the UHI by lowering the ambient temperature, which also reduces the amount of ozone produced (Nowak, 2005). A single tree that is strategically planted to shade a home or office can significantly reduce summertime electricity demands (McPherson et al., 1997).

1.7 Siting and Management of Trees for Energy Reduction

The potential for energy savings resulting from urban trees depends on these main factors: 1) the quantity and quality of shading; 2) structural characteristics (building surface materials and the type of cooling system used); and, 3) the geographic location (McPherson, 1984).

When developing a site design for proper placement of trees, several factors must be taken into consideration. These include orientation, window location, surface colour of building materials, heat capacities and conductivity of walls and the areas where the sun can easily reach the walls of the built structure (solar access) (McPherson, 1984). Building use patterns must also be taken into consideration when assessing tree placement; this will necessitate the requirement for cooling in different living and work-related spaces. For example, it is important to identify which areas of the structure are most essential to shade for practical living and working reasons. The variables that influence these energy use patterns include how many times a room is used throughout the day and at what times. It is also important to note the location of the rooms (i.e., orientation with respect to the sun) (McPherson, 1984). Studies have indicated that shading along west sides of building structures, shading the air conditioner and the exterior heat sinks such as driveways and or patios, are beneficial in reducing energy use (McPherson, 1994; McPherson et al., 2006; Meier, 1991; Simpson & McPherson, 1996). Research indicates that the air-conditioner should be shaded for the entire cooling season and pruning of the surrounding vegetation should be completed so that airflow is not restricted to and from the unit (McPherson, 1984; McPherson et al., 2006; Parker, 1983). These maintenance tactics will allow the summer breeze to reach surface walls and help to reduce the overall surrounding temperatures (McPherson et al., 2006; Parker, 1983).

Studies conducted by McPherson (1984) and Parker (1983) have also found that placement of trees closer to the building wall will provide the greatest benefit in terms of cooling effects. This allows for shading effects to occur for a longer period of time throughout the day. McPherson et al. (2006), suggest that in order to maximize summer shade, trees should be located between 3 and 6 m from the building, while making sure they are not closer than 3 m as roots of trees that are too close can damage the foundation. These researchers also recommend that trees between 9 and 15 m from the building wall will most effectively shade windows and walls; this is largely dependent upon crown shape and size of tree species (McPherson et al., 2006). For example, a tree that is 7.6 m high and which has 4.6 m crown width at 3 m from a west facing wall will shade 47 % of the exposed surface between the hours of 3:00 and 7:00 pm. A tree of the same stature located 6.1 m from the wall will only shade 27 % (McPherson, 1984). It is important to note that these measurements are based upon geographic location and solar access, but nonetheless indicate the significance of tree placement and associated shading benefit.

Many studies recommend that to maximize energy savings through the placement of shade trees, it is important to locate a single tree to the west or southwest exterior of a buildings structure (McPherson, 1984; Simpson & McPherson, 1996; Solecki et al., 2005). McPherson et al. (2006) also suggest that in addition to the west side of a building, the east side should be considered the second most important, in terms of the net impact of tree shade on energy savings. Large windows without existing shade should be a first priority for planting so as to limit the amount of heat gain generated by solar radiation. Also, additional trees are recommended for locations that will shade remaining windows. For maximum shading benefit, they should be planted in such a way that as they mature, the canopy edge will be very close to the building wall (Simpson & McPherson, 1996).

Parker (1983) identifies two main landscape strategies used to reduce energy consumption, which are precision landscaping and peak load landscaping. Precision landscaping, involves the placement of trees and shrubs reasonably close to the residence (McPherson, 1984; Parker, 1983). This proximity leverages solar energy for evapotranspiration close to a building, which can create a cooler microclimate proximate to walls and windows. The addition of dense shrubs underneath walls and windows can intensify this cooling process and will aid in providing the maximum effect of this landscape design strategy (Parker, 1983). The other method used to reduce energy use, by naturally cooling buildings, is through peak load landscaping. This method of vegetation selection and landscaping focuses on mitigating peak energy demand time periods, which usually occur mid-to-late afternoon. The objective is to minimize the heating of built surfaces (especially asphalt and pavement) (through shade and evapotranspiration) during the time period when electrical demand is greatest. Parker (1983) and McPherson et al. (2006) also note that placement of trees and shrubs are important on the south facing sides of buildings. This is because significant amounts of solar radiation are incident on lower sections of the walls and proximate ground (e.g., driveways); this is particularly important during the months between August and September when sun elevation angles are slightly lowered.

Landscaping for wind control is another means of reducing energy use. Wind patterns at specific sites are different than those recorded at local weather stations, particularly because of local surroundings and built structures. Wind speed can result in air exchange being less effective, which may cause areas in the shade to have similar temperatures when compared with locations in the sun only a meter away (Heidt & Neef, 2008). Therefore, it is recommend that landscaping design which uses windbreaks, and other strategic vegetation placement, be based on the data gathered from the specific site (Parker, 1983; Solecki et al., 2005). For example, in areas where air-conditioning will be used minimally, low branches should be pruned to allow summer breeze to move along the exterior surface of the house. However, the movement of air may allow warmer air in the summer to infiltrate into the house, which can have negative impacts. Parker (1983) notes these negative impacts can be alleviated with careful placement of shrubs or trees so that wind is channelled into the house when windows are open providing a cool breeze; with closed windows, wind will be conducted away from the house. For example Parker (1983) states that if summer winds are dominant from the southeast, then tall shrubs should be placed on the south sides of east windows and at the east side of south windows. This type of arrangement can reduce the wind velocities reaching the windows, thus decreasing the impact of warm air exchange (McPherson et al., 2006; Parker, 1983).

It is also important to take into consideration proper tree species selection, as well as selection of shrubs and vines; each species has its own unique characteristics in the context of moderating temperature in the urban microclimate. Characteristics that must be considered include: canopy height and width, leaf density, foliation period, height-to-canopy bottom, crown form, growth rates, life spans, maintenance requirements, litter drop, as well as tolerance and susceptibility to pest and disease (McPherson, 1984; McPherson & Dougherty; 1989). Leaf (canopy) density is of great importance in terms of solar control as it directly relates to the trees shading coefficient, which measures the incident solar radiation that is transmitted through the canopy. Interpretation of this coefficient is as follows: values of 1.0 indicate that all solar energy is transmitted and values of 0.0 indicate no solar energy is transmitted (McPherson, 1984).

The foliation period is important as it denotes how long the plant is in leaf and can provide knowledge concerning the microclimate conditions in the area (McPherson, 1984). Height-to-bottom measurements are important to understanding shading patterns in summer and winter. This characteristic relates strongly to solar access, where high branching can obstruct summer sun, but still allow for lower angle winter sun. Lower branching, on the other hand, may block more winter sun resulting in increased energy usage for heating (McPherson, 1984). The size and form of a tree have an obvious positive correlation with shading patterns. Growth rate refers to how quickly the species will reach maximum shading efficiency. Selecting a tree with a longer life span and disease resistance (tolerance) is also highly beneficial; this will limit costs associated with treatment, or removal, thus increasing the overall net benefits of the tree for shading purposes. Tree maintenance is another factor to consider and is one of the major costs associated with urban trees (Winsa, 2007). Pruning, watering, seasonal pick-up of leaves, or other forms of litter drop, are costly, but essential to ensure tree survival. Therefore, ways of minimizing these costs would be beneficial when selecting or locating trees to manage energy usage as well as other ecological services (McPherson, 1984).

It is important to consider proximate land uses when managing and locating trees or vegetation in an urban setting. Land use is an important variable as it influences tree planting and survival; it refers to the primary activity occurring on the land (e.g., commercial, residential, industrial) while land cover refers to the physical surface materials (e.g., tree, building, grass, pavement) (McPherson & Rowntree, 1993). The potential for success of new tree planting programs depends largely on the amount of plantable space available. Assessing the potential for residential plantings is significant because residential and commercial areas consume most of the heating and cooling energy used in cities (McPherson & Rowntree, 1993). One study (Sacramento, California) by McPherson & Simpson (2003) used a simulation model to assess planting potential for a large tree planting program. They found that there were approximately 241.6 million empty planting sites, and if sites with existing trees already were included, there were 418.9 million potential sites for shade trees (McPherson & Simpson, 2003). When assessing monetary values, the 177 million existing trees were shown to provide electrical savings to utilities of $485.8 million (wholesale), and $970 million (retail) to customers; this was roughly equivalent to $3 / tree annually. These researchers sought to determine the benefits associated with the same trees after a 15 yr period. They found that, if properly maintained, peak electricity demand would be reduced by 5190.2 MW, or 10 % over present. The net economic impact was found to be $458 million for both heating and cooling, with a net annual benefit per tree of 1 to $7.

Another study conducted by Huang et al. (1987) assessed the increase in canopy cover, and the electrical saving benefits for the cities of Sacramento, Phoenix, Lake Charles, and Los Angeles. This study found that savings, provided by shade trees, account for 10 to 35 % of the total savings of energy, with the remainder attributable to evapotranspiration (Huang et al., 1987). When assessing potential savings from an increase in canopy (i.e., 1 tree/home (10 %) to 2 1/2 trees/home (25 %)), these same authors found that in all four US cities there were savings in summer peak cooling loads of 9 to 20 % where there was an increase in canopy of 10 % and a savings of 17 to 44 % for a 25 % increase in canopy cover.

McPherson and Rowntree (1993) also conducted a similar study in San Diego to examine the potential for growing space to plant trees for energy conservation purposes. Their results showed that over 40 % of all houses surveyed had space available for a shade tree opposite their west wall. They summarized the general cost effectiveness of a shade tree program by stating that planting 5000 trees in areas proximate to air conditioners would produce a 0.07 MW electrical savings within the first 6 yrs, and approach 1 MW over 20. McPherson and Rowntree (1993) also noted that there would be an average annual cooling savings of approximately 80 kWh per tree.

1.8 Purpose

The purpose of this study was to investigate the influence of tree shading on temperature moderation in the microclimate surrounding built structures in a densely settled urban area. It was hypothesized that the cooling effect associated with trees, where they are present, would assist in reducing electricity consumption by lessening demand for air-conditioning. This effect would ultimately assist in mitigating the UHI effect. There are significant benefits associated with cooling the urban core which include reducing peak energy demands and aiding in public health problems, as cooler temperatures will reduce the production of ground-level ozone and thus improve the air quality in the area.

It was anticipated that findings from this research project would identify the following: 1) the ability of trees to moderate temperature; 2) the importance of the urban forest and, more specifically, the value of mature trees; and, 3) landscape design strategies for energy conservation, and their potential connections to policy.

2.0 MATERIALS AND METHODS

2.1 Study Site

The study location for this research was the University of Toronto, St. George Campus (UofT), which is in the downtown heavily urbanized core of Toronto. UofT extends West to East from Spadina Avenue to Bay Street, and South to North from College Street to Bloor Street West (Figure 2.1). The St. George campus is 68 ha, and is comprised of various parklands, and interconnected courtyards. The buildings present are constructed of variable materials that include concrete, brick, and stone. In many ways it is comparable to other areas present in the urban environment that blend built and natural spaces.

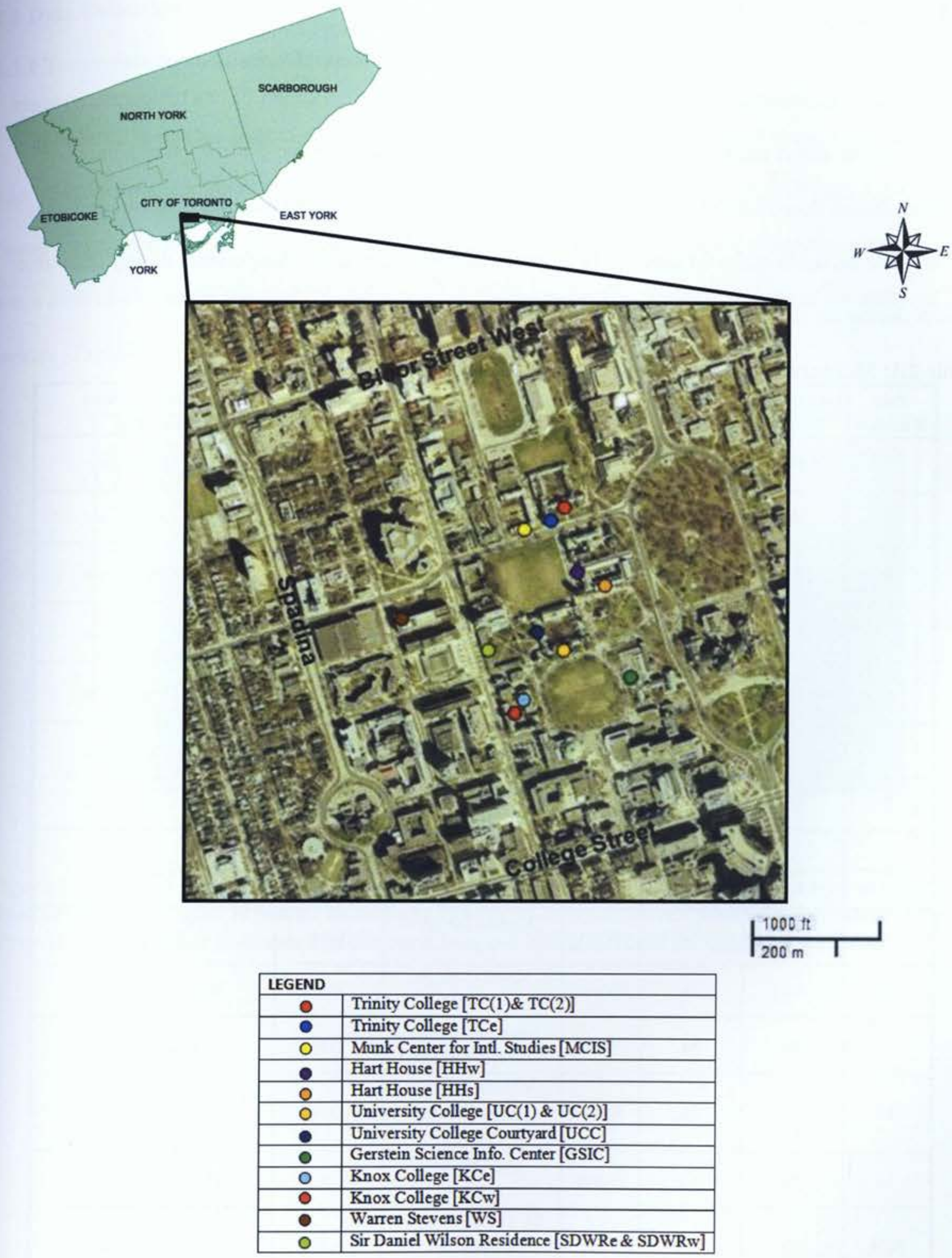

Figure 2.1: Study site: St. George Campus, University of Toronto, Ontario Canada. Air Photo (2007) with study site locations indicated. Source: DMTI Spatial (2007)

2.2 Site Selection

Measurement locations (Table 2.1) were selected based on the ability of one temperature logger to be situated in direct shade, and the other in an area with no shading. [See description of paired sampling design in section 2.3]. Based on an extensive review of the literature, logger positioning was concentrated on south and west aspects. This permitted assessment of the temperature during peak time periods during the months of May to October 2008.

Table 2.1: Measurement locations and their respective descriptions.

Pair Number	Logger Identification		Aspect	Campus Location	Vegetation Type	Building Surface Material
	Shade	Sun				
1	6a	1b	East	Trinity College [Tce]	Tree	Dark Gray Stone
2	4b	6x	East	Knox College [Kce]	Tree	Dark Gray Stone
3	1a	2a	South	Trinity College [TC(1)]	Tree	Dark Gray Stone
4	7x	2a	South	Trinity College [TC(2)]	Tree	Dark Gray Stone
5	2b	9a	South	University College [UC(1)]	Tree	Dark Gray Stone
6	4x	9a	South	University College [UC(2)]	Tree	Dark Gray Stone
7	9b	3a	South	Hart House [HHs]	Vines	Dark Gray Stone
8	6b	7b	South	Munk Center for Intl Studies [MCIS]	Tree(s)	Red Clay Stone
9	3x	5x	West	Warren Stevens [WS]	Tree	Cement
10	4a	7a	West	Knox College [KCw]	Tree	Dark Gray Stone
11	3b	8a	West	University College Courtyard [UCC]	Tree	Dark Brick
12	5a	8b	West	Gerstein Science Info. Center [GSIC]	Tree	Cement
13	2x	1x	West	Hart House [HHw]	Vines	Dark Gray Stone
N/A	5b		East	Sir Daniel Wilson Residence [SDWRe]	Tree(s)	Beige Brick
N/A	10b		West	Sir Daniel Wilson Residence [SDWRw]	Tree(s)	Beige Brick

2.3 Data Collection

2.3.1 Temperature and Field Methods

In order to assess the overall effect that tree shading had on moderating temperatures in the microclimate surrounding built structures, a paired sampling methodology was used (Figure 2.2 & 2.3). Paired loggers were positioned on the same building to hold aspect and building materials constant. There was a total of 13 pairs in the study, with some sites having more than one pair at each of the different aspects (Table 2.1).

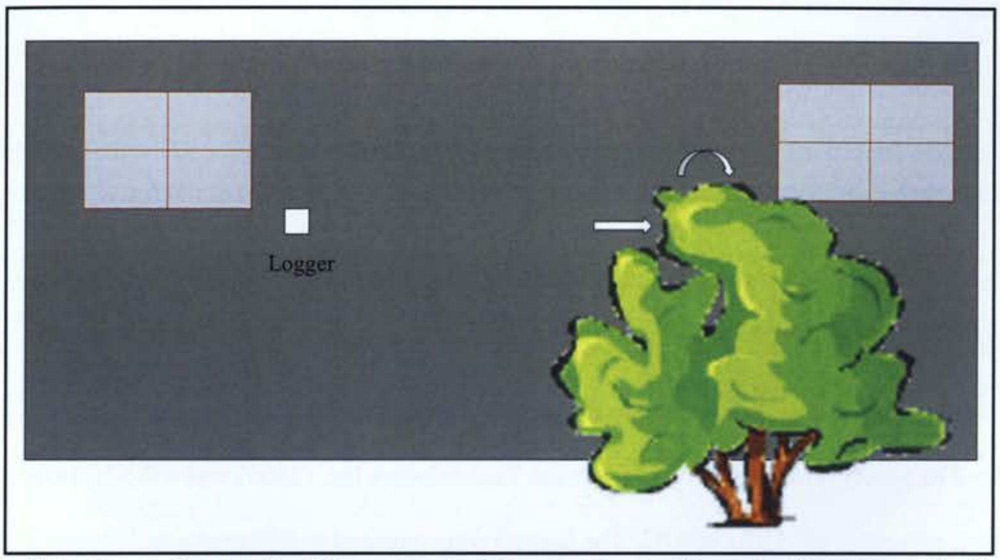

Figure 2.2: Paired sampling methodology on a building surface, with and without tree shading. One temperature logger is placed behind the canopy of a tree in direct shade (represented by the arrows), and the other is situated in the open to avoid being affected by shade.

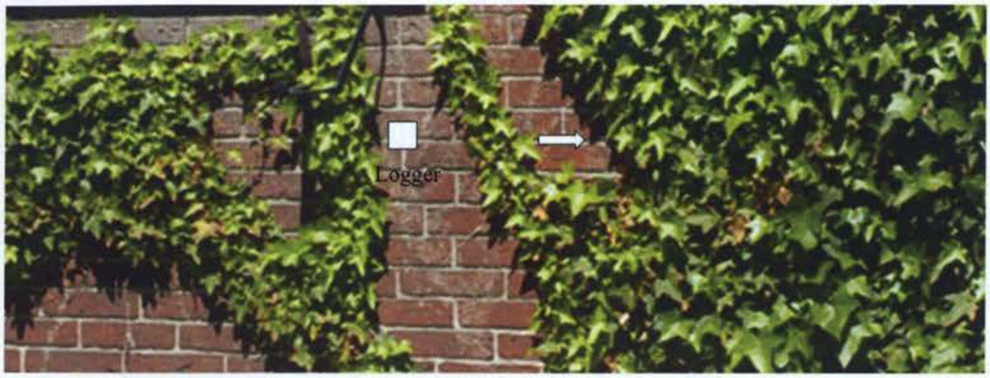

Figure 2.3: Paired sampling methodology on a building surface, with and without shade cast by vines. One temperature logger is within the vines, and is in direct shade (represented by the arrow); the other is situated in the open to avoid vegetation shading.

The paired sampling approach was conducted using 26 WatchDog 100 series water resistant button loggers (Spectrum Technologies Inc). The loggers chosen were white, to maximize their surface albedo (high reflectivity); this was done so as to minimize the absorption of solar radiation and the potential for biasing results (elevating temperature readings for the unshaded logger), that may have occurred with a darker surface colour. In order to determine which of the loggers were best paired with one another, a linear regression analysis was completed to model the relationship between all potential pair sets. The logger error reported by Spectrum Technologies Inc. (2009) was ± 0.6 °C between temperature readings of -15 to +65 °C. The loggers were exposed to temperatures that ranged from 4 to 26 °C, and ran continuously recording data every 10 minutes for approximately 13 days prior to experimental set-up. In order to determine the reliability and synchronous manner of the loggers, significant R-square values that were close to 1 were identified, and contributing pairs of loggers noted. The assumption was that logger pairs with significant R-square values that were closest to 1 exhibited the greatest similarity in performance and would be coupled as a pair for the purpose of this project. This was based upon the understanding of a regression line with an intercept value approximately equal to 0, and a slope very close to 1.

The loggers were placed on buildings at each of the sites using a ladder; pairs were positioned as close to 5m above the ground surface as was possible. This maintained consistency across the entire study area and also approximated the height transition between the first and second storey of most buildings. Loggers were affixed to the buildings using all-weather Extreme Velcro™. All loggers were programmed to take synchronous temperature readings every 10 minutes during 2008 from April 25th, to November 3rd, (193 days). Recording 144 entries each day, the total number of temperature recordings amounted to approximately 27,792 during the time period.

Data were downloaded from each logger on May 5th, June 2nd, July 17th, August 18th, and September 22nd, as the loggers had a maximum memory capacity of approximately 8000 entries. All data recorded on collection days were subsequently removed from further analysis (Reason: there was a need to stop loggers for data download resulting in an incomplete sequence for that day). To collect data, loggers were retrieved from the wall, and all data were uploaded to a laptop using the software package called SpecWare Professional (Spectrum Technologies Inc., 2009). Once the logger data were uploaded successfully, each logger was re-deployed by re-programming it and placing it back on its original wall location.

2.3.2 Tree Characteristics

Data were collected to describe tree characteristics for each of the individual trees present at each study location. Tree and canopy measurements included: crown depth, crown width, drip-line area, crown base height (CBH), tree height, Leaf Area Index (LAI), distance from centre of trunk to the building wall, diameter at breast height (DBH), and species (Figure 2.4).

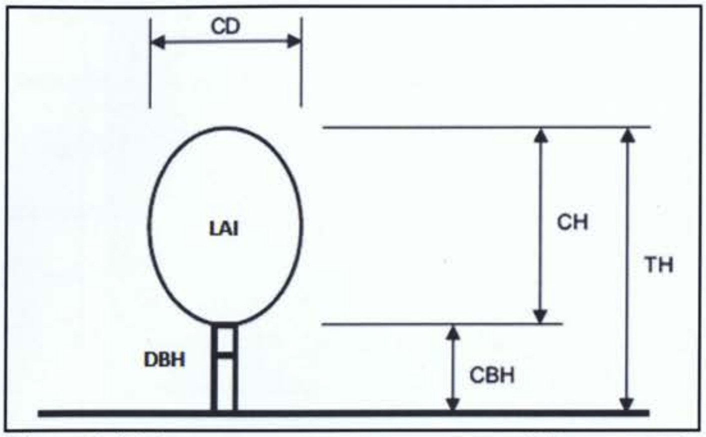

Figure 2.4: Tree measurement parameters: Diameter at Breast Height (DBH); Leaf Area Index (LAI); Crown Diameter (CD); Crown Height (CH); Crown Base Height (CBH); Tree Height (TH) (adapted from Stoffberg et al., 2008).

Crown diameter (m) was assessed using a measuring wheel to determine the length of the longest (primary) axis (assuming few tree canopies are perfectly symmetrical); a second measurement was made perpendicular to the axis (secondary) (Figure 2.5). These two values were averaged arithmetically to produce a final crown value:

$$\text{Crown Width} = [(\text{primary axis}) + (\text{secondary axis})]/2 \tag{1}$$

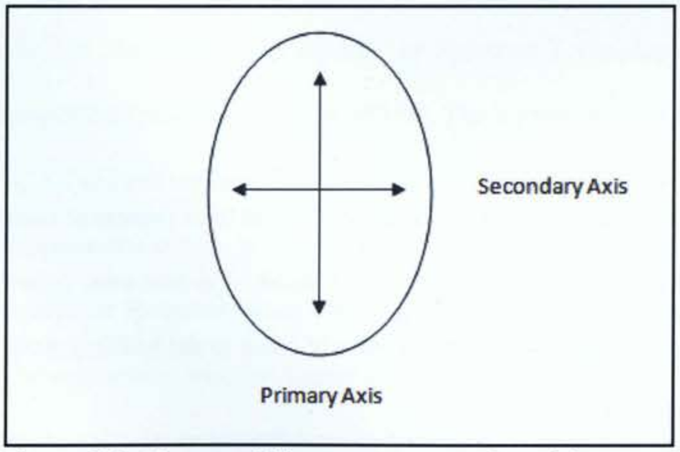

Figure 2.5: Crown width measurement viewed from nadir (above); measurement taken edge to edge at each axis.

DBH was collected using metric measuring tape at 1.4m about ground level. The circumference value was divided by the value of π (assuming a trunk of circular shape) in order to obtain DBH value for each tree in the study.

To measure tree height (m), where a fully leafed-out canopy is marginally taller (< 0.5 m), a percent scale clinometer and metric measuring wheel were used. With the measuring wheel, a standard distance from the tree base was identified (usually either 10 or 20 m; greater in the case of larger trees); the selection of distance was dependent on the ability to observe both the tree's top and its crown base. Using the clinometer, a percent value for the base of the tree was obtained by pointing its levelling guide at the transition location between trunk and growing medium; this was followed by two additional measurements at the crown base and tree top. The base of the crown was determined by drawing an imagery horizontal line across the trunk at the bottom of the lowest live foliage. The bottommost point was accessed based upon what appeared to be the natural lowest branch that had a sufficient amount of foliage present, not necessarily the lowest shoots with a few leaves. CBH was determined by subtracting the percent at tree base from that obtained for crown base and multiplying that by the distance from the tree. For example, assume measurements were taken 20 m from a tree; the tree base percent was recorded to be 10 and the value at crown base was 95. By subtracting 10 % from 95 and multiplying this proportion by 20 m, it follows that the tree's CBH was 17 m. With crown base height and crown height, the vertical proportion of the tree with canopy was calculated. The procedure used to calculate CBH follows:

$$\text{Proportion of Distance from Tree} = \text{Crown Base Percent} - \text{Tree Base Percent} \quad (2)$$

$$\text{CBH} = (\text{Proportion of Distance from tree}) \times (\text{Tree Height Percentage}) \quad (3)$$

Tree height (m) was measured using the same method as CBH, except that the percent at the top of the tree was recorded instead of at the crown base (see Formulae 2 & 3).

Crown surface area is important as it denotes the area available for tree foliage to intercept and absorb particulates from the air, as well as block and filter incoming solar radiation (Miller, 1997). To model crown surface area, crown shade was evaluated and integrated with the previously collected values of crown depth and width. The paraboloid shape, mainly assigned to deciduous trees that display a circular crown shape, was selected for application in this study. The formula to calculate crown surface area was taken from Brack (1999) as follows:

$$\text{Paraboloid:} \qquad \text{Crown surface area} = [(\pi D)/(12H^2)((D^2/4) + 4H^2)^{1.5}] - D^3/8 \tag{4}$$

Crown volume was calculated using crown width (D) and depth (H), measured in m^3. The formula to calculate crown volume was also taken from Brack (1999) as follows:

$$\text{Paraboloid:} \qquad \text{Crown volume} = \pi\,(D^2H/8) \tag{5}$$

An exact measurement for LAI, total leaf surface area per unit land area, was not easily obtained for practical reasons (Kenney, 2008). Instead, LAI was calculated using hemispherical photos, which were taken for each of the individual trees used in the study. Photographs were taken in the early hours of the morning to ensure homogenous sky conditions (i.e., no direct sunlight is visible). Photographs taken with direct sunlight in the field of view tend to be unevenly exposed, which can compromise the ability to distinguish foliage from canopy gaps (Delta-T Devices, 1999). Digital photo images were taken looking upwards (at right angles to the ground surface) from beneath the plant canopy using a 180° fisheye lens (FC-E9) mounted on a Nikon Coolpix 8400 camera. A tripod was used to adjust and level the camera underneath the canopy; this ensured complete control of camera orientation and minimized wobble during image acquisition. A total of four pictures were taken underneath the canopy for each individual tree (at North, South, East and West sides of the trunk). Each of the photos was examined on-site to ensure that the tree crown was captured correctly.

Hemispherical photos were saved in JPEG format (8 megapixels) and processed using the software program HemiView 2.1 (Delta-T Devices, 1999). All images were aligned north to south in the software to ensure proper LAI calculation. A threshold procedure was used to classify various components present in the photograph, which included tree canopy, building structures and open sky.

Images were processed in binary format (1s and 0s, rendered in black and white) to distinguish between foliage and open sky. A section of the image that encompassed approximately 30 % of the tree canopy was selected, ensuring that there was minimal representation of tree branches, or the trunk, that would otherwise influence the LAI estimation. Because branches, trunk, and leaves appeared as black in the image, it was important to go back and forth between the binary image and full colour original to visually assess the best possible area of the leafy canopy representative of the entire tree. Once thresholding was complete and the desired photo area selected, HemiView 2.1 software was used to calculate LAI for each of the trees in the study. This process used all four images acquired for each individual tree in the study. An arithmetic mean for LAI was then determined for each tree.

LAI values were then used to calculate a shading coefficient (sh) for each tree, where sh is the fraction of incident solar radiation that is able to penetrate through the canopy (McPherson, 1984). Values can range between 1.0 (full transmission of solar energy) to 0.0 (no solar energy transmitted). The measurement of shading coefficients is considered difficult, as shadow patterns and the quantity and intensity of solar radiation are variable (McPherson, 1984). To determine the shading coefficients for each study site tree, a commonly used equation (Nowak, 1994) to calculate leaf area was rearranged. The linear models used for tree species were developed by Nowak (1994) for open grown deciduous trees. Such that,

$$\ln Y = b_o + b_1X + b_2S \tag{5}$$

$$Y = (\varepsilon^{-4.3309 + 0.2942H + 0.7312D + 5.7217Sh - 0.0148S + 0.1159}) \tag{6}$$

where: Y is leaf area (m^2); ε is the natural logarithm; X is diameter at breast height 1.4m above the ground; b_0-b_2 are regression coefficients; H is crown height (m); D is crown width (m); Sh is the shading coefficient (%); S is the crown surface area (m^2)

In practice, (LAI) is a commonly used to describe leaf area, because it refers to the total combined area of all leaves on a tree relative to the dripline area; it will be used henceforth for this purpose. LAI values calculated with HemiView 2.1, were used as input into Equation 6, which was rearranged to solve for sh as follows:

$$Sh = ((\ln[LAI \times G]) + 4.3309 - 0.29424H - 0.7312D + 0.0148S - 0.1159)/5.2717 \quad (7)$$

Where H is crown height (m), D is crown width (m), G is the drip line area (m^2), and S describes outer surface area of the tree crown (m^2).

S was calculated as follows:

$$S = D \pi ((H + D)/2) \quad (8)$$

G was calculated as follows:

$$G = \pi(D/2)^2 \quad (9)$$

2.4 Data Analysis

2.4.1 Data Processing

Data were imported from SpecWare Professional input into Microsoft Excel. Times were averaged on a 30-minute and one hour interval basis. Temperatures recorded by the shade loggers were subtracted from those recorded by sun loggers for each of the 13 pairs. These differences allowed for the assessment of temperature moderation; whether the tree/vine was moderating temperature in the microclimate surrounding the shaded logger.

Shading coefficient (sh) values that exceeded the limitations ($0 > X > 1$) were calculated using 'average tree' measurements for crown width (D) and crown height (H) (Nowak, personal communication, October 28th, 2008). Height and width values that were greater than 12 m and 14 m respectively were 'capped' at these values, with all other inputs unaltered (Nowak, personal communication, October 28th, 2008). This was only done for those trees that had sh values that exceeded the boundaries. Trees that had height and width values that were greater than the capped values, but sh values that still came within the 0 to 1 range, were unaltered. All shading coefficient values were then compared to Nowak's (1996) values.

Comparisons were also conducted for each of the sites based on differences in aspects (East, South and West). Peak solar access time periods were assigned to each of the aspects based upon temperature difference analysis for the entire six month period. These solar access periods correspond with peak summer cooling times and provide information on energy conservation.

To provide an overview of temperature differences for a 'typical day' arithmetic means were generated for each measured time across an entire month (e.g., 31 measurements of 12:00 am, 31 for 1:00 am, and so on for the month of May). Data obtained for the entire study period were analyzed (six months: May 1st to October 31st, 2008). Temperature data were examined and found to approximate normal distribution, therefore, a standard error of $\pm$ 1.96 was calculated and used to produce a confidence envelope around mean values. This was completed for each of the logger pairs, producing a 'typical day' for each month across the six month period.

In addition, tree characteristics were introduced into the analysis as independent (predictor) variables. It was hypothesized that these variables may have some explanatory value between and among logger temperature differences. The temperature difference caused by vine and tree shading was evaluated, as well as the difference between greater than one tree compared to a single tree.

Even though the amount of energy being used by the buildings at each of the study sites was not measured, it was still important to get an idea of the types of savings that could come from each of the trees examined. The Sacramento Municipal Utility District (SMUD) has developed a Tree Benefits Estimator on its website, whereby it can estimate the amount of annual energy savings from shading (kWh), the total summer cooling benefits ($) and the carbon and CO_2 sequestration (kg) (SMUD, 2009). The climate reference city of Buffalo, N.Y. was used as it represented the closest climate zone to the City of Toronto (the current model was designed for the USA). Electricity charges used in the model were based on the current electricity rates applied in the City of Toronto. There are two price units for electricity: 5.7 cents for the first 600 kWhs / 30 days used, and 6.6 cents for the remaining power consumed (Toronto-Hydro Electric System, 2009). On top of electricity rates, there are additional charges that consist of delivery, regulatory, and debt retirement, all of which are found in Table 2.2 below.

Table2.2: Electricity Bill Charges for the City of Toronto (adapted from Toronto-Hydro Electric System, 2009)

CHARGES	Cents/kWh
Delivery	
Transmission Charge	1.05
Customer Charge	2.43
Distribution Charge	1.432
Regulatory Asset Recovery Charge	0.041
Lost Revenue Adjustment Charge	0.018
Shared Savings Charge	0.021
Regulatory Charges	
Wholesale Market Operations	0.65
Debt Retirement Charges	0.7

Delivery Charge incorporates such things as transporting the electricity from the generator to the Toronto Hydro Electric System and then to a customer's residence or business, as well as meter readings, billing, customer service and maintenance (Toronto-Hydro Electric System, 2009). Regulatory Charge is the cost associated with administering the wholesale electricity system and maintaining the reliability of the provincial grid (Toronto-Hydro Electric System, 2009). Lastly, the Debt Retirement Charge of 0.7 cents/kWh is levied in order to pay down the debt of the former Ontario Hydro (Toronto-Hydro Electric System, 2009).

The City of Toronto has recently identified peak energy demand periods and has assigned various time of use energy rates (TOU) to them. TOU rates in the City of Toronto are set in preparation for Smart Metering. Smart Meters are devised to help conserve energy, by identifying peak energy demand periods and applying an electricity rate that reflects those demands (Table 2.3).

Table 2.3: Time of Use (TOU) Rates for the City of Toronto to be implemented from June 2009 to June 2010.

TOU Rates	Cents/kWh
Highest Price (On-Peak)	9.1
Mid Price (Mid-Peak)	7.6
Lowest Price (Off-Peak)	4.2

The classification of summer months extends from May 1st to October 31st, with On-Peak times ranging from 11:00 am to 5:00 pm; Mid-Peak times from 7:00 am to 11:00 am and again from 5:00 pm to 10:00 pm; and, Off-Peak hours between 10:00 pm and 7:00 am (Toronto Hydro Electric System, 2009). Holidays are considered to be Off-Peak. During winter months (November 1 – April 30), On-Peak time extends from 7:00 am to 11:00 am and again from 5:00 pm to 8:00 pm. Mid-Peak occurs during the day from 11:00 am to 5:00 pm and again from 8:00 pm to 10:00 pm, and Off-Peak is the same as that of summer months (10:00 pm to 7:00 am). These TOU rates were to be applied to the first 10,000 electricity users beginning June 2009, while all remaining users will experience switches to Smart Metering over the next 12 months (Toronto-Hydro Electric System, 2009).

2.4.3 Statistical Modeling

To analyze the temperature data in the statistical software package, SAS, the original data set (in Microsoft Excel) was re-formatted. A stratified random sample (based on time) was extracted from the population of temperature data for each of the subsequent SAS-based analyses. Stratified sampling of the logger and month ensured that each of the loggers was represented, and that the full data - set was sampled for all the analyses. Coding of the SAS PROC MIXED procedure was employed to ask specific questions of the data set. One of the major elements of the code developed was to generate estimate statements that were applied to the model in order to answer questions such as: 1) are the temperatures recorded in the shade significantly cooler than the temperatures recorded in the sun during peak hours at a specific aspect? 2) are vines providing a similar quality of shading benefit as compared to trees? and, 3) do two or more trees provide greater shading benefits than a single tree? Once run, these estimate statements produced a series of p values that assisted in interpreting the significance of model results.

Statistical models for data are considered a mathematical representation of a class of procedures that permit the analysis of results from experimental studies (Littell et al., 2006). In this study, data were classified as longitudinal, acquired from repeated observations of the same item over long periods of time (Laird &Ware, 1982). Longitudinal data sets can be unbalanced and are not easily used with multivariate models that assume general covariance structures (Laird & Ware, 1982). An example of the longitudinal data collected in this study is provided in Figure 2.6.

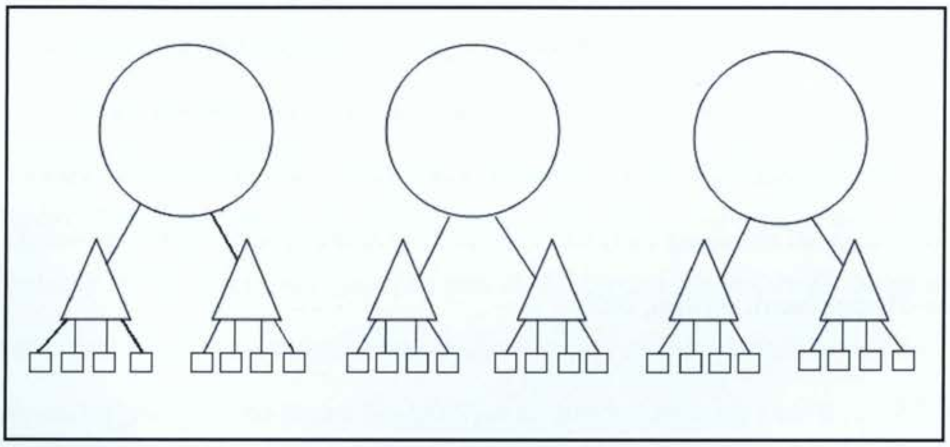

Figure 2.6: Data representation: building-to-building variation (circles); logger-to-logger variation (triangles); temperature measurements themselves (squares).

Circles represent the buildings used in the study; some of the analyses attempted to account for building-to-building variation, as temperatures taken on the same building may have been more similar than temperatures recorded at other building pairs. Triangles represent the logger analyses to model logger-to-logger variation, as temperature measurements obtained by the same logger will tend to be more similar than those obtained by different loggers. Lastly, squares represent the temperature recordings themselves, which were gathered very close together in time (10-minute intervals) and, therefore, cannot be classified as independent.

To use longitudinal data in a statistical analysis, special methods are required to compensate for the presence of autocorrelation in the data structure. Studies using repeated measures, such as temperature measurements obtained from the same unit (logger) close together in time exhibit higher positive temporal autocorrelation than measurements taken further apart in time. Similarly, measurements obtained by the same logger (or pair of loggers) tend to be more similar than measurements acquired from different, more distant loggers (higher positive spatial correlation) (Littell et al., 2006). Therefore, an appropriate covariance structure was built into the SAS PROC MIXED model used in subsequent analyses. Without accounting for this, hypotheses tests, confidence intervals, and estimates of means, produced by standard regression and ANOVA models may have produced invalid (biased) results (Littell et al., 2006).

The ability to model variance structure is one of the most important features of a mixed model (e.g., SAS PROC MIXED). Mixed models contain both fixed and random effects (Littell et al., 2006). A fixed effect is where all the levels in the study are representative of all possible levels of the factor. For example, the effects that sun and shade have on a particular logger are fixed. Factor effects can be considered random if they are used in the study to represent only a sample of a larger set of potential values (Littell et al., 2006). Therefore, a factor may be considered random if its values are a possible representation of a larger population with a probability distribution (Littell et al., 2006). This study compared temperature recordings for each logger, as well as differences between loggers in a pair; therefore, data may also be considered to have random effects, such that each of the measurements can be considered a sample of a larger population.

Temperature measurements that are continuously collected at the same location are often described as repeated measures data. The term repeated measure refers to data sets with multiple measurements of a response variable on the same experimental unit (i.e., specific building location over six months) (Littell et al., 2006). There are three general types of statistical analysis used for repeated measures data: 1) univariate analysis of variance; 2) multivariate and univariate analysis methods to linear transformations (i.e., means, differences between responses at different time points, slopes of regression curves, etc); and, 3) mixed model methods with special parametric structures for covariance measures. In this study, the third method was applied using the PROC MIXED procedure in SAS (SAS/STAT Software, 2007).

In SAS PROC MIXED procedure, autocorrelation within measurements across time is accounted for using the REPEATED statement (Rothman, personal communication, April 30th, 2009). A First-Order Autoregressive (AR(1)) structure was used as it required equally-spaced observations (30-minute intervals in this study). AR(1) structure (Figure 2.7) accounted for the correlation between observations as a function of the number of time points apart (Littell et al., 2006). With this model, correlation in temperature decreases exponentially across longer and longer lags of time. For the AR(1) model, correlation between adjacent within-subject errors is denoted as ρ, regardless of whether the pair of observations is the 1st and 2nd, 2nd and 3rd, and so on (Littel et al., 2006). For example, if $\rho = 0.5$ then the correlation of lag-1or adjacent time points is 0.5, the correlation of lag -2 is $0.5^2 = 0.25$ and the correlation of lag -3 is $0.5^3 = 0.125$, and so on. For repeated measures data it is common for correlations to diminish as lag between the time points increases (Hedeker & Gibbons, 2006).

	1.0	ρ	ρ^2	ρ^3
$\Sigma = \sigma^2$	ρ	1.0	ρ	ρ^2
	ρ^2	ρ	1.0	ρ
	ρ^3	ρ^2	ρ	1.0

Figure 2.7: First-order Autoregressive (AR(1)) structure which explains the correlation of lag times using equally spaced time points, where ρ is the AR(1) parameter and σ^2 is the error variance. Source: Adapted from Littell et al., 2006.

In this study, the dataset gathered resulted in unequally spaced time points and, therefore, negated the validity of the AR(1) structure. Data were considered unequal because only certain time periods of the day were considered. For example, some of the analyses focused on peak solar access periods, such that only the time period between 5:30 and 11:30 am was examined, meaning that from day-to-day the model would extract temperatures from only that time period (values after 11:30 am one day to 5:30 am the next day are omitted), this results in a different spacing than the rest of the 30-minute interval measures. To accommodate this, PROC MIXED offers other spatial structures that allow for unequally spaced time points. The spatial power structure or SP(POW) (Figure 2.8) is a simple generalization of the AR structure in which the exponent of the correlation coefficient (ρ) is calculated directly from distances between unequally spaced time points. For the spatial structure the distance between observations is calculated from the data (data/time variable) rather than assuming it is at a constant distance. In a spatial study there are usually at least two dimensions (e.g., longitude and latitude). A spatial structure for longitudinal analysis can be constructed by specifying only one dimension (time).

$$\Sigma = \sigma^2 \begin{bmatrix} 1.0 & \rho^{d12} & \rho^{d13} & \rho^{d14} \\ \rho^{d21} & 1.0 & \rho^{d23} & \rho^{d24} \\ \rho^{d31} & \rho^{d32} & 1.0 & \rho^{d34} \\ \rho^{d41} & \rho^{d42} & \rho^{d43} & 1.0 \end{bmatrix}$$

Figure 2.8: Spatial power structure (SP(POW)) structure which is a generalization of the AR structure where distance (d) is calculated from the data. Source: Adapted from Littell et al., 2006)

The variation in pair(s) (logger-to-logger or building-to-building) is accounted for by identifying these terms as random effects and using the RANDOM statement in PROC MIXED (SAS/STAT Software, 2007). With random effects, it is assumed that the categories in the study (loggers and pairs) represent random samples from a normally distributed population. This assumption permits conclusions to be drawn beyond the loggers and pairs used in the study sample, to all loggers and pairs used in the study. This is termed a wide inference space.

On the other hand, if variation in logger pair(s) values (logger-to-logger or building-to-building) were classified as fixed effects (by removing them from the RANDOM statement and placing them on the MODEL statement), it would be assumed that these loggers and pairs were the only ones that existed in the population, or are the only ones of interest. This would produce a narrow inference space. In other words generalizations about results could not be made beyond the particular loggers and buildings used in this study.

3.0 RESULTS AND DISCUSSION

3.1 Tree Characteristics

The University of Toronto was a study site comprised of many different tree species; in total, ten were represented out of all the sampling locations. The most common species encountered was London Plane (*Plantanus x acerifolia*), representing four of the total count (seventeen trees) that were investigated. This was followed by Honey Locust (*Glenitsia triacanthos var. inermis*), Silver Maple (*Acer saccharium*) and Little Leaf Linden (*Tilia cordata*), each occurring twice. All other trees represent a single occurrence of the species and are described in Table 3.1, with further information provided in Appendix A.

Eight of the trees (47 %), were within 5 m of a building wall, whereas the remaining nine (53 %), were found at distances greater than 5 m. More specifically, a total of three trees investigated were at distances greater than 10.7 m from the building, which according to Carver et al. (2004) should not provide direct shading benefits to the building structure.

LAI values ranged from 1.66 to 3.66 for all tree species examined in the study. The species with the largest LAI value was Green Ash (*Fraxinus pennsylvanica var. lanceolata*) located at UCC, followed by Silver Maple (*Acer saccharium*) (3.44), located at KCe , and the European White Birch (*Betula pendula*) (3.42), located at UC(2). The shading coefficients (sh) ranged from 0.62 to 0.89 which coincided with Nowak's (1996) range of 0.67 to 0.88 for the same species. The Little Leaf Linden (*Tilia cordata*) located at the MCIS had the smallest shading coefficient (0.62), whereas the species with the highest shading coefficient was White Mulberry (*Morus alba) (*0.89) followed by the London Plane (*Platanus x acerifolia*) located at SDWRw (0.84) and Green Ash (*Fraxinus pennsylvanica var. lanceolata*) (0.80) located at UCC.

Table 3.1 Tree characteristics and measurements for each of the study sites.

Pair Number	Campus Location	Common Name	Latin Name	Distance from the center of the crown to the building (m)	LAI	Melissa Shading Coefficient [sh] (%)	Adjusted sh values (%)	Nowak Shading Coefficient (%)
1	Trinity College [Tce]	Sugar Maple	*Acer saccharum*	3.5	2.94	0.67		0.84
2	Knox College [Kce]	Silver Maple	*Acer saccharinum*	9.9	3.44	1.13	0.79	0.83
3	Trinity College [TC(1)]	White Mulberry	*Morus alba*	11.3	2.91	0.89		N/A
4	Trinity College [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	4.9	N/A	N/A		0.81
	Trinity College [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	3.3	N/A	N/A		0.81
5	University College [UC(1)]	Honey Locust	*Gleditsia triacanthos var. inermis*	7.6	2.20	1.17	0.71	0.67
6	University College [UC(2)]	European White Birch	*Betula pendula*	10.4	3.42	0.70		0.82
7	Hart House [HHs]	Boston Ivy	*Parthenocissus tricuspidata*	N/A	N/A	N/A	N/A	N/A
8	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	3.4	2.55	0.62		0.88
	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	3.5	2.75	0.56		0.88
9	Warren Stevens [WS]	Honey Locust	*Gleditsia triacanthos var. inermis*	4.1	2.22	0.77		0.67
10	Knox College [KCw]	Silver Maple	*Acer saccharinum*	8.5	2.20	1.57	0.72	0.83
11	University College Courtyard [UCC]	Green Ash	*Fraxinus pennsylvanica var. lanceolata*	8.5	3.66	1.10	0.80	0.83
12	Gerstein Science Information Center [GSIC]	London Plane	*Platanus x acerifolia*	5.4	2.30	1.19	0.72	0.86
13	Hart House [HHw]	Boston Ivy	*Parthenocissus tricuspidata*	N/A	N/A	N/A	N/A	N/A
N/A	Sir Daniel Wilson Residence [SDWRe]	Siberian Elm	*Ulmus pumila*	14.6	2.40	3.30	0.73	0.85
N/A	Sir Daniel Wilson Residence [SDWRe]	London Plane	*Platanus x acerifolia*	11.9	1.66	1.37	0.67	0.86
N/A	Sir Daniel Wilson Residence [SDWRw]	London Plane	*Platanus x acerifolia*	3.4	1.86	0.84		0.86
N/A	Sir Daniel Wilson Residence [SDWRw]	London Plane	*Platanus x acerifolia*	3.6	2.52	0.79		0.86

Adjusted shading coefficient: shading coefficient calculated using Nowak's average tree measurements; N/A: No data available; Nowak shading coefficients taken from Nowak (1996). Refer to Appendix A for full tree measurements.

3.2 Solar Path and its Respective Aspect

It is important to understand the sun's solar path when deciding where a tree might be better suited for planting in terms of mitigating the warming of the surrounding area. It is also important to note how the path changes throughout the year and how that may affect a tree's ability to cool a certain area. Table 3.2 contains the respective p-values taken from a 20 % random sample of the entire data set; it presents results of a comparison of temperatures recorded at different aspects (East, South and West) with one another. Peak solar access periods were assigned based on the patterns observed daily throughout the six month period for each of the respective sites. These periods were delineated as follows: 5:30 am to 11:30 am for east; 11:00 am to 4:00 pm for south; and, 3:00 pm to 8:00 pm for west facing sites. For each of the peak periods, greater than half of the results were found to be statistically significant (58 %, 58 % and 62.5 % respectively), whereby temperatures were either recorded as significantly cooler or significantly warmer.

Table 3.2: p-value results from the mixed model for the peak solar access periods of 5:30 am to 11:30 am, 11:00 am to 4:00 pm, and 3:00 pm to 8:00 pm, showing which values from the a test of difference were significant(p ≤ 0.05), and which aspect was warmer or cooler. A comparison between the temperatures recorded at the sun and shade logger (paired sample) is provided; in addition information is presented as to whether the shade logger was cooler than the sun logger during the same time period for each of the respective months.

5:30 am - 11:30 am	May	June	July	August	September	October
East to South	0.98	0.0732	0.1412	0.9512	0.2074	0.2104
East To West	**0.0318**	**0.0003**	**0.0004**	**0.0076**	0.0804	0.4429
South to West	**0.0147**	**0.0262**	**0.0138**	**0.0018**	**0.0015**	**0.0041**
Shade to Sun	0.731	**0.0239**	**0.0402**	**0.0132**	**0.0016**	0.2457

11:00 am - 4:00 pm	May	June	July	August	September	October
East to South	**0.0424**	0.9546	0.8202	**0.0385**	**0.0056**	**0.0444**
East To West	0.9926	0.2413	**0.0449**	0.5581	0.3835	0.5184
South to West	**0.0146**	0.0588	**0.0028**	**0.0003**	**0.0243**	0.09
Shade to Sun	0.0574	**<0.0001**	**<0.0001**	**<0.0001**	**0.0006**	**0.0004**

3:00 pm - 8:00 pm	May	June	July	August	September	October
East to South	0.6417	0.9991	0.9738	0.4099	**0.0098**	0.2457
East To West	**0.0092**	0.0773	**0.0014**	**0.0072**	**0.0006**	0.2868
South to West	**0.0282**	**0.0303**	**0.0004**	**0.045**	0.3587	0.9731
Shade to Sun	**0.0264**	**0.0003**	**<0.0001**	**<0.0001**	**0.0001**	**0.0255**

- **Bold figures are significant p ≤ 0.05.**
- **Indicates significantly warmer**
- **Indicates significantly cooler**

When comparing the different sites, it was evident that early on in the morning when the sun was rising, the east facing sites tended to be warmer than the other aspects investigated, with temperatures significantly warmer than those measured on west facing building surfaces (p = 0.0318, 0.0003, 0.0004, and 0.0076 for the months of May to August respectively) (Table 3.2). As a typical day elapsed and the sun moved into a southern position at solar noon (1:00 pm during daylight savings), it was evident that the temperatures recorded on south facing buildings were significantly warmer than west facing temperatures, and that the east facing temperatures became cooler than the south, but still warmer than the west due to the time lag experienced (McPherson, 1984). These time lags are best explained by the fact that the surfaces that were exposed to the early morning sun have absorbed solar energy and were re-radiating energy back into the atmosphere in the form of longwave radiation (thermal energy) throughout the course of the day. Therefore, this area on average will be warmer than west facing sites that have yet to receive any sun exposure (Heidt & Neef, 2008).

Later in the day, during the peak period of 3:00 to 8:00 pm, it was found that east facing sites had cooled such that temperatures recorded on west facing building surfaces were significantly warmer. They were also significantly warmer than temperatures recorded for south facing building surfaces even when considering the time lag. This is an indication that the warmest air temperatures throughout the day, on average, occur between 3:00 and 8:00 pm, as ambient loads reach a maximum (McPherson, 1984). The ambient load refers to the notion that temperature is the same on all surfaces. The heat lag of a building's thermal mass results in peak ambient interior loads later on in the day, even though temperatures on exterior surfaces may be beginning to decline. Urban materials such as concrete, asphalt and glass absorb higher levels of solar radiation throughout the day, and once the sun goes down, these urban surfaces re-radiate the stored heat energy back in lower atmosphere (Estes et al., 2003). The effect of this thermal energy re-radiated as longwave radiation produces elevated air temperatures in the surrounding microclimate (Estes et al., 2003).

Results from this project, found in Table 3.2, can be compared with Toronto Hydro peak energy demand periods, as peak solar access (time where solar radiation is most intense), and higher temperatures are directly correlated with an increase in energy usage (McPherson et al., 2006). The City's On-Peak time from 11:00 am to 5:00 pm corresponds with the results; many west facing sites experienced their greatest difference in temperature when comparing sun and shade loggers at 5:00 pm. However, extending the peak energy demand or On-Peak period to 7:00 pm and starting it a bit later in the day (for example 12:00 noon) may be beneficial as that is when temperatures between the two loggers (sun and shade) in the present study showed the greatest divergence in values. However, that said, to correctly identify TOU rates, all types of commercial usage of power must be evaluated, as TOU rates are not based solely on energy used for cooling.

One of the most important findings of this study was whether loggers situated in the shade of a tree or vines were significantly cooler than those positioned in the full sun. For all peak solar access periods the temperatures recorded by the shaded loggers were always cooler than those recorded in full sun; for most of the months investigated results were found to be statistically significantly cooler ($p \leq 0.05$). This is an indication that the tree or vine located at the site played an important role in preventing warming of the built structure and, by extension, acted to moderate the temperature in the proximate area. When comparing monthly values, the prime summer months (June, July, August, September) had significantly different values, especially at times when the sun was considered to be at its most intense (12:00 noon – 2:00 pm). During the summer of 2008, leaf-on periods started a little sooner, due mostly to warmer weather early in April. This explains why even in May, the temperatures recorded at the shaded loggers are still significantly cooler than those recorded at each paired sun logger.

3.3 Temperature Difference Analysis for Shade and Sun Loggers

To measure the value of a tree to shade a built surface and, therefore, to mitigate warming of the proximate microclimate, it was necessary to design a paired logger study where tree shading alone was the sole factor preventing a surface from warming. Temperature differences recorded at paired loggers situated in the shade and sun for each of the sites were investigated. In addition to plotting a mean temperature difference line, the standard error was calculated and a 95 % confidence envelope generated. The confidence envelope was developed to show that no matter where the mean temperature difference curve lies, as long as the envelope does not include zero, there is a statistically significant difference in mean temperatures between the loggers evaluated. The full six month analysis, including all logger pairs is found in Appendix B1.

For the east facing aspect there were two sites for comparison TCe and KCe. TCe was shaded by a Sugar Maple (*Acer saccharum*), whereas KCe received shading from Silver Maple (*Acer saccharinum*). The largest temperature differences recorded at TCe occurred in August with a mean difference of 6.3 °C (Figure 3.1); followed by July, June, September, May and October in sequential order of decreasing difference. The greatest variation in temperature occurred between 9:30 and 10:00 am for all the months except for October, where the greatest difference occurred at 9:00 am and was found to be 0.97 °C. Temperature differences were only significant for the middle of the day. The confidence envelopes include zero during the early morning and late evening hours (Appendix B1). It is also worth noting that in the early morning (pre-dawn) hours the sun logger was statistically significantly cooler than the shade logger. A possible explanation for this is that the tree provided a small dampening effect on wind, and therefore, provided a minor insolating role that mitigated heat loss from the built surface. Another explanation may be that trees can provide insulation, which may trap the heat in the surrounding area that is being re-radiated from the building and ground surfaces nearby.

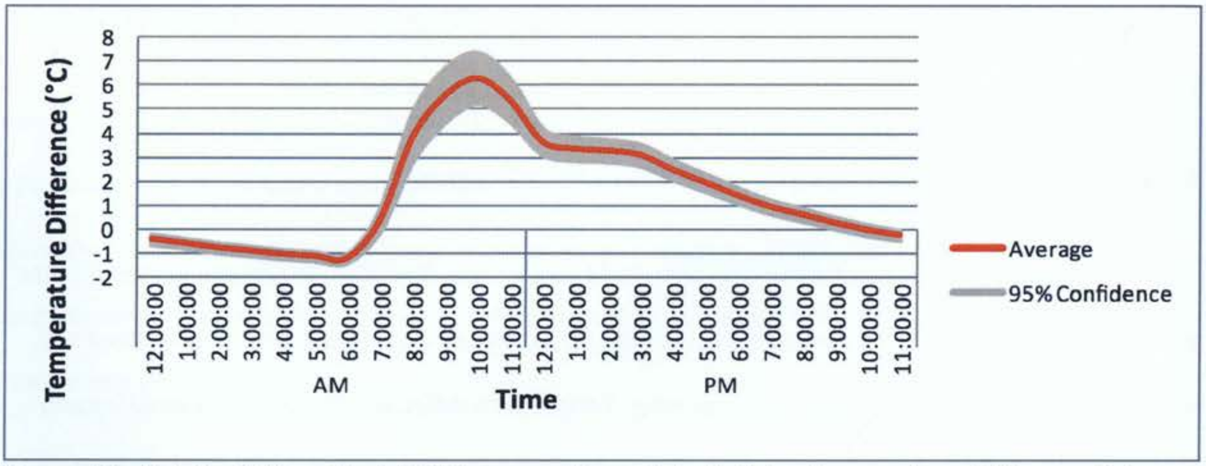

Figure 3.1: Trinity College East (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

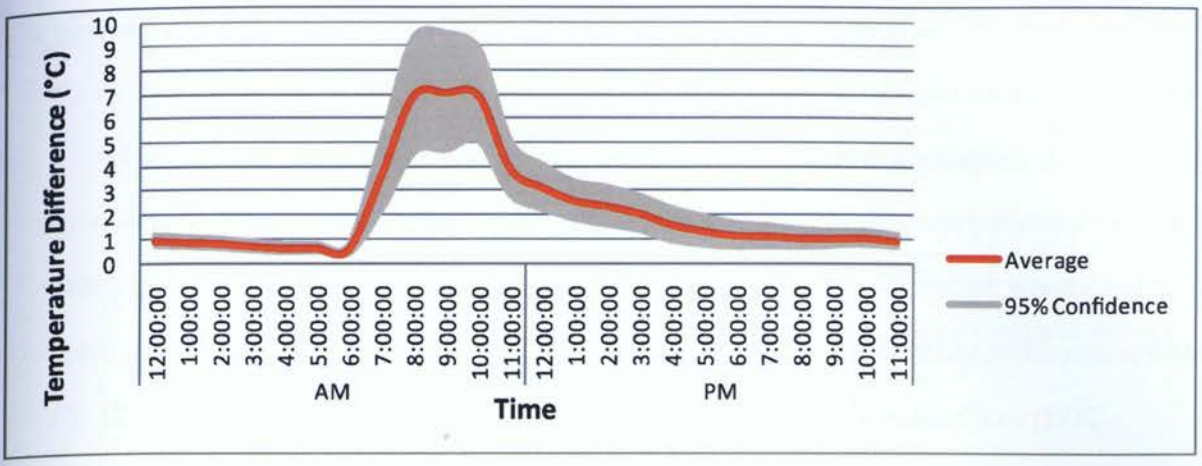

Figure 3.2: Knox College East (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

Similarly, KCe experienced its greatest difference between the two loggers in August with a temperature difference of 7.1 °C at 9:00 am (Figure 3.2). Unlike TCe, temperature difference values stay significantly above zero for June, July and August and only dip slightly below zero during May and September (Appendix B1). The month of October was omitted from the study, due to complications with on-site construction.

Overall, KCe was found to have a greater temperature difference than TCe; however, there was some change in this pattern during August when TCe was higher from 11:00 am to 6:00 pm and again in September from 1:00 pm to 5:00 pm. The greatest difference between the sites occurred in July, where at 9:00 am the temperature difference between the two loggers at KCe was 6.8 °C and at TCe was 4.1 °C, this represented a 2.7 °C difference between the two sites. This observed difference can be attributed to the tree's shading ability. The tree located at KCe was almost double in size when considering its canopy diameter, canopy height and tree height. In other words, a much greater portion of the built surface was shaded, thus preventing the warming of a larger area of built surface, even though KCe was 9.9 m from the built surface and TCe was only 3.5 m. The tree located at KCe also had a higher sh value (0.79) in comparison to TCe (0.67) which was interpreted to mean more solar energy was blocked from the building wall.

McPherson et al. (2006) states that the second most important building side on which to plant a tree is the east when considering the net impact of shading on energy savings. The present study was designed to investigate a greater number of south and west facing aspects because the bulk of the literature (including an earlier work by McPherson) suggests that trees situated south west or west of a building were of greatest importance concerning shading benefits (Heisler, 1986a; McPherson, 1984; McPherson, 1994; McPherson et al., 2006; Meier, 1991; Parker, 1983; Simpson & McPherson, 1996).

TC(1) was found to have its greatest temperature difference in October at 11:00 am (8.25 °C) (Figure 3.3). September, July, August, June, and May follow in order from the greatest to least temperature difference; this was found to mostly occur at noon, except for May, which like October had its greatest difference at 11:00 am. The months of May to August had a similar overall pattern in terms of temperature difference, while September and October had much larger variations between their sun and shade loggers. For most of the day TC(1) had significantly different values between both the sun and shade temperature measurements. Difference values dip below zero only between 7:30 and 8:00 am. Greater differences later on in the summer and early fall may be attributed to the shape of the tree crown and its position relative to the wall. The tree crown at TC(1) was not symmetrical over the trunk (slightly skewed to the side relative to the tree base); therefore, during earlier months (May through August) the angle of the sun may have reached the shade logger creating an 'imperfect' shading condition. However, later in the year when the sun's angle is lower, the tree crown position was observed to be more prominent in terms of shading.

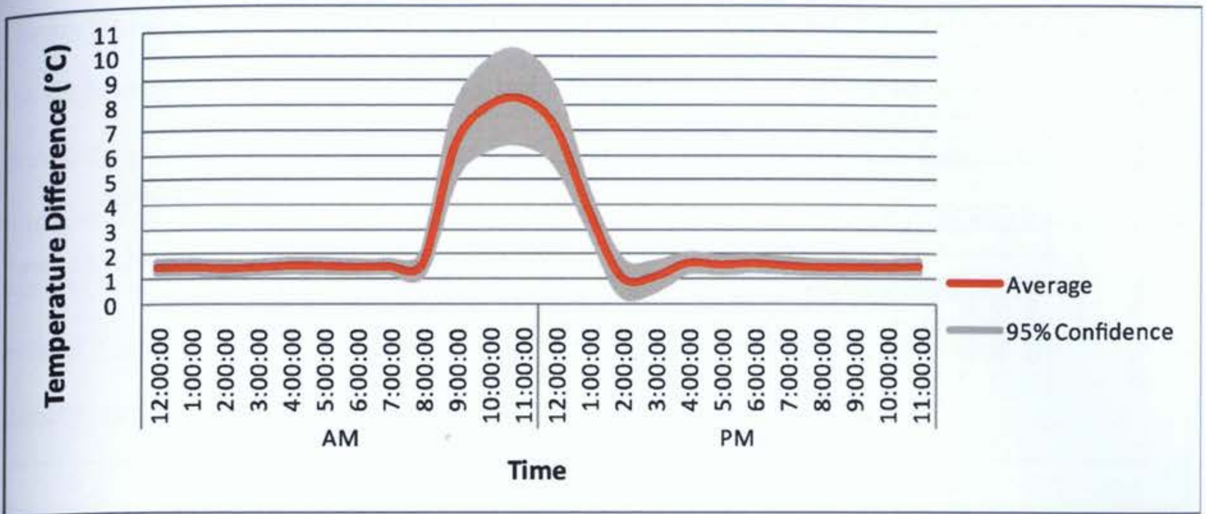

Figure 3.3: Trinity College South (1) (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008.

In comparison, to all other logger sites, TC(2) was first set up on August 18, 2008. This late inclusion in the study occurred because an extra logger became available and there was an interest in determining the shading potential of an English Oak (*Quercus robur* 'Fastigiata') growing to the south of the building. Specifically, this logger addition permitted comparison of the shading benefits of English Oak with the White Mulberry (*Morus alba)* also located at Trinity College TC(1). Largest to smallest temperature differences were recorded respectively in August (partial month data), October and September. August produced a difference of 8.9 °C (Figure 3.4), with September and October falling in between 7.1 and 7.2 °C. The temperature differences measured for this site were above 1 °C from 8:00 am to 3:00 pm during August and September (Appendix B1).

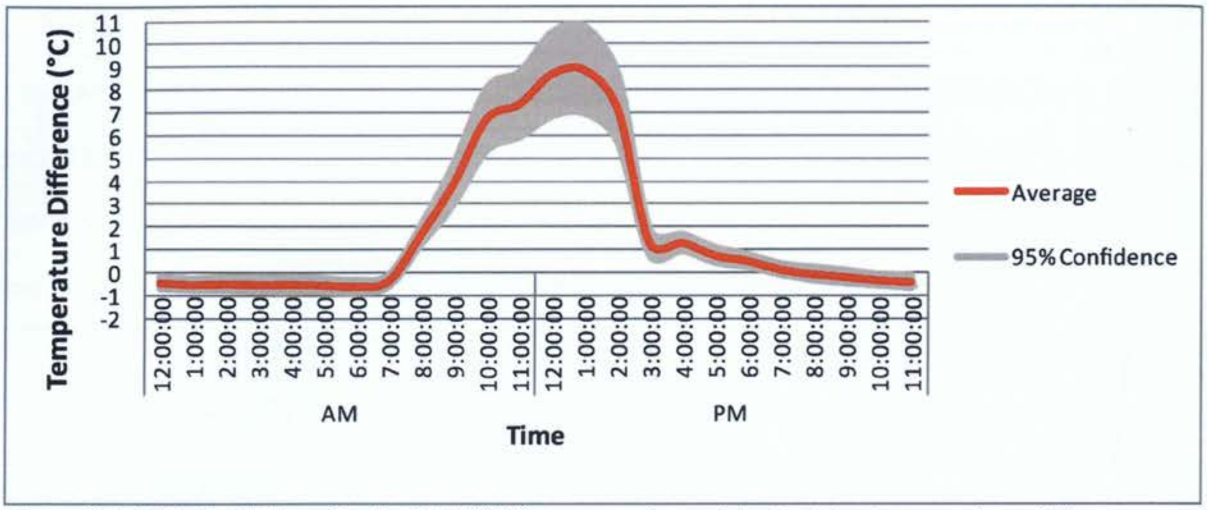

Figure 3.4: Trinity College South (2) (TC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

The differences found between TC(2) and TC(1) are attributable to tree distance from the wall and canopy shade. TC(1) was 11.3 m from the wall, whereas TC(2) was only 4.9 m. The closer distance allowed for less solar radiation to reach the temperature logger. In addition, there were two trees present at TC(2), with the second tree providing early morning shade; this acted to prevent the building surface from heating up during early morning hours.

The University College building had two pairs of loggers denoted by UC(1) and UC(2). Both sites were completely different in terms of tree species and distance from the wall. UC(1) was shaded by a Honey Locust (*Gleditsia triacanthos var. inermis*) and UC(2) was shaded by a European White Birch (*Betula pendula*). UC(1) was observed to have the greatest temperature difference in September, (7.0 °C at 1 pm), followed by August, July, October, June and May in sequential order of decreasing variation (Figure 3.5). The greatest sun-shade temperature difference for UC(2) was found to occur at 3:00 pm, where the variation was 3.1 °C for the month of August (Figure 3.6); recorded differences were similar for September and October. Temperature differences were mostly statistically significantly cooler for UC(1), as the 95 % confidence envelope only included zero early in the morning (Appendix B1). When considering UC(2), many of the difference values were found to be negative; an indication that at this time of the day the temperature at the shade logger was warmer than the sun logger (Appendix B1).

During the hours of 7:00 to 11:30 am, the sun logger at UC(2) was statistically significantly cooler than the shade logger. It is believed that this is largely due to the extended wall on University College that provided some shade to the area where the sun logger was placed early in the morning; in addition, the European White Birch was small in stature and located 10.4 m from the wall, leaving ample room for the sun's rays to reach the shade logger during the early mid-morning. As a typical day progressed, it was evident that the tree's shading benefits become more pronounced during the time period when the sun was directly south and south west (12:00 pm to 4:00 pm).

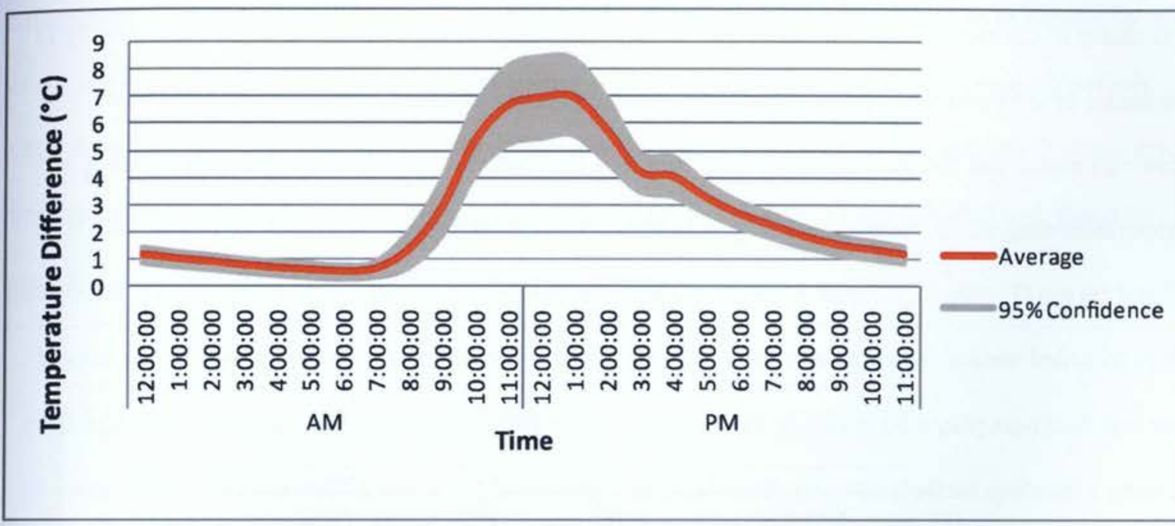

Figure 3.5: University College South (1) (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008.

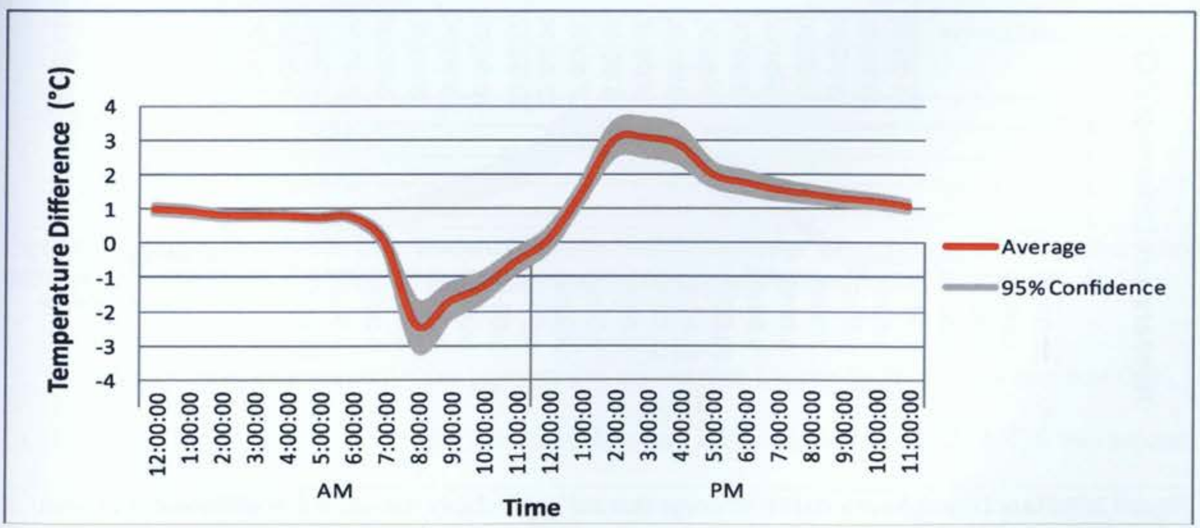

Figure 3.6: University College South (2) (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

The Hart House south location (HHs) is unlike the other sites discussed so far because temperature moderation was not provided by a tree or trees, but rather by vines. Many of the buildings on the UofT campus are covered by vines, mostly Boston Ivy (*Parthenocissus tricuspidata*). For the months of May, June and October, there were a large number of negative difference values, indicating that the sun logger was cooler than the shade logger. It is important to note here that during May and October, vines had very sparse leaf cover; therefore, both the loggers were likely receiving similar amounts of sun. This divergence from what might have been expected could be the result of the shade logger's position, which was closer to the east side of that wall, when compared to the sun logger that was positioned directly in the centre of the building. This position (unavoidable because of where vines were and were not growing) meant that the shade logger was getting sun first each day. When considering differences in temperature magnitude, August had the greatest (3.7 °C) at 2:00 pm, and May had the lowest with 0.57 °C at 2:00 pm (Figure 3.7). These results were lower than some of the other south facing sites, but overall vines recorded similar temperature difference values as those of the tree sites for the same aspect. Leaf size and thickness play a huge role in the amount of solar radiation that is absorbed and/or blocked from striking a building surface; this may provide some explanation for lower difference values on a typical day.

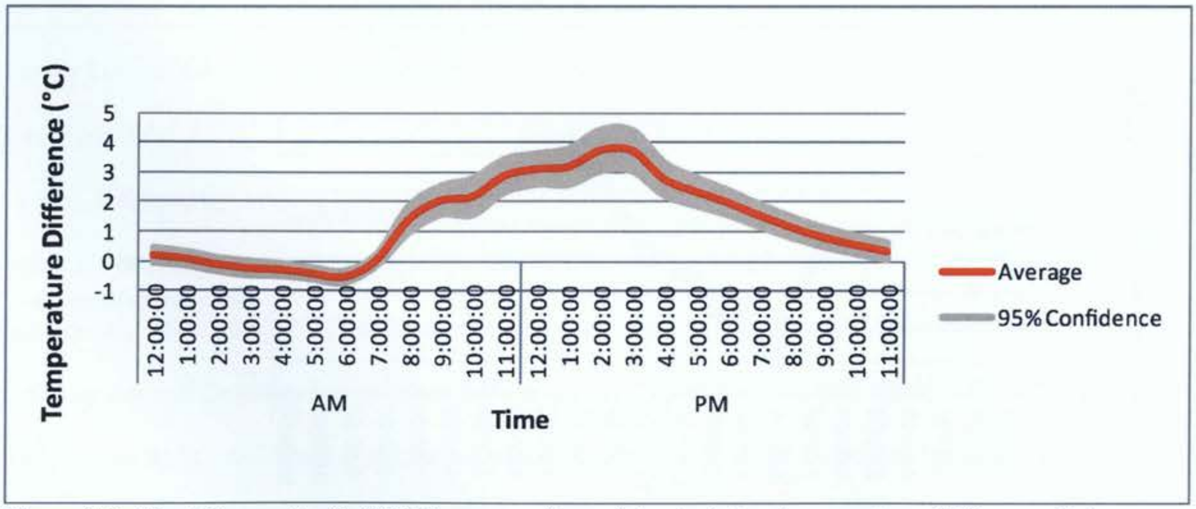

Figure 3.7: Hart House South (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

MCIS was also a unique site, as the shade logger received the benefits of tree shading across the entire day no matter the location of the sun in the sky; this situation arose because there was more than one tree in the surrounding area. The logger situated in the sun did, however, receive solar radiation for only a portion of the day; as the other trees in the surrounding area provided more shade than was present at any of the other south facing building sites investigated. Greatest to least differences in temperature between logger pairs occurred in September, with a difference of 6.4 °C (Figure 3.8) followed by August, October, July, June and May respectively. The temperature difference is statistically significantly different from approximately 10:00 am to 4:00 pm. This pattern was generally found to be similar for the six month period. There were some negative values during the early morning and late evening periods when there was little or no sun present. Again this may be due to insulation from wind that the trees are providing in the immediate area, or the fact that at those times both loggers were shaded and, therefore, recording more similar temperatures (Appendix B1).

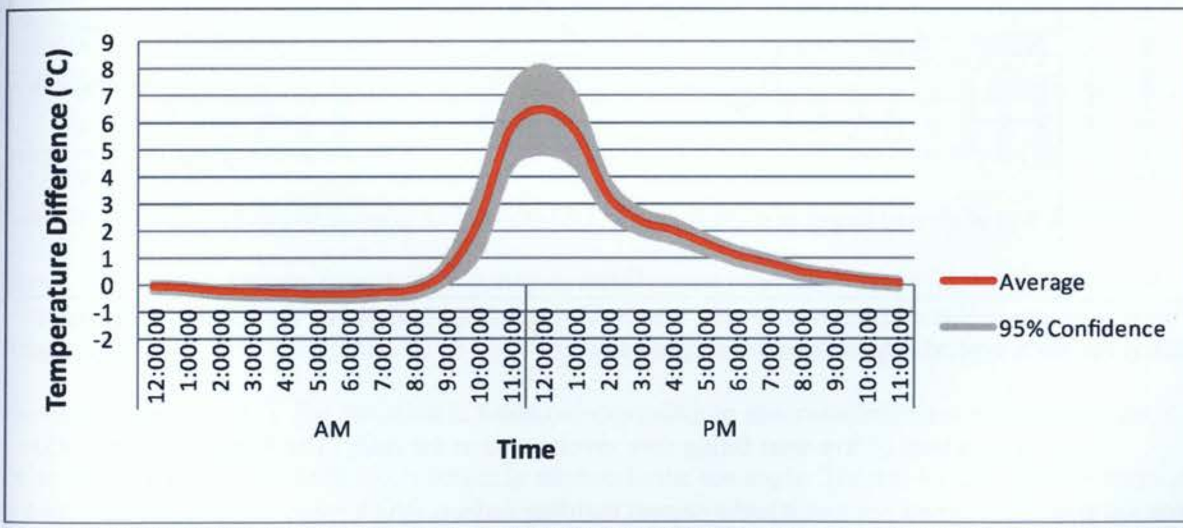

Figure 3.8: Munk Centre for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008.

When all south facing sites were compared to one another (Appendix B3), it was apparent that UC(1) had the greatest difference for the months of June and July, followed by MCIS. MCIS was second in terms of temperature difference and had its highest measured difference amongst all the sites in the month of May. UC(2) had the lowest difference amongst the sites, such that there was a 3 °C difference between the sites during June at 12:00 pm and 3.8 °C in July at the same time. In the months of August and September, once the new logger was placed at TC(2), it became the site with the greatest difference. For example, in August, the difference between the two loggers was 8.9 °C, while at UC(1) it was 6.8 °C at 1:00 pm which was a difference of 2.1 °C (Figure 3.9). The tree present at TC(2) was 4.9 m from the wall, whereas the tree present at UC(1) was 7.6 m. For the majority of the day TC(2) was in complete shade, while UC(1) received some sun early in the morning until about 10:30 am. The logger pair at HHs had smaller temperature differences than most of the other sites, indicating that vines may be less beneficial than trees when it comes to cooling on the southern side of buildings. A more in depth look at trees versus vines, from the perspective of shading is found in section 3.5.

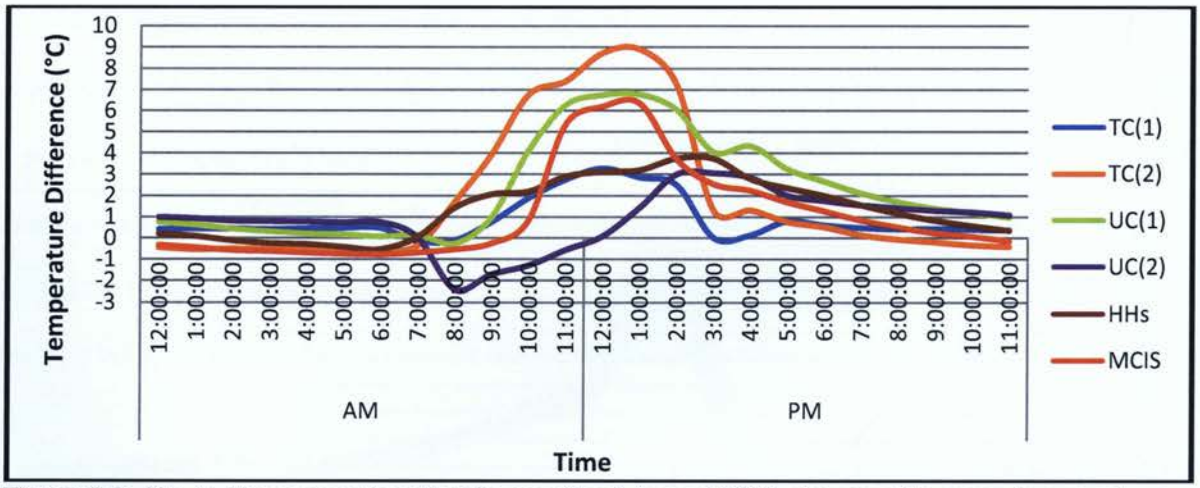

Figure 3.9: Site to Site comparison for the month of August 2008, showing the mean temperature difference for a typical day for south facing sites.

There were a total of five west facing sites investigated in the study. The Warren Stevens (WS) location was unlike others because it had a cement building surface, which meant that it most likely had a higher albedo (greater surface reflection of solar radiation), than the other buildings discussed thus far. In terms of temperature differences, August was the greatest having a peak variation of 5.0 °C on a typical day (Figure 3.10), followed by July, September, June, October and May in decreasing order of magnitude difference. The largest variability in temperature between the paired loggers occurred at 5:00 pm, except for the months of September and October, where it was recorded at 3:00 pm (Appendix B2). Overall, the

95 % confidence envelope only went below zero in the early morning and late evening, a pattern observed at other sites and something most likely attributable to moderation of heat loss by the tree.

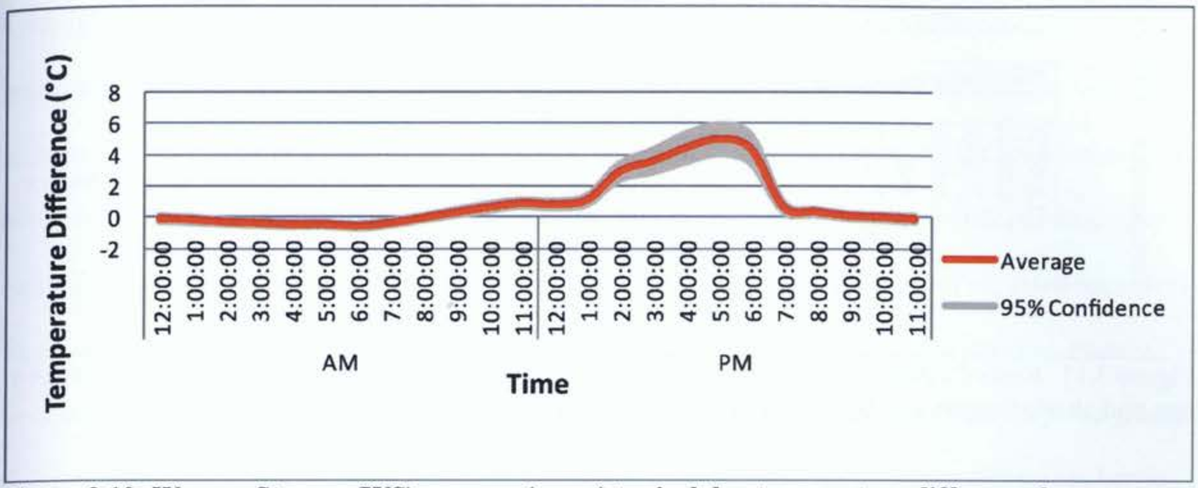

Figure 3.10: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

The Knox College location (KCw) had some variation in terms of the time when the greatest temperature difference was noted throughout the course of the study. For May, July and August it occurred at 6:00 pm with differences of 3.2, 3.9 and 5.6 °C respectively (Figure 3.11). In June the greatest temperature difference occurred at 5:00 pm (2.5 °C), in September it occurred at 3:00 pm (3.8 °C), and lastly in October it occurred as early as 2:00 pm (3.1 °C). October was found to only have a difference above 1°C between loggers from 1:00 to 2:00 pm, while for the other months considered it was a much longer interval (2:00 to 7:00 pm). The 95 % confidence envelope again drops below zero in the early morning (Appendix B1). The variation in times corresponding to observed differences in temperature is believed to be due to the shade tree's height in relation to the sun angle. The tree located at KCw was the tallest in the study (32.25 m) (Appendix A). It is interesting to note that the difference in temperatures for KCw decreased between 4:00 and 5:00 pm for most of the study. This may be due to logger positioning, as the sun logger is fairly close to the edge of the building wall, which may have caused it to experience cooler temperatures because of microwind patterns at the corner of the building, or perhaps related to other trees growing in relatively close proximity.

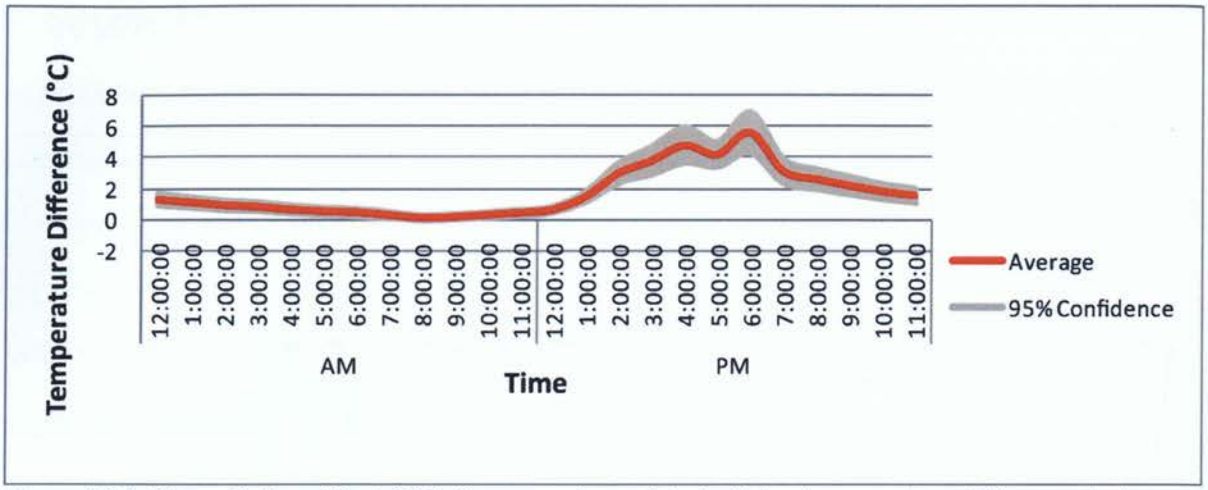

Figure 3.11: Knox College West (KCw) average(mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

University College Courtyard (UCC) was found to have a large difference between the sun and shade loggers for all six months (Appendix B2). The greatest differences were found for August (Figure 3.12), September, July, June, October and May with peak temperature variability on a typical day recorded at 11.7 °C, 8.7 °C, 7.7 °C, 6.0 °C, 5.8 °C, and 5.4° respectively (Appendix B2). Temperature differences were found to be above 1 °C from approximately 1:00 to 7:00 pm in the evening for every month except October, which had a temperature above 1 °C from 12:00 to 5:00 pm.

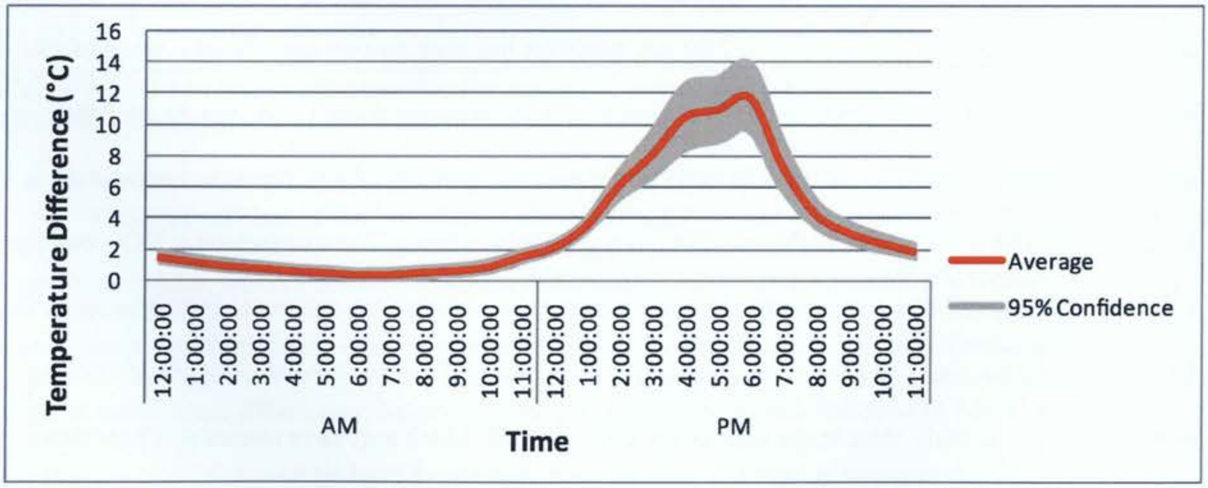

Figure 3.12: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008.

The mean and associated 95 % confidence envelopes were found to have greater oscillations over a typical day for the Gerstein Science Information Centre (GSIC) when compared with other sites investigated (Appendix B1); this site also experienced a decrease in temperature difference around 5:00 pm similar to that observed at KCw. In August and September the oscillations ceased to exist. This suggests that there may have been some obstruction to the sun logger, or conversely the shade logger may not have always been shaded. This, however, was not the case with KCw which experienced its greatest oscillation patterns during August and September. There was much variation (lack of expected sequence) found when comparing month-to-month temperature differences. From the largest to smallest, months were found to have the following sequence: August, September, July, October, June and May; the greatest difference was 6.0 °C and occurred in August at 5:00 pm (Figure 3.13). Temperature differences between the two loggers were above 1 °C from 2:00 to 8:00 pm from July to September. In contrast, temperature differences were only above 1 °C at 4:00 pm in May, while the rest remained close to zero or very slightly negative.

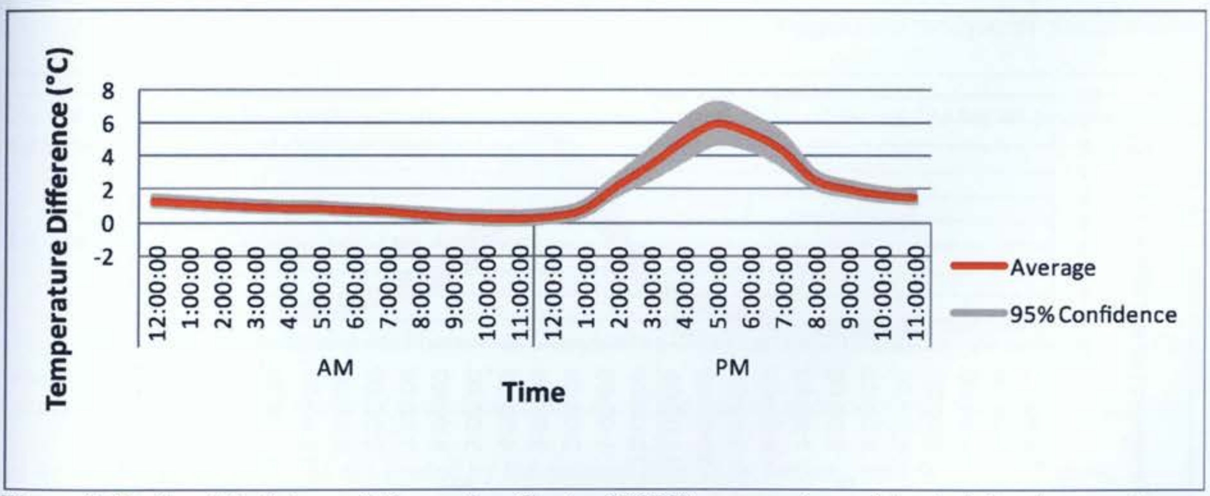

Figure 3.13: Gerstein Science Information Centre (GSIC) average (mean) typical day temperature difference between those values recorded from sun and shade loggers during the month of August 2008.

Hart House west (HHw), the second vine covered site, had fairly high temperature differences between the two loggers; this difference was found to remain relatively consistent for the six month duration except for May when it was only 3.4 °C (Appendix B2). This observed difference is likely an effect of the vines not being fully leafed out, a similar situation as was present for vines at HHs. When assessing the largest to smallest temperature differences on a month to month basis, October at 7.4 °C (3:00 pm) was found to exhibit the greatest (Figure 3.14). This was followed by September, July, August, June and May, in order of decreasing difference (Appendix B2). For the months of August, September and October, the temperature difference between the two loggers rose above 1 °C starting as early as 11:00 am and lasting until 2:00 am. In May, it was found to rise above 1 °C at 2:00 pm and stayed above zero (no difference) until 7:30 pm, while in June and July this difference (or greater) was recorded from 11:00 am to 11:00 pm. Overall, for a considerable portion of the day, the logger situated in the shade was cooler. The 95 % confidence envelopes revealed that from the months of June to October temperature difference values were mainly above zero indicating significant differences between the two loggers (i.e., the shaded logger was cooler than the sun logger). Examining the months as a whole, (Appendix B2), the typical day curves seem to have the same general pattern and shape, which indicates that vines provided consistency in terms of their ability to moderate wall temperatures, and by extension the proximate microclimate, throughout the summer months.

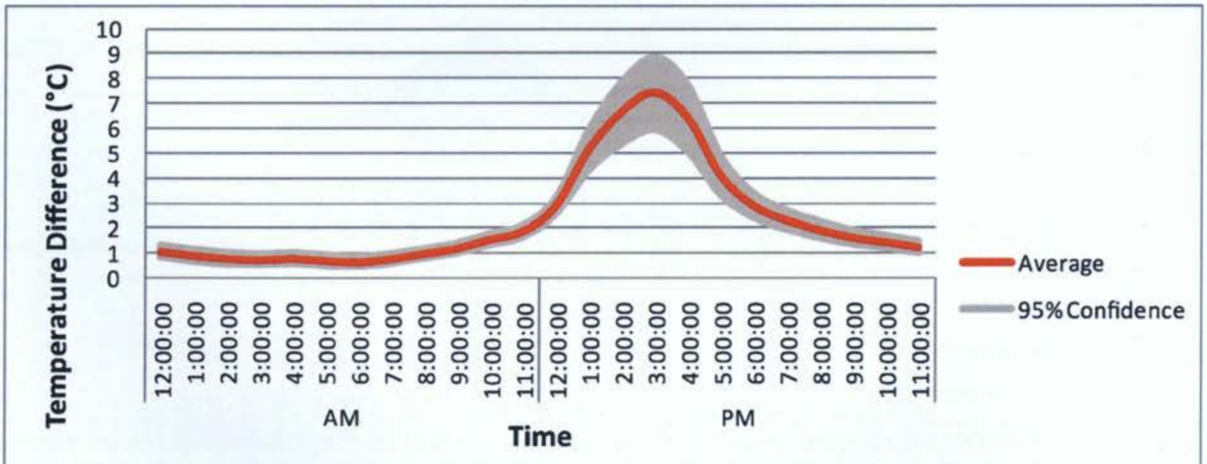

Figure 3.14: Hart House West (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008.

When considering all of the west facing sites, UCC had the greatest temperature difference followed by HHw, where HHw was found to surpass UCC during the month of October. The other sites, (WS, KCw and GSIC) were found to be relatively similar in their patterns of temperature difference, as they each had comparable LAI and sh values. This may indicate that the amount of sun reaching the built surface wall for each of these site locations was similar. The greatest difference amongst the sites took place in August at 6:00 pm where UCC was found to have an 11.7 °C temperature difference between the sun and shade logger. During the same month, the next largest difference occurred at HHw and was found to be 6.6 °C. The smallest difference in August was recorded at WS (4.3 °C), making it 7.4 °C less than UCC (Figure 3.15).

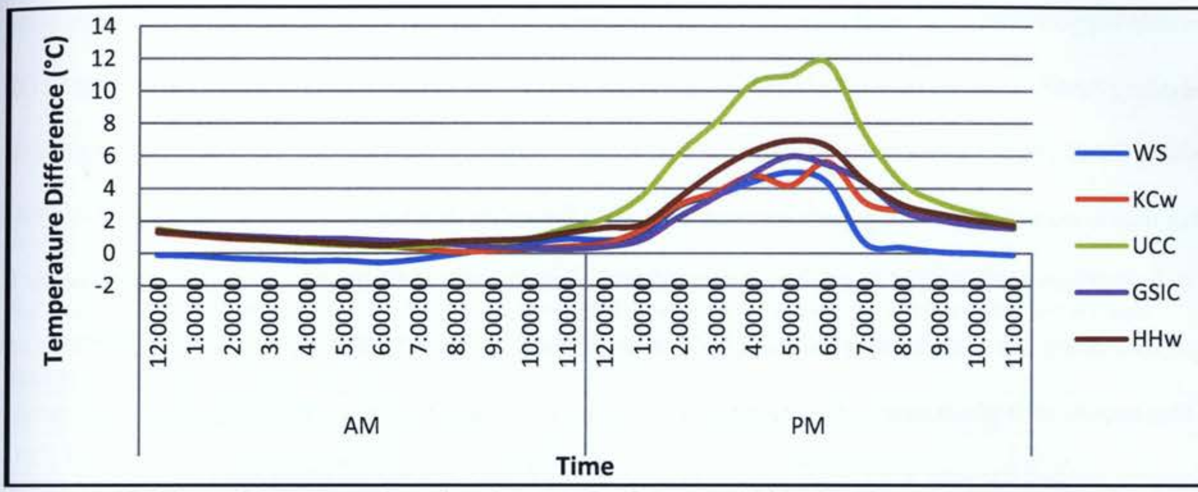

Figure 3.15: Site to Site comparison for the month of August 2008, showing the mean temperature difference for a typical day for west facing sites.

3.4 Multiple Tree Comparison and Analysis

Research conducted by McPherson & Dougherty (1989) reported that there was only a benefit to increasing the number of shade trees at a particular site if the second and additional tree(s) shade an area of the built structure that was not shaded by the original tree. They further noted that the two most important factors associated with energy savings were tree size and form; these characteristics largely influenced the amount of building area shaded (McPherson & Dougherty, 1989). In the present study, a statistical model was run using a 20 % random sample to test the applicability of the arguments made by McPherson & Dougherty (1989) to the University of Toronto location. To do this, temperatures recorded at loggers shaded by one tree were compared to those temperatures recorded at loggers shaded by multiple trees; this was conducted for each of the three aspects, and during each of the respective peak solar access periods.

SDWRe, an east facing site that had several shade trees present, was compared with TCe and KCe (each having one tree). Analyses were completed for each of the respective time periods (Appendix C1). Results indicate that there was not a statistically significant difference in temperature recorded for SDWRe when compared to either of the east facing sites with one tree present. Even though results were not statistically significantly different ($p > 0.05$) between the sites, there does appear to be a trend that would support the argument that increasing the number of well-positioned trees does provide greater shading benefit in terms of minimizing built surface warming (Appendix C2). The graphs presented in C2 show the difference between temperatures recorded for a typical day for the two shade loggers over the six month period; they were generated using data from the entire data set.

When SDWRe and TCe were compared, it can be seen that for the majority of the 24 hr time periods across the summer months (June, July, August and September), SDWRe was cooler than TCe. This mainly took place later in the evening and morning hours. Otherwise, values remained close to zero, confirming that the sites were fairly similar in their ability to cool the surrounding area. During July and August SDWRe was 1 °C cooler than TCe between 7:30 am and 8:30 am and 7:00 am to 9:00 am respectively. However, it is also important to note that the opposite occurred, where TCe was found to be more than 1 °C cooler than SDWRe; this typically occurred between 11:00 am and 12:00 pm. These results suggest that there was not much difference between the two sites, and hence an explanation as to why the mixed model may not have produced significant values (Table 3.3; Appendix C2).

Sun versus shade differences in temperature at SDWRe and KCe were found to be very similar. During the summer months the average temperature differences were close to zero, rarely going below minus 1 °C or above 1 °C suggesting that there was little variability in tree shading from one site to the next. SDWRe was only found to be cooler than KCe between 9:00 and 11:00 am; difference values were observed to go below zero (during the peak solar access period for this aspect) (Appendix C2).

SDWRe was cooler than both TCe and KCe during the time periods when the solar access was highest for this aspect (5:30 am to 11:30 am). This indicated that there was some shading benefit to having more than one tree at a site, but only at a time when the sun was at its strongest and only because more of the area was being shaded. The tree canopy difference between SDWRe and TCe was quite significant, such that the trees present at SDWRe had crown diameters more than three times that of TCe (Appendix A). It is important to note, however, that McPherson and Dougherty (1989) used standard tree size and distance when assessing the benefits of increasing the number of trees on a site. Results from the present study could not control for distance to building wall, tree species and canopy size. This inability to control site variables provided some explanation for the lack of statistically significant different shading impacts between sites (i.e., why findings from this study did not match those of McPherson and Dougherty (1989)).

Table 3.3: p-value results from the mixed model showing a comparison of shaded loggers located at the east facing aspect. Information is presented to determine whether the loggers shaded by one tree were significantly ($p \leq 0.05$) cooler than those shaded by multiple trees during the peak solar access period of 5:30 am to 11:30 am.

5:30 am – 11:30 am	May	June	July	August	September	October
KCe to SDWR	0.411	0.8994	0.7142	0.9585	0.325	
SDWR to TCe	0.4612	0.8296	0.5812	0.8504	0.8584	0.6566

Similar to the east facing sites described in Table 3.3, the south facing site, MCIS, was investigated to determine whether multiple trees provided constant shade through the day. This site was compared to all the other temperature loggers situated in the shade for that same aspect. The mixed model again used a 20 % random sample when comparing the temperature recordings for both shade loggers. Values for MCIS were found to be much cooler than at other sites, especially for UC(2) and HHs. This was both evident in the output from the statistical tests (Table 3.4), as well as the multiple graphical outputs (Appendix C2). On a month-by-month basis, the difference between the temperatures recorded at the shade MCIS logger and those recorded at shade loggers with individual trees increased. As early as June, temperature differences between MCIS and the other south facing logger locations were found to be cooler by a difference of 1 °C, mainly from 9:00 am to 6:00 pm. For example, the difference between

MCIS and TC(1) peaked at 5.7 °C in the month of August, with regular difference values observed as high as 5 °C from 10:00 am to 2:00 pm. The patterns of differences were similar for comparisons between MCIS and UC(1), but not quite as pronounced in magnitude, reaching as high as 3.7 °C, 3.5 °C and 3.9 °C during the months of August, September and October respectively. However, there was a difference between MCIS and UC(1) of at least 1 °C for a large portion of the day.

Table 3.4: p-value results from the mixed model showing a comparison of shaded loggers located at the south facing aspect. Information is presented to determine whether the loggers shaded by one tree were significantly ($p \leq 0.05$) cooler than those shaded by multiple trees during the peak solar access period of 11:00 am to 4:00 pm.

5:30 am – 11:30 am	May	June	July	August	September	October
TC(1) to MCIS	0.9999	0.9994	0.7906	0.3868	0.9766	0.9989
UC(1) to MCIS	0.9968	0.9999	0.9663	0.8563	0.8895	0.932
UC(2) to MCIS	0.6719	0.5819	**0.03**	**0.0038**	**0.0116**	0.3095
MCIS to TC(2)				0.9971	0.9633	0.9984
MCIS to HHs	0.3804	0.8501	0.4362	0.196	0.0797	**0.0322**

11:00 am – 4:00 pm	May	June	July	August	September	October
TC(1) to MCIS	0.9895	0.9059	**0.0012**	**<0.0001**	0.155	0.9999
UC(1) to MCIS	0.9221	0.9919	0.3533	0.1438	0.4705	0.6768
UC(2) to MCIS	0.2015	0.358	**<0.0001**	**<0.0001**	**<0.0001**	0.0904
MCIS to TC(2)				0.4949	0.6344	0.9244
MCIS to HHs	0.3639	0.8933	**0.0371**	**0.0007**	**0.0132**	**0.0339**

- **Bold figures are significant p-value ≤ 0.05.**
- **Indicates significantly warmer**
- **Indicates significantly cooler**

UC(2) showed the greatest difference in temperature when it was compared to MCIS. This was evident in both the mixed model output and mean difference graphs (Table 3.4 & Appendix C2). Differences in temperature were statistically significant for the months of July, August and September. During August there was a difference of 8.9 °C at 11:00 am, and consistent values above 8 °C from 10:00 am to 12:00 pm. This pattern was similar to the one found for September, which had a maximum difference of 8.7 °C, and values above 8°C from 10:00 am to 12:00 pm.

HHs had negative values 24 hrs a day for every month but June, which indicated that temperatures recorded from the shade logger at MCIS were cooler. September showed the greatest difference peaking at 6.1 °C (11:00 am), and had differences of at least 5 °C from 10:00 am to 1:00 pm. These findings suggest that multiple shade trees provide better cooling than vines when considering south facing aspects. HHs was also found to be significantly warmer in July, August, September and October during the peak solar access period for this aspect (11:00 am to 4:00 pm). Unexpectedly, MCIS was always cooler than TC(2) during the three months of comparison. This was surprising because when inspecting graphs that compare site-to-site (Appendix B3), it appeared that TC(2) showed the greatest difference in temperature between sun and shade loggers. Further analysis revealed that the temperature difference between the two shade loggers was attributable to MCIS recording temperatures lower than those at TC(2).

A west facing site with multiple trees was also located at SDWR. Only one of the site-to-site comparisons was found to be statistically significantly different (Table 3.5). Corresponding tables and graphs in Appendix C1 and C2 further support this statement. Most values reported in the 'typical day' graphs were slightly positive and/or close to zero (Appendix C2); this indicated that SDWRw was not recording temperatures much different from other shade loggers at that aspect. Nothing greater than a 3 °C difference was observed. Most of the negative values (times where SDWRw was cooler than its respective comparator) occurred with HHw and GSIC. Results for the vine site (HHw) were somewhat similar to those for south facing aspect, but less pronounced; negative values were found only during the night and early in the morning. It was interesting to observe the difference between GSIC and SDWRw as both were shaded by London Plane, and both were roughly 5 m from the building wall. Crown shape and size for the tree located at SDWRw and at GSIC were quite different, as well as the shading coefficient (sh). GSIC was smaller in stature and had a lower sh value, which was one explanation why SDWRw was cooler, as well as the fact that it was shaded by more than one tree.

Table 3.5: p-value results from the mixed model showing a comparison of shaded loggers located at the west facing aspect. Information is presented to determine whether the loggers shaded by one tree were significantly ($p \leq 0.05$) cooler than those shaded by multiple trees during the peak solar access period of 3:00 pm to 8:00 pm.

3:00 pm - 8:00 pm	May	June	July	August	September	October
SDWRw to HHw	0.6153	0.9993	0.7276	1	0.9989	0.9893
SDWRw to UCC	0.9764	0.8723	**0.0039**	0.6268	0.6847	0.9208
SDWRw to WS	0.9999	0.9681	0.222	0.7894	0.8207	0.9169
SDWRw to KCw	0.9845	0.9834	0.2131	0.9802	0.999	1
SDWRw to GSIC	0.9992	1	0.7405	0.9534	0.9998	0.9988

- **Bold figures are significant p-value ≤ 0.05.**
- **Indicates significantly warmer**
- **Indicates significantly cooler**

The results presented concerning the value of multiple shade trees (and vines) at different aspects are mixed. Findings suggest that there may have been some benefit to having more than one tree shading a building surface during the peak solar access period; this was especially relevant for trees growing to the south of a building. However, at each of the sites this research could not control for shade tree distance from the building, species, tree size, or canopy form. Therefore, results must be considered site-specific and should not be extrapolated to all situations. Findings, however, did point clearly to the fact that shading benefits increase when trees are much closer to a building, such that the edge of the canopy touches the surface; a situation found at MCIS. The trees providing shade at MCIS were the same species, very similar in size, and distance from the wall - comparable to the experimental setup described in McPherson and Dougherty (1989). The present research indicates that tree placement and species selection are of great importance to achieving consistent shading benefits. Planting various species at assorted distances from a building will not guarantee uniform shading.

3.5 Comparison of Trees with Vines for Temperature Moderation

Growing space for trees within a city is severely limited, especially that which is necessary to meet the requirements of large growing shade trees. Therefore, it was important in this study to investigate whether vines could play a similar role to shade trees – reduce warming of built surfaces and thereby keep the urban microclimate cooler. If this were true, it could be an important method of achieving shading benefits where planting space was minimal. In order to examine this, another mixed model was run (20 % random sample) to investigate whether or not the temperature differences recorded at the shade loggers located at the vines sites (HHs and HHw) were significantly different than differences recorded by shade loggers at each of the tree sites with the same aspect. Both vine sites were covered in Boston Ivy (*Parthenocissus tricuspidata*).

Results of the comparison are found in Tables 3.6 and 3.7, which are split into the three peak solar access time periods.

HHs was determined to not be statistically significantly cooler than any of the other south facing treed sites. There were, however, statistically significant differences for the other site-to-site comparisons (Appendix D). In terms of HHs versus the other sites, it was found to be cooler than UC(2). There was only one value that was found to represent a statistically significant difference, which is for the month of July between 11:00 am and 4:00 pm ($p = 0.0112$) (Table 3.6). When assessing the warming and cooling trend at HHs, it was determined only to be cooler than UC(2) and TC(1) (Appendix D). Therefore, it can be argued that vines growing at HHs provided similar benefits (prevented warming of a built surface) when compared to those recorded by most shade tree sites for the same aspect (south).

Table 3.6: p-value results from the mixed model showing a comparison of shaded loggers located at the south facing aspect. Information is presented to determine whether the loggers shaded by vines were significantly ($p \leq 0.05$) cooler than those shaded by trees during the respective peak solar access period (5:30 am to 11:30 am, 11:00 am to 4:00 pm, and 3:00 pm to 8:00 pm).

5:30 am – 11:30 am	May	June	July	August	September	Octobe
TC(1) to HHs	0.3087	0.9329	0.9778	0.9988	0.3528	**0**
UC(1) to HHs	0.5923	0.9133	0.8265	0.8495	0.5624	0.
UC(2) to HHs	0.9895	0.9895	0.6972	0.6883	0.9807	0
MCIS to HHs	0.3804	0.8501	0.4362	0.196	0.0797	0.
TC(2) to HHs				0.7595	0.3999	0.

11:00 am – 4:00 pm	May	June	July	August	September	Octobe
TC(1)to HHs	0.6499	1	0.7938	0.8866	0.9236	0.
UC(1) to HHs	0.8457	0.9898	0.8281	0.4717	0.5864	0.
UC(2) to HHs	0.9966	0.8678	**0.0112**	0.0526	0.6475	0.
MCIS to HHs	0.3639	0.8933	0.0371	**0.0007**	**0.0132**	**0.**
TC(2) to HHs				0.6264	0.4246	0.

3:00 pm – 8:00 pm	May	June	July	August	September	Octobe
TC(1) to HHs	0.7638	1	0.8312	0.9952	1	0.
UC(1) to HHs	0.8905	0.999	0.9947	1	1	0.8
UC(2) to HHs	0.9448	0.9966	0.6578	0.987	0.9984	0.8
MCIS to HHs	0.809	0.9947	0.6648	0.5803	0.7124	0.
TC(2) to HHs				0.9986	1	0.

- **Bold figures are significant p-value ≤ 0.05.**
- **Indicates significantly warmer**
- **Indicates significantly cooler**

Unlike HHs, HHw was not found to be statistically significantly cooler or warmer than west facing sites with a shade tree (Table 3.7). However, this does not mean that HHw was less cool than other sites. The temperature difference graphs for a typical day during the months investigated (See Appendix B3) showed evidence that HHw had a greater variation in temperature between its sun and shade logger than did most treed sites; UCC was an exception.

A visual assessment of the warming and cooling trends at HHw (Appendix D) revealed that this site appeared to be warmer than most of the other west facing sites; but differences were not statistically significant ($p \leq 0.05$).

Table 3.7: p-value results from mixed model showing a comparison of shaded loggers located at the west facing aspect. Information is presented to determine whether the loggers shaded by vines were significantly ($p \leq 0.05$) cooler than those shaded by trees during the respective peak solar access period (5:30 am to 11:30 am, 11:00 am to 4:00 pm, and 3:00 pm to 8:00 pm).

5:30 am - 11:30 am	May	June	July	August	September	October
SDWRw to HHw	0.797	0.9997	0.9998	0.9989	0.9991	0.999
HHw to UCC	0.6262	0.994	0.9729	0.9889	1	1
HHw to WS	0.5695	0.9865	0.9113	0.9674	1	1
HHw to KCw	0.6579	0.9988	0.9967	0.9984	1	1
HHw to GSIC	0.8876	0.9999	0.995	0.9953	0.9999	0.9991

11:00 am – 4:00 pm	May	June	July	August	September	October
SDWRw to HHw	0.8154	1	0.9876	1	0.9977	0.9892
HHw to UCC	0.5698	0.9998	0.9969	0.9627	0.9999	1
HHw to WS	0.7678	1	1	0.9949	1	1
HHw to KCw	0.651	1	0.9988	1	0.9992	1
HHw to GSIC	0.8524	1	1	0.9789	1	0.9994

3:00 pm – 8:00 pm	May	June	July	August	September	October
SDWRw to HHw	0.6153	0.9993	0.7276	1	0.9989	0.9893
HHw to UCC	0.2004	0.9722	0.203	0.7567	0.9508	0.999
HHw to WS	0.4751	0.9978	0.9585	0.8796	0.9845	0.9989
HHw to KCw	0.2281	0.9995	0.9541	0.9929	1	0.9962
HHw to GSIC	0.8273	0.9999	1	0.9802	1	0.9999

Even though the mixed model output did not reveal a significant difference in temperature values, based upon the 'typical day' mean difference graphs, it was evident that vines were providing similar benefits to shade trees, which represents an important contribution to temperature moderation in the urban microclimate. A lack of statistical significance may be due to the present study's minimal replication of vine sites (i.e., only one vine site in each analysis to compare treed sites). Results showing that west facing vines were not statistically significantly cooler, in contrast to some of the comparisons for south facing vines, should not be considered an indication that vines provided greater benefits on south facing walls. Maximum temperatures recorded at west facing sites were higher than those recorded for south facing sites, and showed evidence of less between-site variability; this may indicate why p-values generated from the model were not significant. Overall vines were not found to provide significantly more shading benefit than trees, but results point toward their providing comparable benefit concerning the mitigation of built surface warming. This is profound in its implications for strategic placement of vegetation within an urban landscape. Where it is not possible to grow a sizable shade tree (limited space and soil volume), vines represent a similarly beneficial alternative.

3.6 Energy and Cooling Benefits of Trees

The Tree Benefits Estimator (SMUD, 2009) produced direct shading annual kWhs saved, indirect cooling benefits of trees (mostly through evapotranspiration), lifetime CO_2 sequestration for each of the trees in this study (Table 3.8). The City of Toronto's current electricity rate (12.04 cents / kWh charged) was used as an input for the Tree Benefits Estimator. Model outputs revealed that trees with the highest annual kWh savings were growing at sites KCw (200 kWh / yr), UCC (133 kWh / yr), GSIC (129 kWh / yr), and SDWRw (105 kWh / yr). In all cases, trees with the minimal direct shading benefits, as determined by the Tree Benefits Estimator, were those growing farthest from a building: (UC(2) and SDWRe (1)), followed by TCe. For TCe, estimates of electricity savings were largely attributed to the size of tree rather than its distance from the building surface. When comparing species, especially where the species occurred at more than one site location, none were found to have similar estimated energy savings. For example, a Honey Locust (*Gleditsia triacanthos var. inermis*) was located at both WS and at UC(1); however, estimated energy savings at WS were almost double that of UC(1), (68 kWh / yr and 33 kWh / yr respectively). This was the result of the Tree Benefits Estimator prioritizing west over south aspect and closer proximity to a building (UC(1) 7.6 m south of building, WS 4.1 m west of building). Overall, aspect seemed to have a large influence on the model results, as west facing sites consistently showed greater electrical savings. The results of the present study (measured temperature differences between sun and shade) show a strong positive relationship with the Tree Benefits Estimator output, especially concerning larger temperature differences that were found to exist between sun and shade loggers at west facing sites.

Table 3.8: Results from the Tree Benefits Estimator using Toronto Hydro's current electricity rate of 12.04 cents / kWh

Pair Number	Campus Location	Common Name	Latin Name	Direct Shading Annual kWh Saved	Total Summer Cooling Benefits	Stored CO_2 kg (Current age)
1	Trinity College [Tce]	Sugar Maple	*Acer saccharum*	23	$5	174
2	Knox College [Kce]	Silver Maple	*Acer saccharinum*	35	$8	1371
3	Trinity College [TC(1)]	White Mulberry	*Morus alba*	0	$0	1545
4	Trinity College [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	37	$8	1204
	Trinity College [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	72	$16	1286
5	University College [UC(1)]	Honey Locust	*Gleditsia triacanthos var. inermis*	33	$7	969
6	University College [UC(2)]	European White Birch	*Betula pendula*	0	$0	137
7	Hart House [HHs]	Boston Ivy	*Parthenocissus tricuspidata*			
8	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	59	$13	1082
	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	54	$12	907
9	Warren Stevens [WS]	Honey Locust	*Gleditsia triacanthos var. inermis*	68	$15	560
10	Knox College [KCw]	Silver Maple	*Acer saccharinum*	200	$43	3565
11	University College Courtyard [UCC]	Green Ash	*Fraxinus pennsylvanica var. lanceolata*	133	$29	1726
12	Gerstein Science Information Center [GSIC]	London Plane	*Platanus x acerifolia*	129	$28	1635
13	Hart House [HHw]	Boston Ivy	*Parthenocissus tricuspidata*			
N/A	Sir Daniel Wilson Residence [SDWRe]	Siberian Elm	*Ulmus pumila*	N/A	N/A	3565
N/A	Sir Daniel Wilson Residence [SDWRe]	London Plane	*Platanus x acerifolia*	37	$8	1545
N/A	Sir Daniel Wilson Residence [SDWRw]	London Plane	*Platanus x acerifolia*	105	$23	1286
N/A	Sir Daniel Wilson Residence [SDWRw]	London Plane	*Platanus x acerifolia*	88	$19	895

Total summer cooling benefits (measured as $ saved) varied with the rate charge for electricity (kWh). The highest cooling benefits were associated with KCw, UCC, GSIC and SDWRw (both trees). For the current rate (Table 3.8), the highest benefits were $43 for the tree at KCw and $29 for the tree located at UCC. Both of these trees were larger in stature compared with other trees growing at the study location; in general, it was found that larger trees were estimated to provide greater overall electrical savings, especially when situated to the west of a building. The Tree Benefits Estimator was designed as a simple tool for providing general estimates of shading benefit; it was designed around an 'average' tree and its associated growth characteristics that were compiled by SMUD and subsequently endorsed by the USDA Forest Services. Therefore, benefits estimated for each of the specific trees examined in the study should be considered just that, estimates; they are recommended as complementary information that may be used in landscape planning with the aforementioned caveat.

Another important component of the present study was to illustrate the importance of mature trees. Examining CO_2 sequestered (kg at its current state) of each of the tree species found in the study was useful in exemplifying the benefits associated with mature trees in urban landscapes. CO_2 sequestered ranged among tree species, and was found to be largely influenced by size, which is correlated with age. Larger trees had an enhanced ability to sequester CO_2: this was, however, dependent on the biomass and growth rate of the tree species. For example, the Silver Maple (*Acer saccharinum*) located at KCw had a DBH of 104 cm and was estimated to have sequestered 3565 kg of CO_2 in its lifetime compared to the Sugar Maple (*Acer saccharum*) with a 20 cm DBH located at TCe (174 kg of sequestered CO_2 in its lifetime up until now).

The values for sequestered CO_2 (Table 3.9) indicate the importance of mature trees in an urban landscape. Large stature trees provide the greatest collective benefit to a city. Those species growing to maturity will sequester much more CO_2 when compared with smaller stature trees or those that must be replaced on a semi-regular basis (street trees). Summer cooling benefits clearly increase with larger trees, which will be of even greater benefit (economically) when the City of Toronto commences TOU billing. Both Mid-peak and On-peak rates will be greater than the current rate, and encompass 15 hrs of the day;

as electricity rates rise over time, the dollar value of shade trees will also increase. Ensuring proper tree selection and placement, as well as regular maintenance, will assist greatly in helping trees reach maturity within the urban environment. Therefore, management strategies to provide adequate growing space and encourage strategic selection, placement, and care of trees are required to leverage this natural resource for the purpose of energy conservation.

Table 3.9: DBH Classes with their respective CO_2 Sequestration measurments (Values taken from SMUD Tree Benefits Estimator)

DBH Class (cm)	Stored CO_2 kg (Current Age)
35 - 50	800 - 1100
51 - 60	1101 - 1400
61 - 75	1401 - 1750
76 +	1750 +

3.7 Siting and Management of Trees

Strategic placement and proper management of trees are crucial when it comes to utilizing a tree's full shading potential within the built urban environment. Identifying the optimal location to place a tree in order to maximize its benefits is conducted through in-depth analyses that include assessing the growing medium for sustainability (e.g., soil volume and quality), identifying potential conflicts (e.g., overhead wires), and planning the orientation with respect to the building. Active management of urban trees is important, as many of their environmental services increase with proper care and their ability to attain mature stature. Findings of this study that included examination and comparison of the shading benefits determined through paired sampling locations may be used to assist in the selection of optimal planting locations that could greatly benefit the future management of urban landscapes.

Shade tree locations that were found to be the most beneficial at preventing the warming of built surfaces were those where the tree was growing 5 to 10 m from the building wall (i.e., measured for UCC and UC(1)). In the cases of TC(1) and UC(2), both had trees shading the wall that were greater than 10 m away. Results confirmed that this distance was too far from the building to provide measurable shading benefits. It was also found that trees growing closer to the walls did not always provide shading for a longer duration throughout the day. Site locations that included MCIS, WS, TC(2), and, TCe showed that the temperatures recorded at the shaded logger were not significantly cooler than the sun logger for an extended portion of the day, when compared to other site locations (Appendix B1). Research conducted by Heisler (1986b) concluded that trees growing on the south side of buildings do not block much sun during mid-summer (time of greatest solar elevation) unless they are within a few meters of the building, or overhang the roof. These findings were in agreement with the results in this study; for example, comparison of MCIS and TC(2) revealed the largest difference between temperatures recorded from sun and shade loggers. UC(1) was one location that showed a greater difference between the two loggers, but whose shade tree was growing 7.6 m from the wall. Its canopy, however, did come very close to the built surface, which blocked much of the solar access to the building surface.

In this research the greatest differences between temperatures recorded between sun and shade loggers occurred at sites where trees shaded the west facing building walls; this was followed by trees shading south and east walls respectively. These results are immediately relevant to landscape planning concerning optimal placement of new trees, as well as to the management prioritization of existing trees. Shading east facing walls, however, does prevent warming in the general vicinity (microclimate around the building), and may keep temperatures lower throughout the day (McPherson et al., 2006). Findings of this research show that sun loggers located on east facing sites recorded temperatures warmer than west facing sites until approximately 4:00 pm. Mitigating warming of built surfaces early in the day may assist in reducing energy consumption as temperatures rise to their maximum in early to mid-afternoon.

Average values for temperature differences between sun and shade loggers at each of the sites, for the respective peak solar access period to which they correspond are represented in Figures 3.16, 3.17, and 3.18.

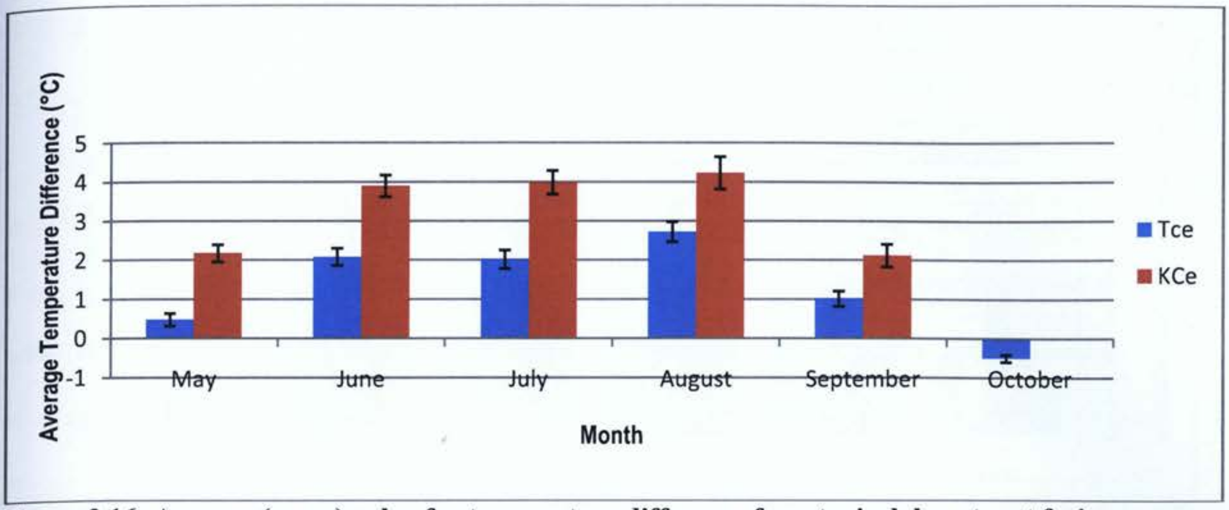

Figure 3.16: Average (mean) value for temperature difference for a typical day at east facing building sites (TCe and KCe) during the peak solar access period of 5:30 am to 11:30 am from May 1, 2008 to October 31, 2008. Error bars represent one standard error.

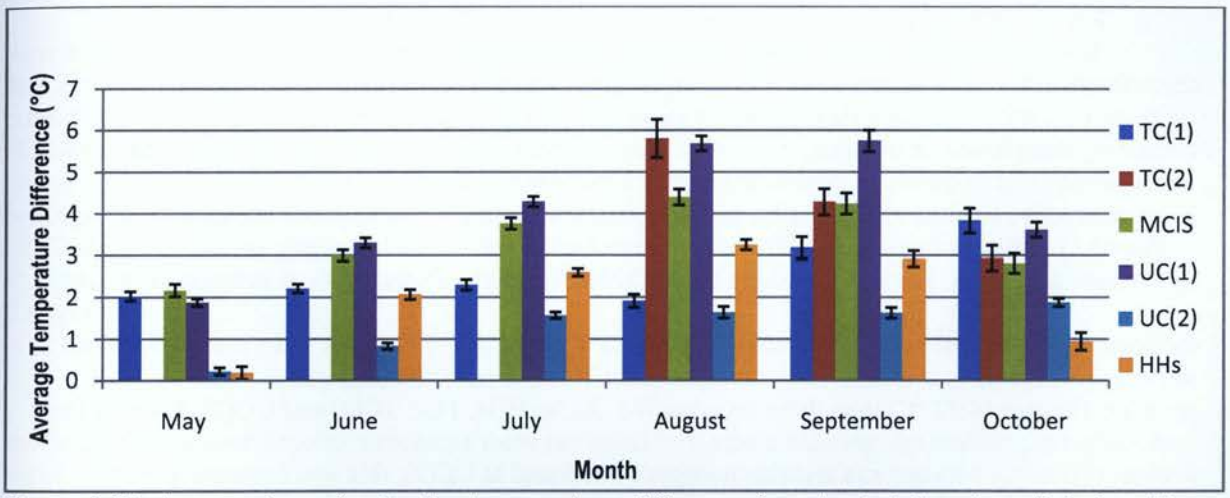

Figure 3.17: Average (mean) value for temperature difference for a typical day at south facing sites (TC(1), TC(2), MCIS, UC(1), UC(2) and HHs) during the peak solar access period of 11:00 am to 4:00 pm from May 1, 2008 to October 31, 2008. Error bars represent one standard error.

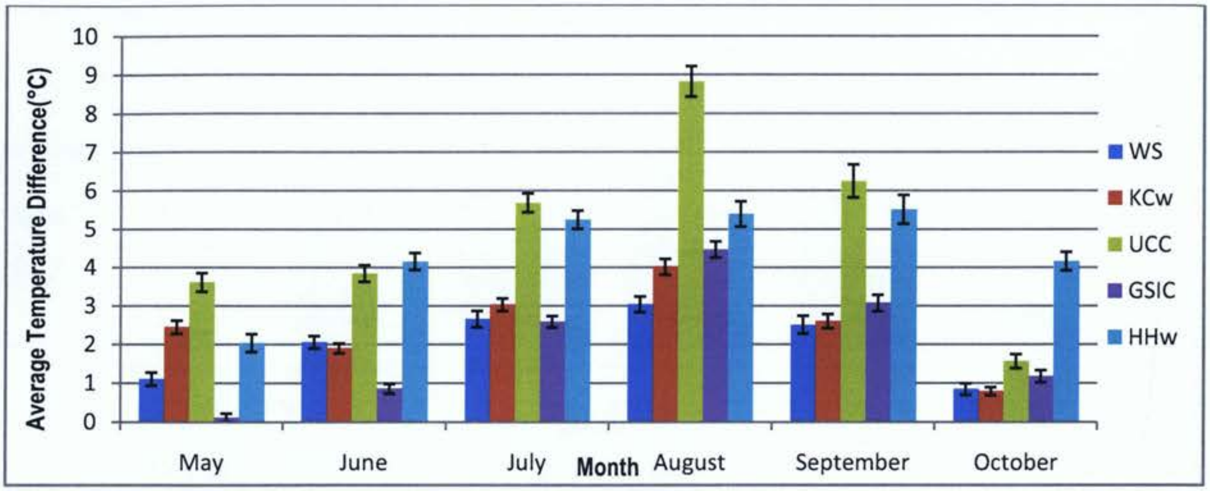

Figure 3.18: Average (mean) value for temperature difference for a typical day at west facing sites (WS, KCw, UCC, GSIC, HHw) during the peak solar access period of 3:00 pm to 8:00 pm from May 1, 2008 to October 31, 2008. Error bars represent one standard error.

For all sampling locations, excluding TC(1), UC(1), UC(2), and HHw, the highest average temperature differences between sun and shade loggers were found in August. By comparing all sites, and examining them based on the time of day they were believed to provide the greatest shading benefits and it was instructive to observe which sites had the greatest variance in temperatures between their respective sun and shade loggers. Findings indicated that UCC had the highest value with an average temperature difference of 8.8 °C; this was followed by TC(2) (5.8 °C) and UC(1) (5.7 °C). Surprisingly, KCe had a greater difference (4.22 °C) than those found at WS, KCw, HHs, TCe, TC(1) and UC(2). The smallest average difference between sun and shade loggers was found at UC(2); this was expected due to the large distance of the shade tree from the wall. Its average difference in temperature during August was 1.6 °C, and its largest difference was found in October (1.9 °C).

Preventing warming of built surfaces in the urban environment is especially important to the moderation of microclimates found within cities; cooler summertime temperatures act to lessen air quality degradation, especially that of smog formation. Therefore, the strategic placement of trees to prevent the warming of built structures can have an important effect on the moderation of urban summertime temperatures. Mitigating the UHI effect through strategic placement and management of urban trees can play an important role in reducing the number of smog days, which in turn will improve air quality in a city.

Optimal site design with respect to tree placement and species characteristics was one of the important factors assessed in the present study. Amongst the site locations analyzed, UCC seemed to be ideal; for all tests completed it always generated the greatest benefits compared with other treed and vines sites. Other site locations, which include: UC(1), TC(2), and KCw, were found to provide greater shading benefits as well compared to all site locations, but benefits varied in terms of the specific tests examined. For example, the shade tree growing at KCw was estimated to have provided greater direct shading annual savings and summer cooling benefits according to the Tree Benefits Estimator, compared with other site locations. In terms of prevention of warming, results showed that both UC(1) and TC(1) were better able to mitigate warming of built surfaces than KCw. Each of these locations showed considerable benefits, but in terms of ranking ideal locations based upon all criteria and tests observed in study, the results varied. This deviation had much to do with management, site location and species type; UCC was a west facing site, had a large stature shade tree, and had higher LAI and sh values (3.66 and 0.80 respectively).

Greater than one tree planted to the south of a building wall (i.e., MCIS) was the only scenario in this study that showed benefits exceeding those provided by a single planting. An inability to control for important characteristics such as tree size, shape, form, species and distance from the building wall, can have an effect on the overall benefit of increasing the number of shade trees, like that found at SDWRe and SDWRw.

Results varied for the vine versus shade tree comparison in relation to prevention of warming. HHw seemed to be more beneficial than HHs at preventing warming when compared to treed sites found at the same aspect, but, overall, there was strong evidence to support the fact that they provided similar shading benefits as trees.

Therefore in terms of site design and landscape planning, in instances where there may not be suitable planting space for a tree, vines can be used to prevent warming in the proximate area, and by extension help to reduce energy used for summer cooling of the buildings on which they grow. A similar strategy can be used by planners where there is ample plantable space to sustain more than one tree. Planting a tree at each aspect (west, south and east; in order of priority) of the building is recommended. The increase in tree population in Toronto will assist the City in reaching its canopy coverage goal; however, strategic selection and management of shade trees will provide benefits specific to energy conservation.

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study has demonstrated the important role that shade trees and vines can play on temperature moderation within the urban microclimate. Statistical modelling revealed that temperatures recorded by loggers situated in the shade were significantly cooler than those measured in full sun during times of peak solar access. Built surface exterior temperatures are positively correlated with heat exchange into interior space; therefore, buildings will receive direct benefits in terms of energy savings (reduced demand for air conditioning) if they are well shaded.

Findings from the study have further illustrated the importance of mature trees. In all cases where there was a large variation between temperatures recorded at the sun logger compared with the shade logger, the site had a large stature tree present (e.g., UCC, UC(1)). The Tree Benefits Estimator provided additional support for these findings, especially concerning the impact and benefits of mature trees. This is important, as it corresponds directly with Toronto Mayor David Miller's goal for increasing canopy coverage to 34 % by 2050. Following from the findings of this research – large stature trees provide the greatest overall benefits - the City of Toronto must investigate and implement measures to better maintain and prolong the life span of its mature trees. In addition, it is strongly recommended that all cities develop and enforce consistent policies regarding tree protection so as to ensure that large stature trees are not removed (unless deemed a hazard), as their benefits far outweigh smaller (newly planted) trees.

Analyses conducted as part of this research focused on optimal tree placement with respect to built structures; findings provided useful and timely information for future management of urban landscapes. Specifically, it was determined that west facing built surfaces experienced the greatest warming compared with other aspects, and therefore should be the first priority for tree placement in terms of shading. South and east facing aspects did show significant variances, and, therefore, should also be considered in landscaping site designs where space is available. Planting trees on the east side of buildings can assist in preventing warming early on in the day; this study showed temperatures recorded at east aspects were warmer than those at west aspects until approximately 4:00 pm. Planting more than one tree was shown to be beneficial in situations where site conditions could be controlled (e.g., at MCIS where distance from the building, species, tree size and form were consistent). The use of vines in instances where there may not be a suitable growing medium for sustaining a shade tree, or there are potential conflicts with nearby obstructions, was demonstrated to be of great benefit. In analyses where shading by vines was compared to treed sites (south and west), results showed that vines were not significantly different than trees in terms of their ability to prevent warming. Further investigation of optimal vine species selection and maintenance strategies is recommended prior to incorporation into landscape design. City of Toronto policy is weak with regard to prioritization of tree maintenance and protection of growing conditions. Results from this study will be instructive to government officials and city planners because the shading benefits of trees and vines within the urban microclimate are so apparent. Findings may be used to enhance future landscape planning that will act to keep built areas cooler, and as a result, contribute to a reduction in summer time energy use.

Trees and vines were demonstrated in this study to provide important benefits concerning mitigation of the UHI effect. The strategic use of shade trees/vines to prevent warming will not only increase human comfort within a city, but will also act to improve air quality, as temperature is directly correlated with the production of ozone, and by extension, smog. The benefits of shading built surfaces with vegetation outlined in this work reinforce the value of nature in an urban environment. They add to a growing body of literature that seeks to quantify the benefits of a healthy urban forest. Such knowledge, while more common in the US, is only slowly being integrated into the psyche of Canadian decision-makers. It is hoped that findings from this research will further support this important information transfer.

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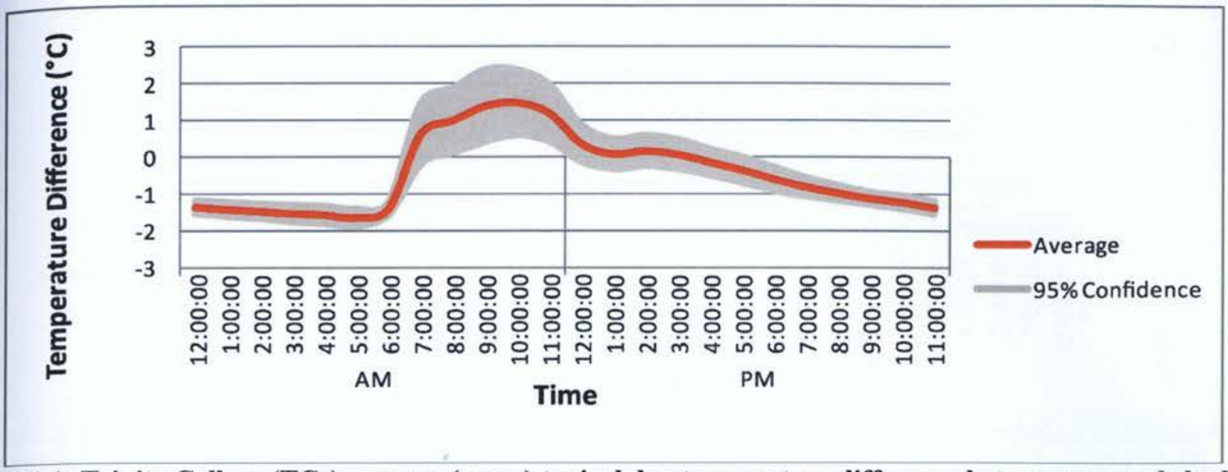
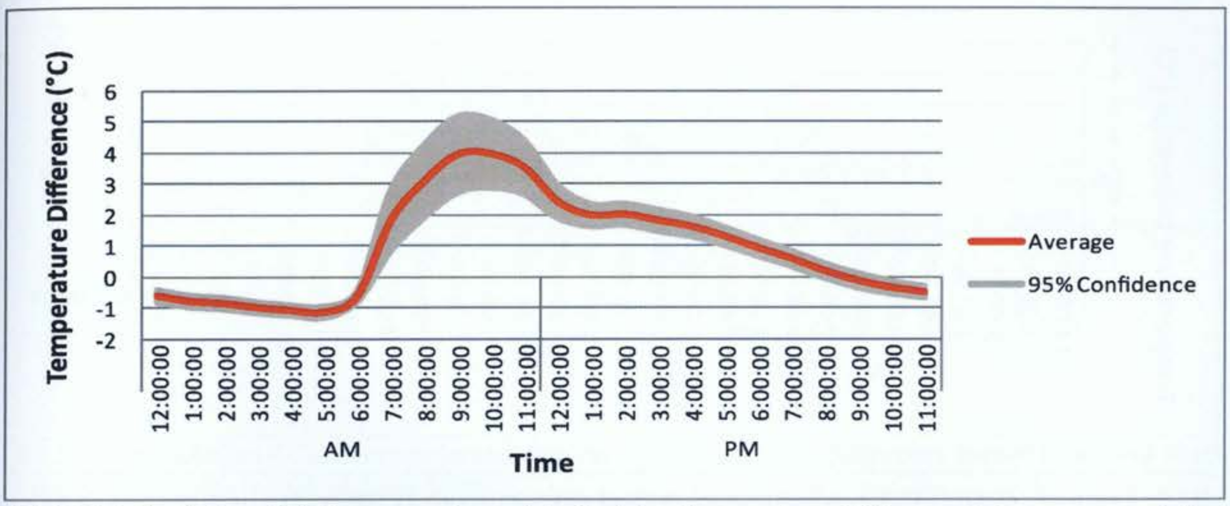
Appendix A – Tree characteristics & measurements

Pair Number	Campus Location	Common Name	Latin Name	DBH (cm)	Crown Diameter [D] (m)	Tree Height (m)	Crown Height [H] (m)	Crown Surface Area (m^2)	Crown Volume (m^3)	LAI	Drip-Line Area [G] m^2	Outer Suface Area of Crown [S]	Melissa Shading Coefficient [sh]	Adjusted sh values	Nowak Shading Coefficient
1	Trinity College[Tce]	Sugar Maple	*Acer saccharum*	20.05	8.40	11.99	9.86	111.31	273.21	2.94	55.42	240.94	0.67		0.84
2	Knox College [Kce]	Silver Maple	*Acer saccharinum*	60.00	15.40	24.94	23.66	336.94	2203.05	3.44	186.27	944.75	1.13	0.79	0.83
3	Trinity College[TC(1)]	White Mulberry	*Morus alba*	65.41	13.65	21.30	19.20	257.20	1404.84	2.91	146.34	704.35	0.89		N/A
4	Trinity College Tree [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	56.50	4.65	16.56	14.24	127.50	120.91		16.98	137.98			0.81
	Trinity College [TC(2)]	English Oak Fastigiata	*Quercus robous 'Fastigiata'*	59.05	5.65	21.66	19.42	209.11	243.47		25.07	222.51			0.81
5	University College [UC(1)]	Honey Locust	*Gleditsia triacanthos var. inermis*	48.06	17.65	17.69	16.20	511.46	1321.21	2.20	244.67	938.48	1.17	0.71	0.67
6	University College [UC(2)]	European White Birch	*Betula pendula*	14.01	7.95	10.86	9.00	98.14	223.38	3.42	49.64	211.67	0.70		0.82
7	Hart House [HHs]	Boston Ivy	*Parthenocissus tricuspidata*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	44.72	9.70	15.54	14.18	186.62	523.75	2.55	73.90	363.78	0.62		0.88
	Munk Center for International Studies [MCIS]	Little Leaf Linden	*Tilia cordata*	40.90	7.95	16.30	14.42	184.18	357.92	2.75	49.64	279.37	0.56		0.88
9	Warren Stevens [WS]	Honey Locust	*Gleditsia triacanthos var. inermis*	36.61	13.10	11.79	9.99	38.43	673.24	2.22	134.78	475.13	0.77		0.67
10	Knox College [KCw]	Silver Maple	*Acer saccharinum*	104.72	19.40	32.25	23.85	117.11	3524.94	2.20	295.59	1317.98	1.57	0.72	0.83
11	University College Courtyard [UCC]	Green Ash	*Fraxinus pennsylvanica var. lanceolata*	70.35	15.80	19.60	17.20	121.75	1686.17	3.66	196.07	819.01	1.10	0.80	0.83
12	Gerstein Science Information Center [GSIC]	London Plane	*Platanus x acerifolia*	68.60	17.70	18.52	16.33	516.41	1339.37	2.30	246.06	946.14	1.19	0.72	0.86
13	Hart House [HHw]	Boston Ivy	*Parthenocissus tricuspidata*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	Sir Daniel Wilson Residence [SDWRe]	Siberian Elm	*Ulmus pumila*	101.86	28.95	25.65	23.70	1262.86	5200.13	2.40	658.24	2394.24	3.30	0.73	0.85
N/A	Sir Daniel Wilson Residence [SDWRe]	London Plane	*Platanus x acerifolia*	66.85	20.20	16.80	15.12	576.95	1615.19	1.66	320.47	1120.71	1.37	0.67	0.86
N/A	Sir Daniel Wilson Residence [SDWRw]	London Plane	*Platanus x acerifolia*	57.93	14.25	18.37	16.17	156.45	1289.44	1.86	159.48	680.92	0.84		0.86

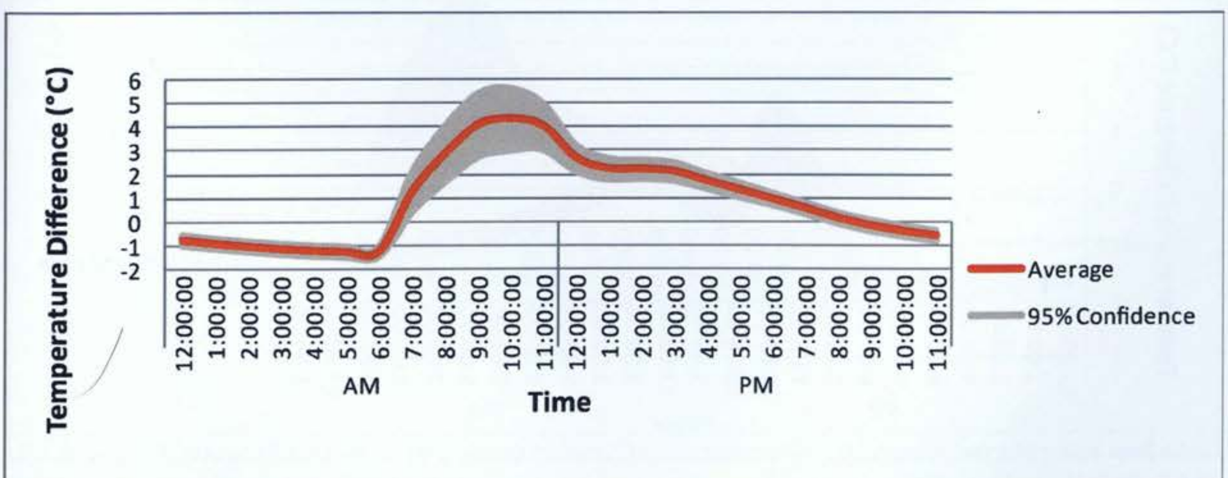
Appendix B1 – Average (mean) typical day temperature differences with standard error envelopes



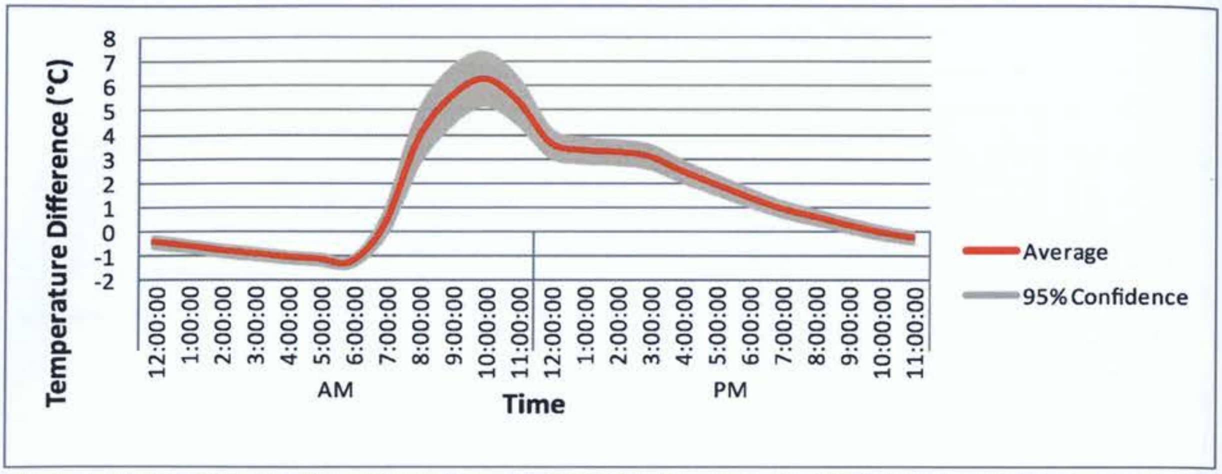
B1.1: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



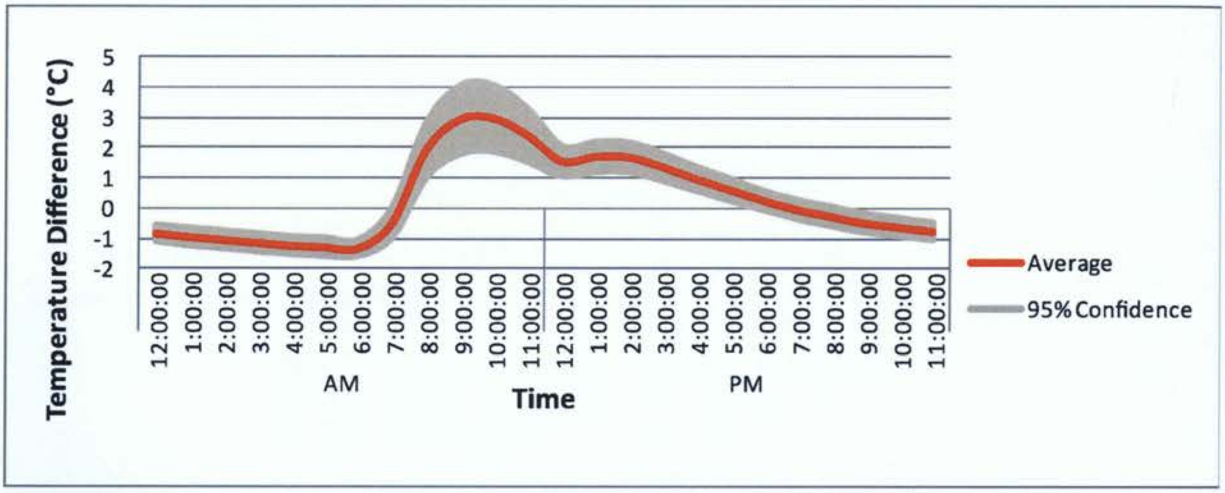
B1.2: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



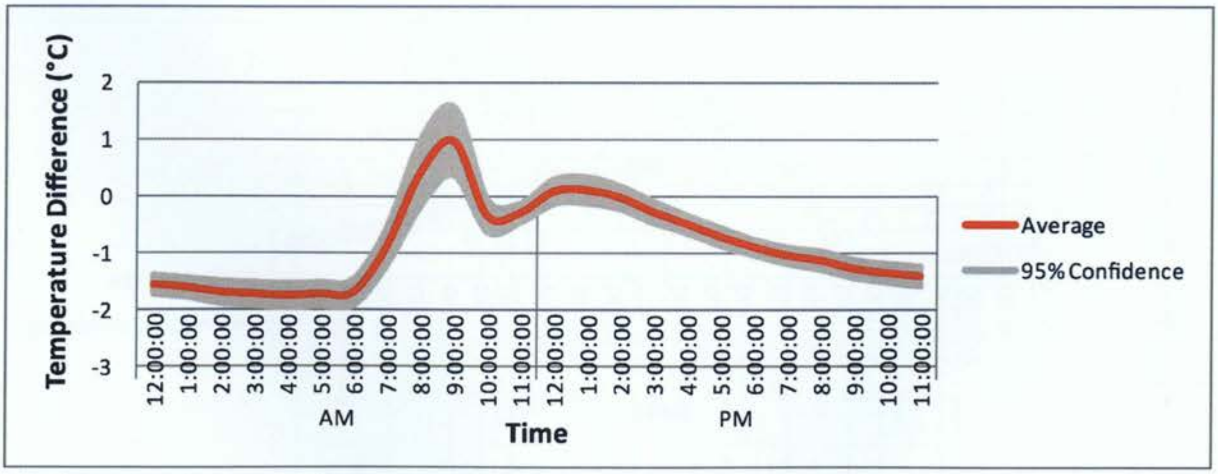
B1.3: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



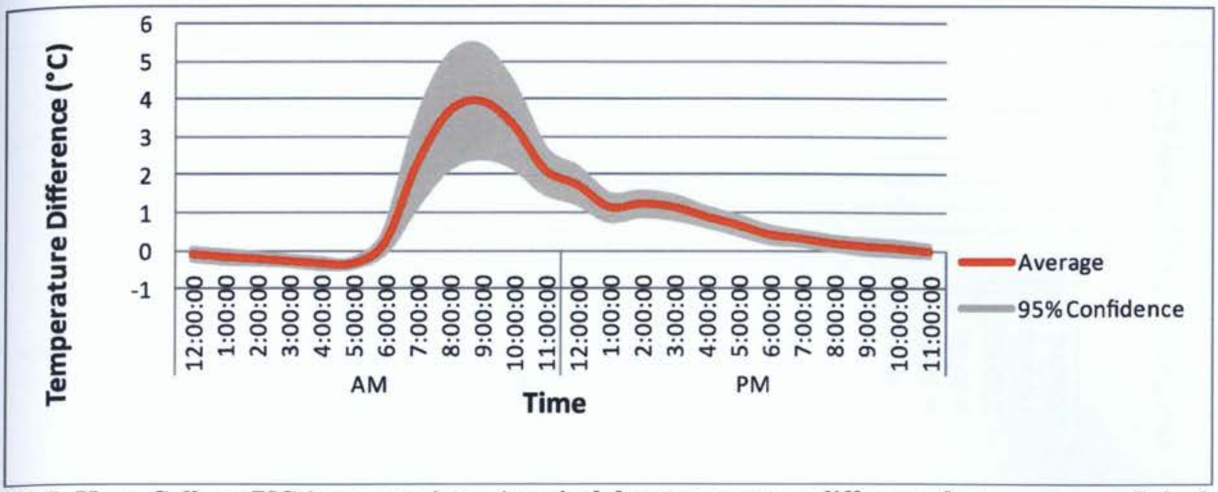
B1.4: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



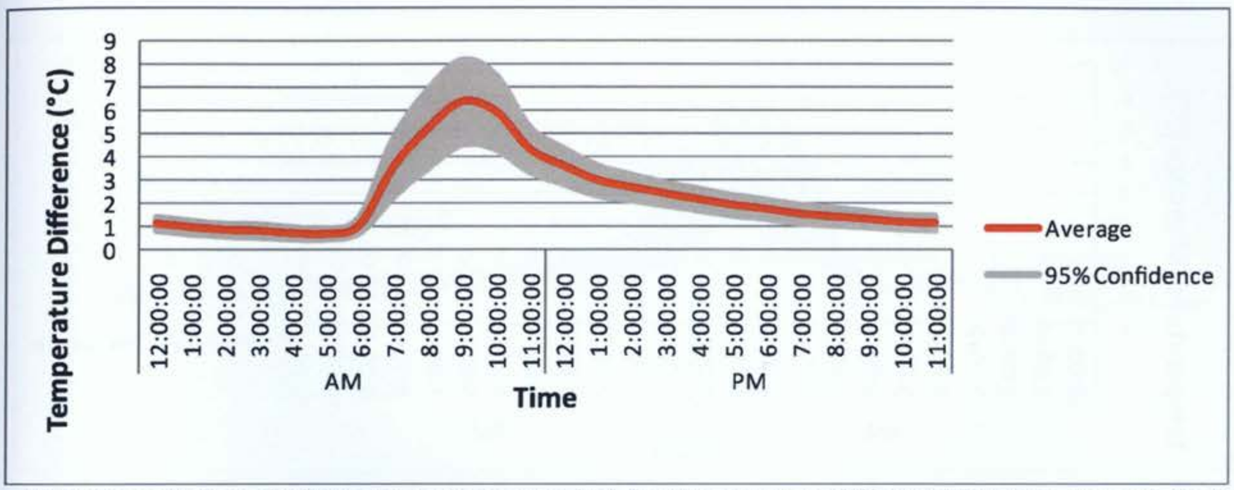
B1.5: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



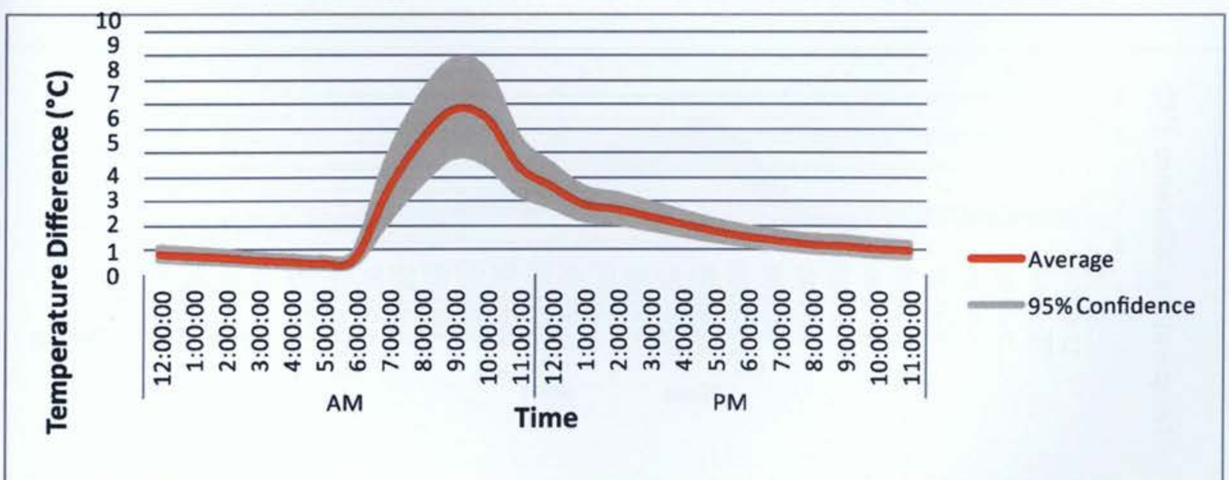
B1.6: Trinity College (TCe) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



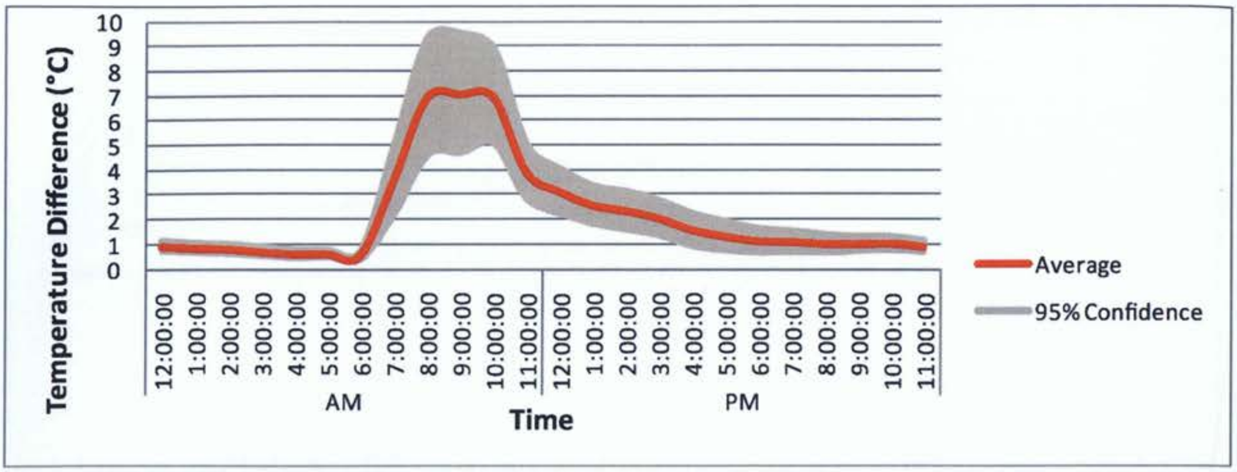
B1.7: Knox College (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



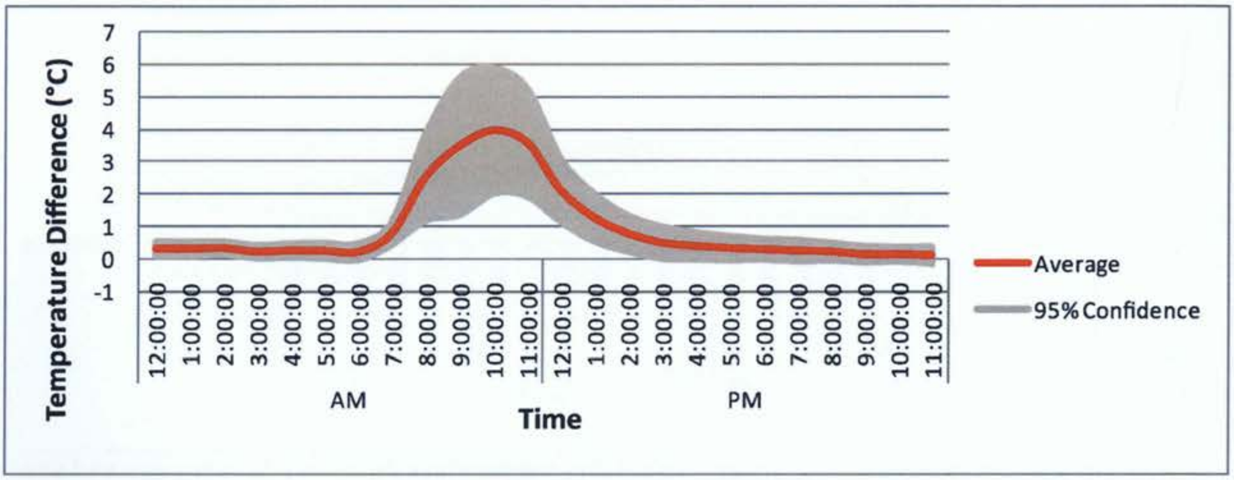
B1.8: Knox College (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



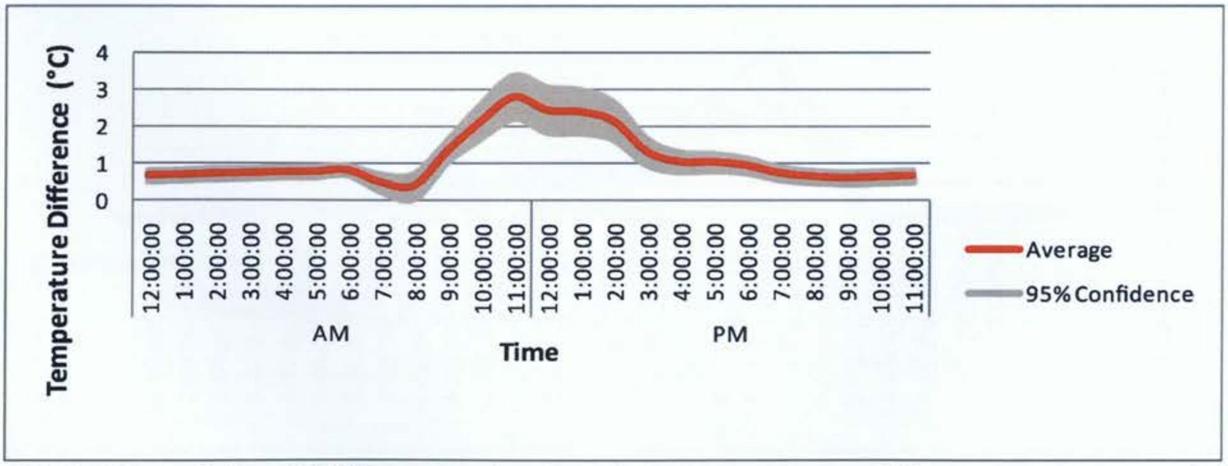
B1.9: Knox College (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



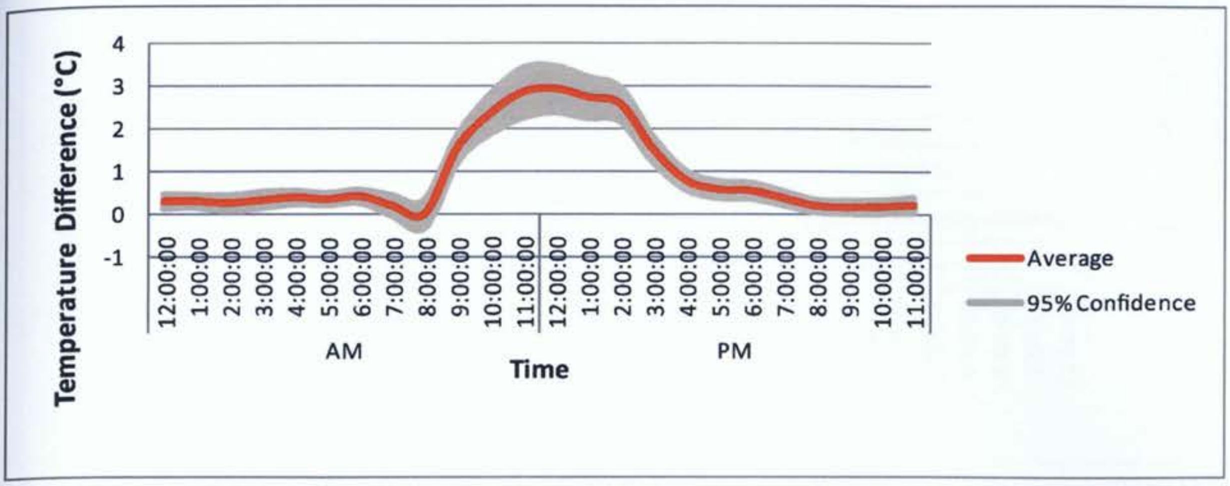
B1.10: Knox College (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



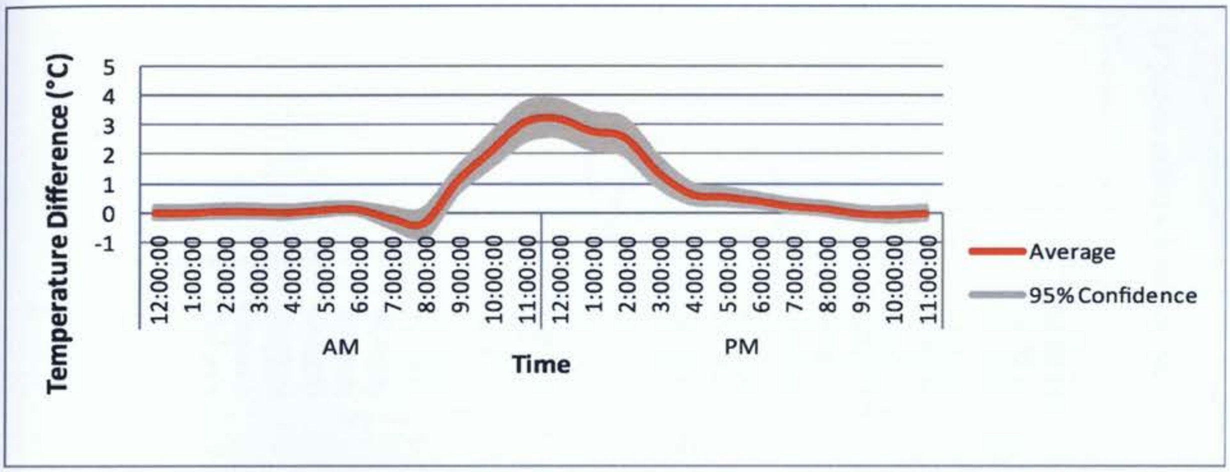
B1.11: Knox College (KCe) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



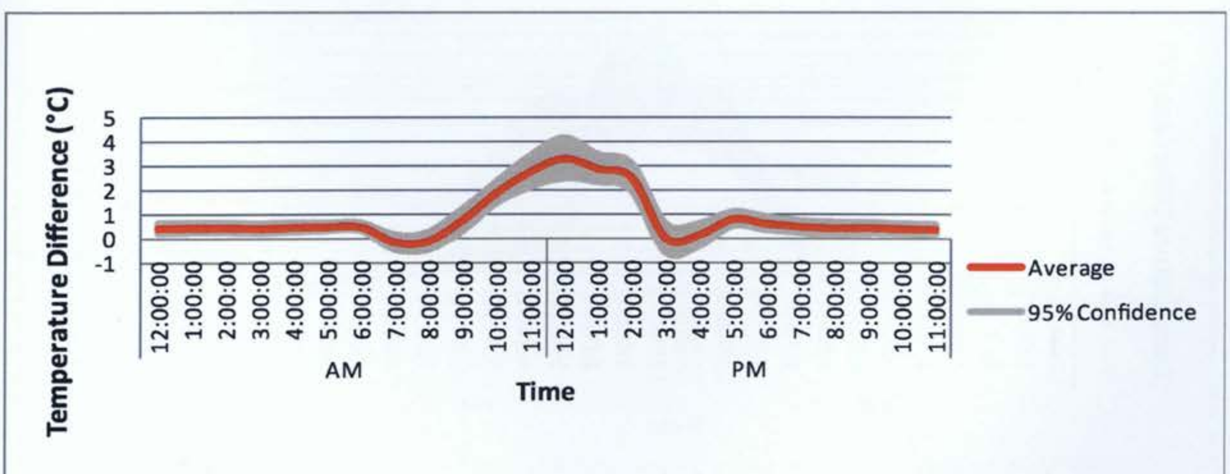
B1.12: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



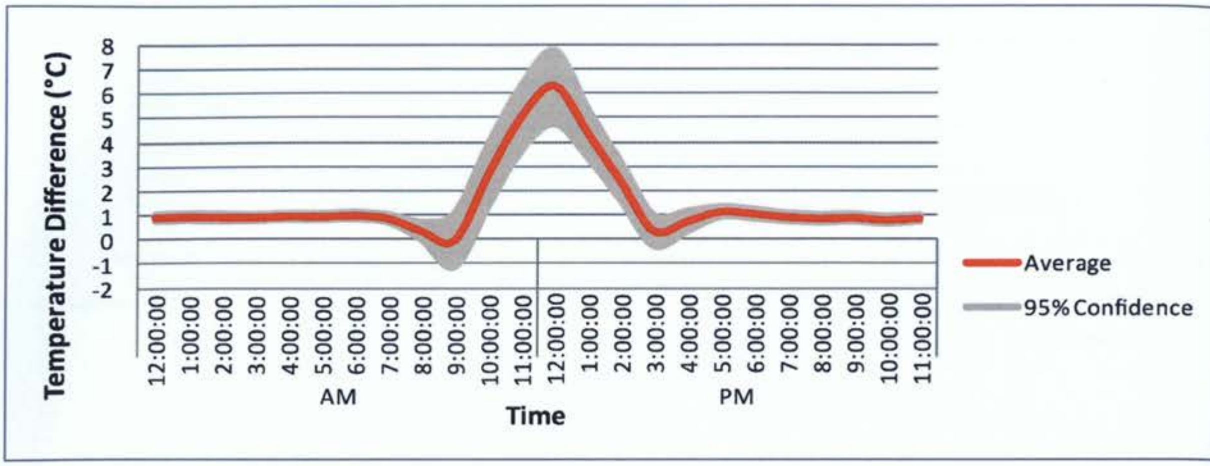
B1.13: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



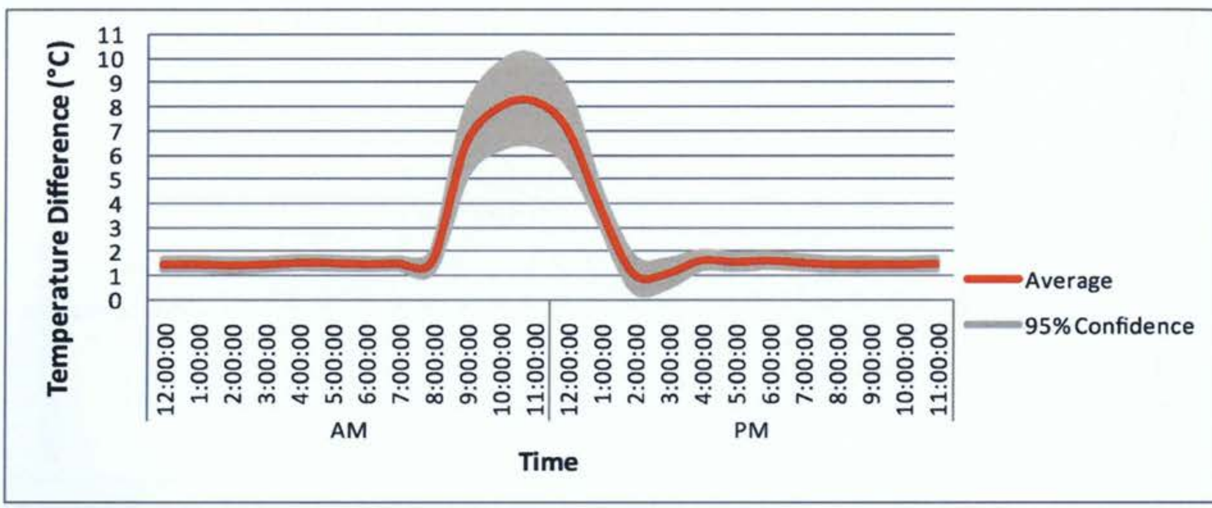
B1.14: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



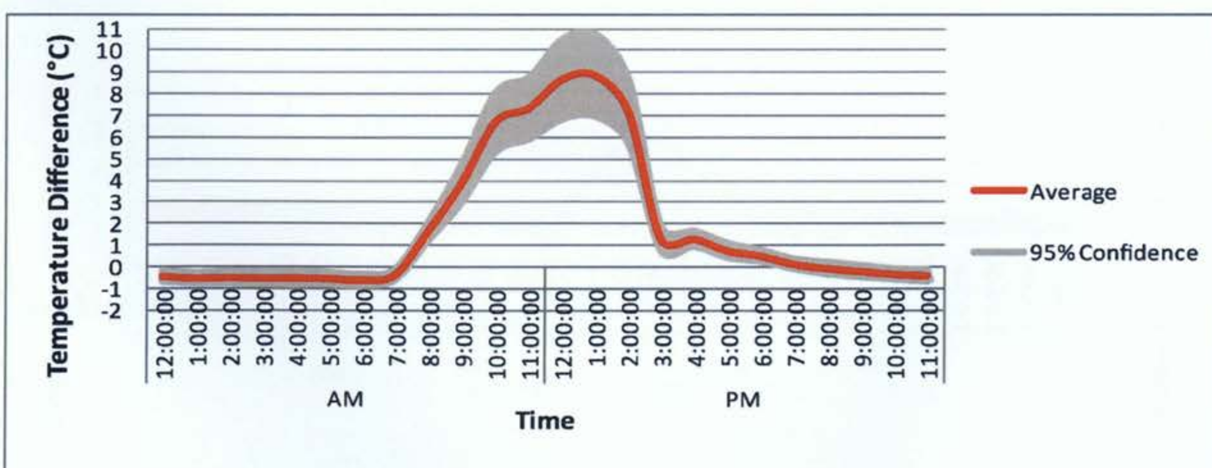
B1.15: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



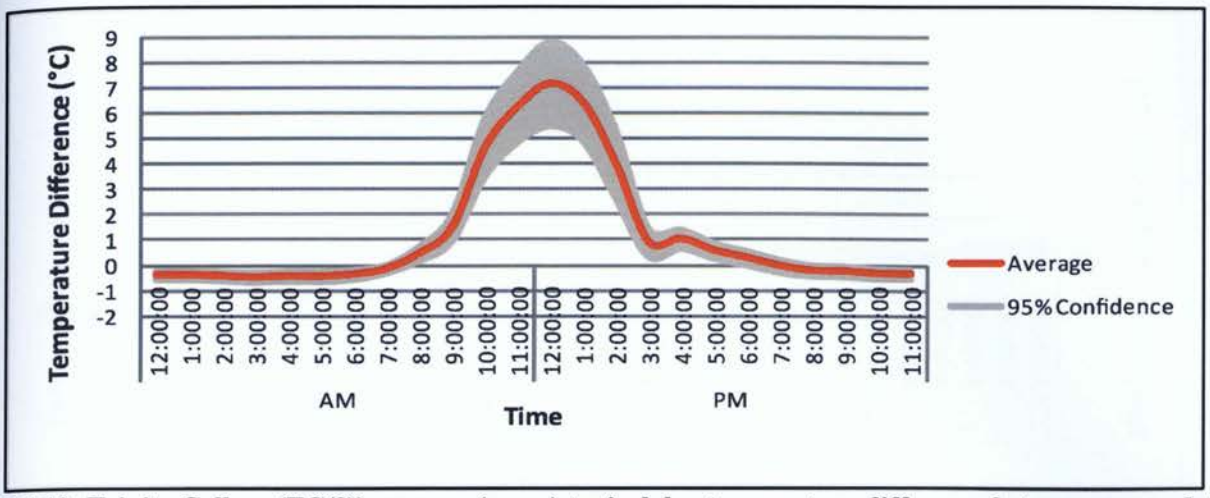
B1.16: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



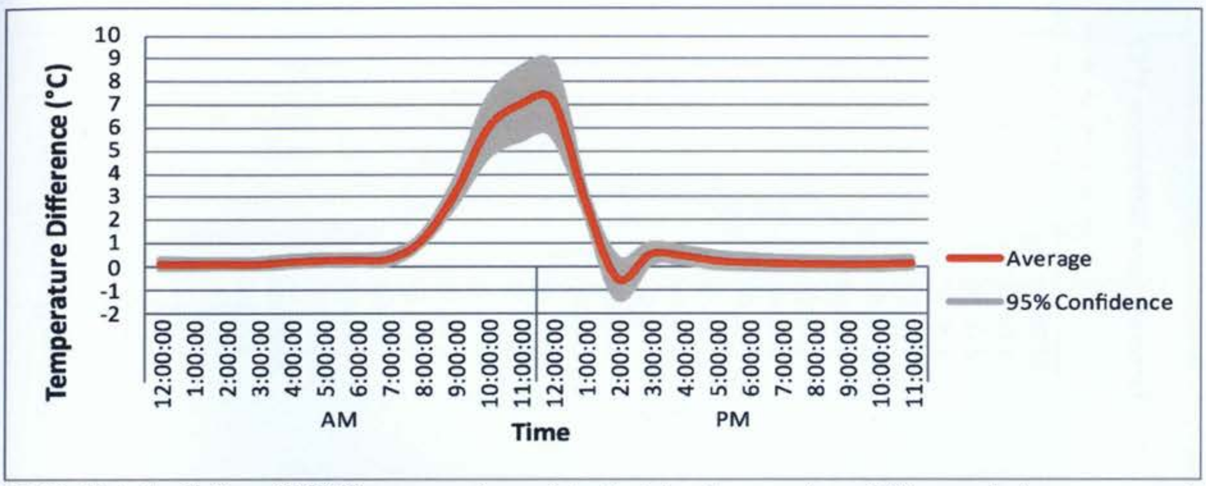
B1.17: Trinity College (TC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



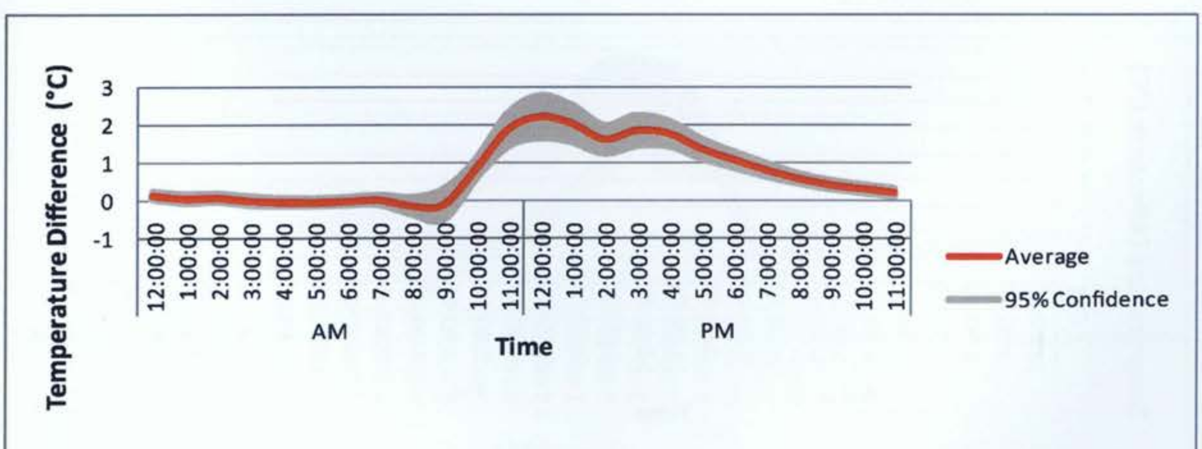
B1.18: Trinity College (TC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



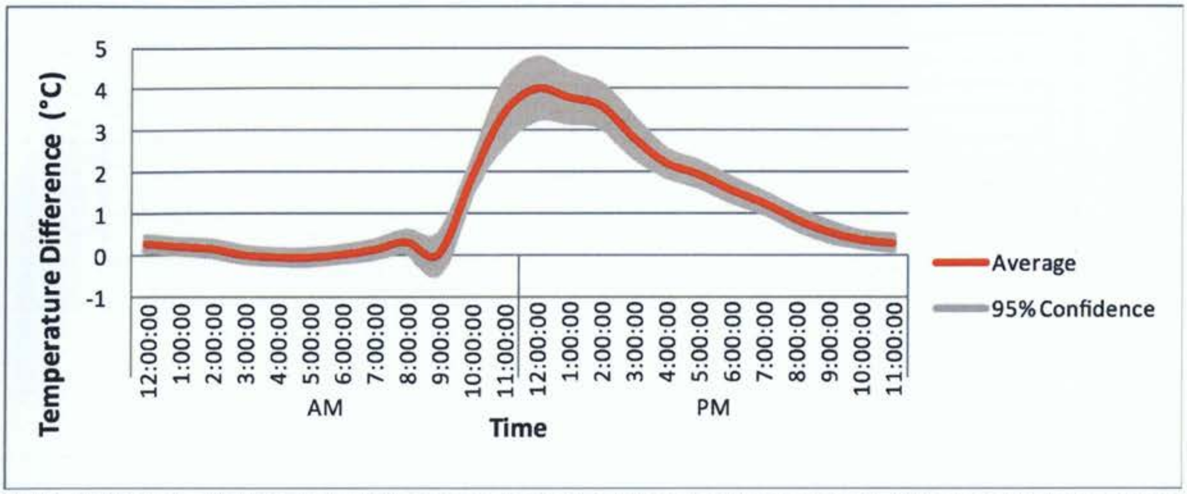
B1.19: Trinity College (TC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



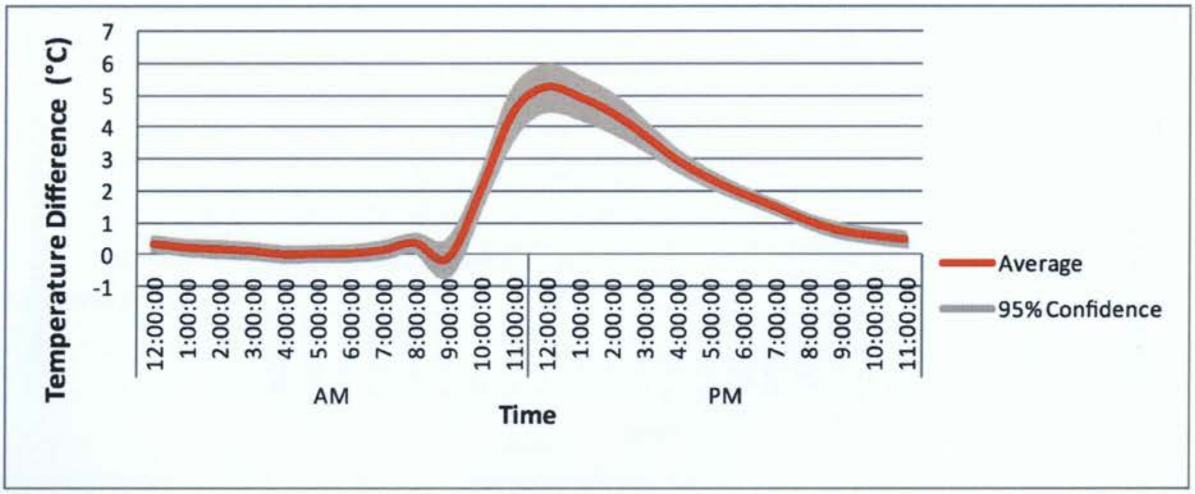
B1.20: Trinity College (TC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



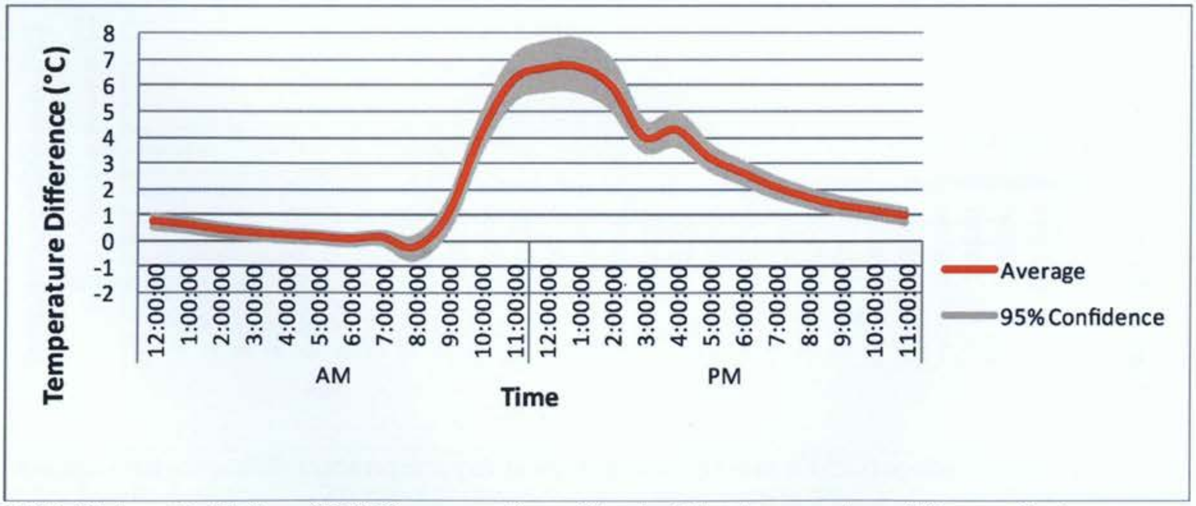
B1.21: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



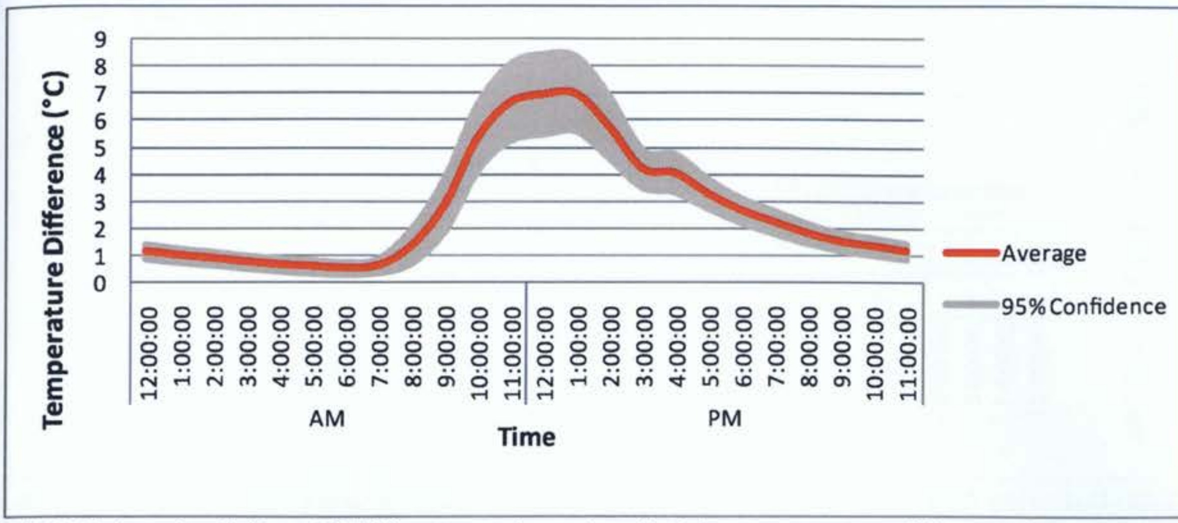
B1.22: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



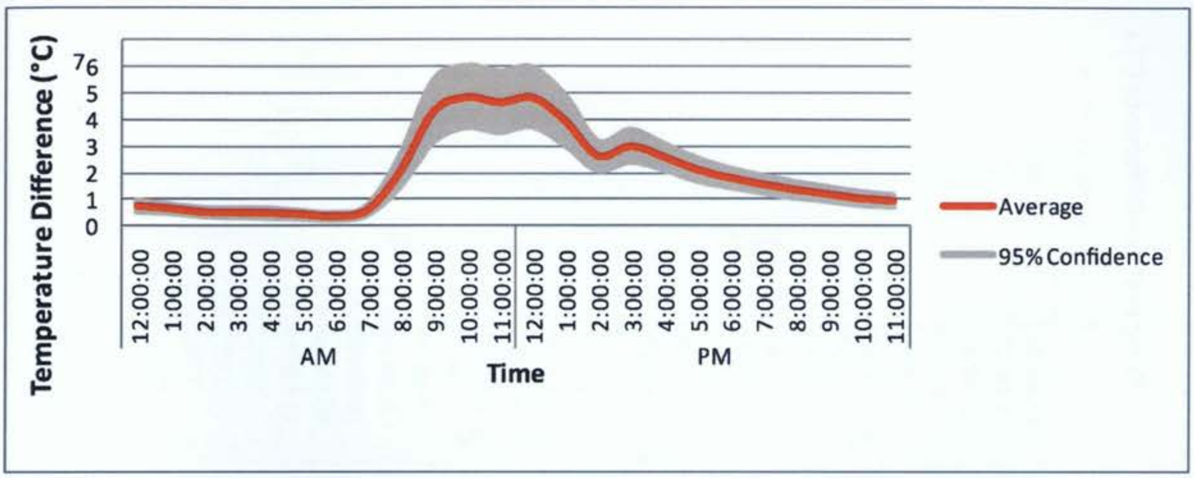
B1.23: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



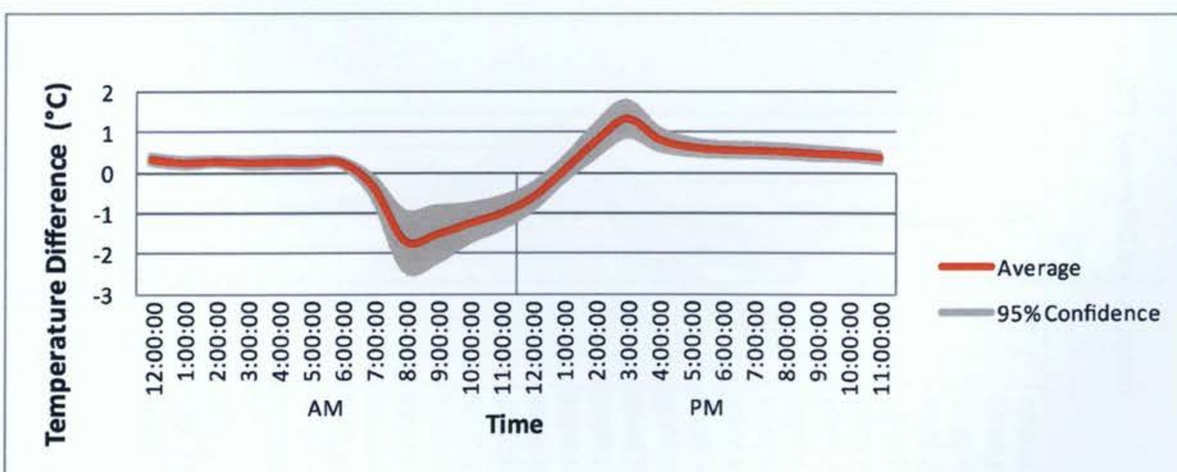
B1.24: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



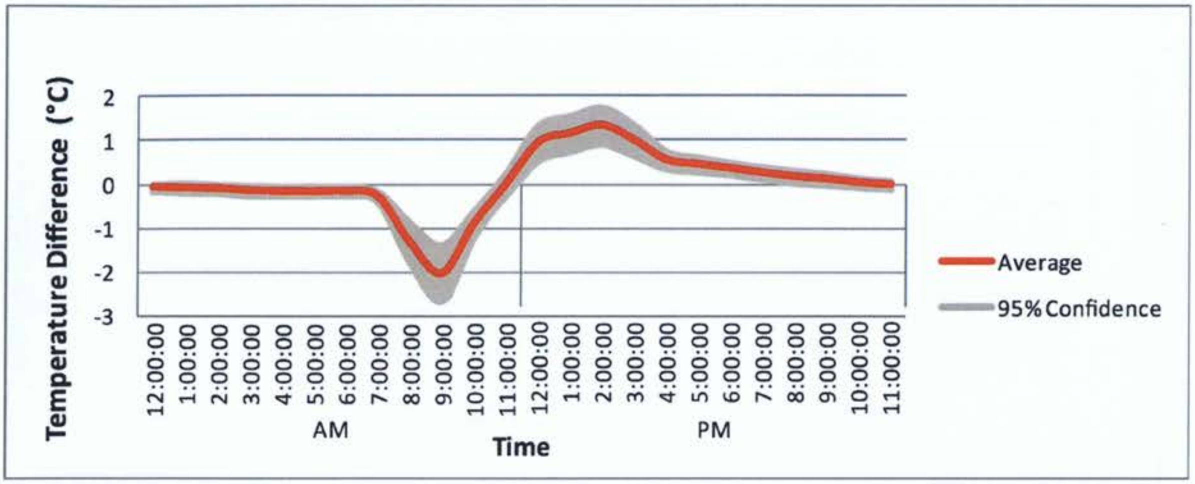
B1.25: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



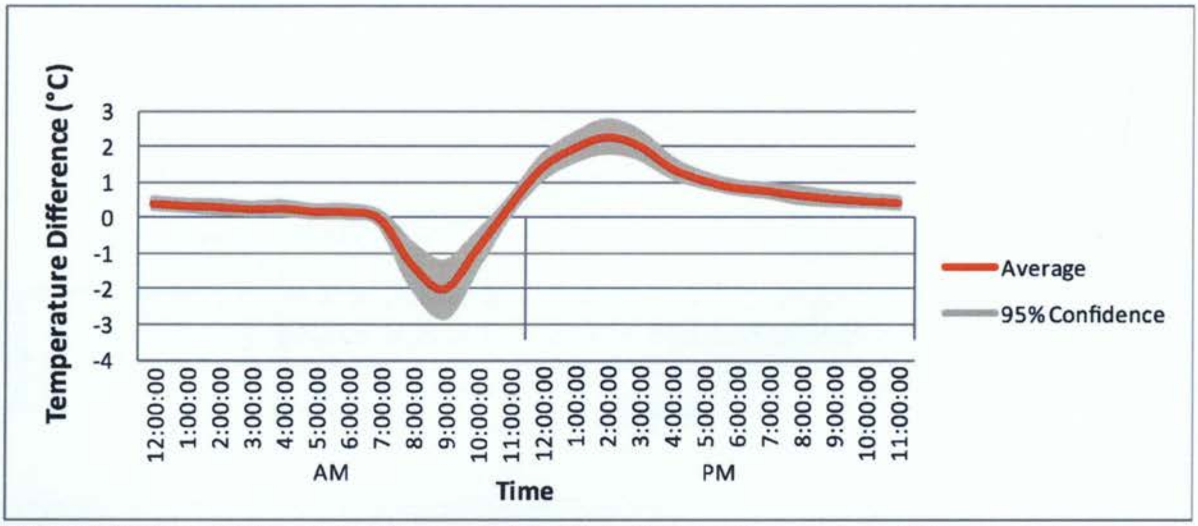
B1.26: University College (UC(1)) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



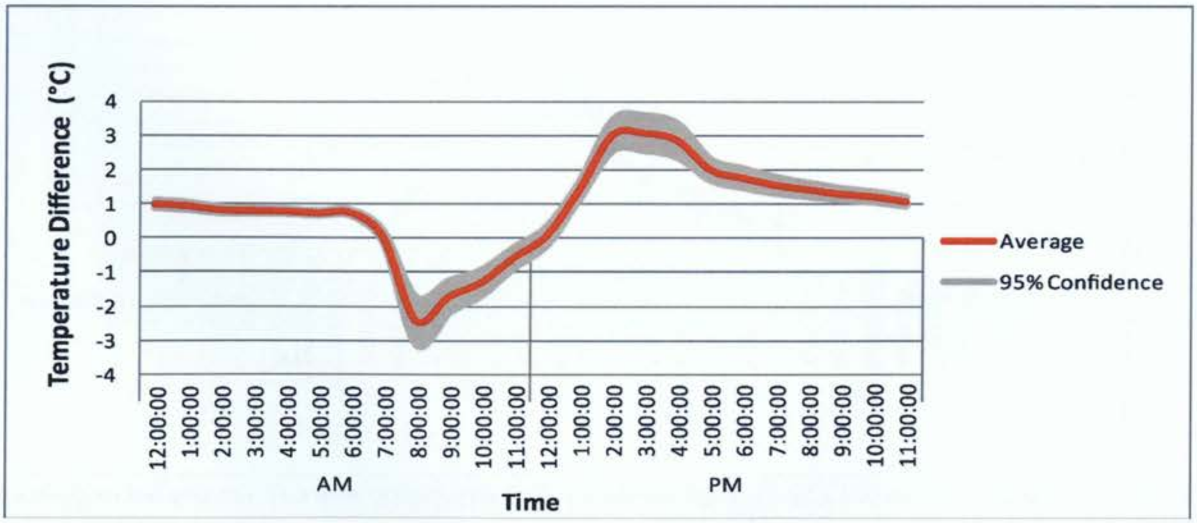
B1.27: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



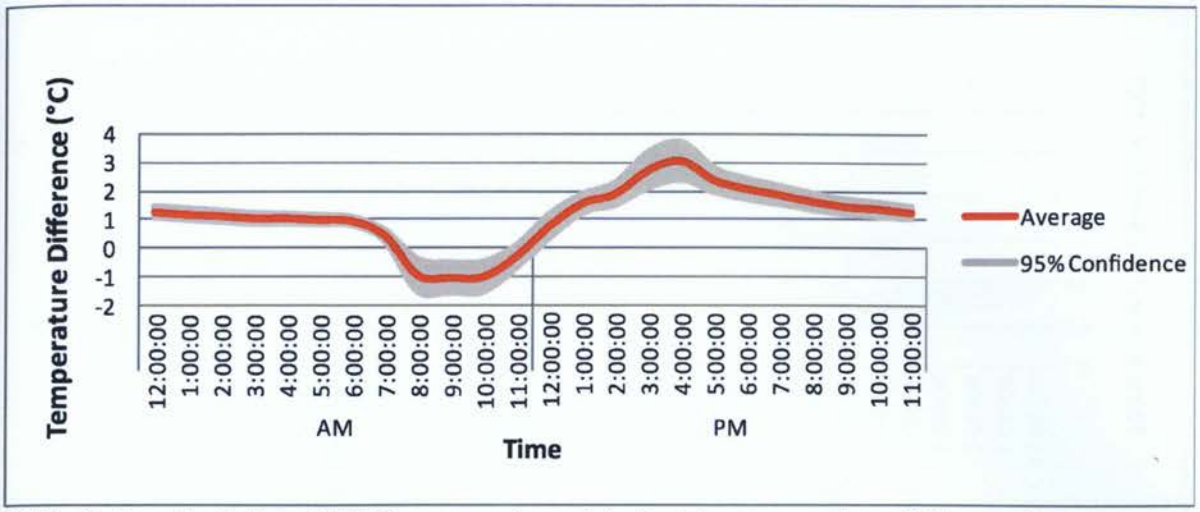
B1.28: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



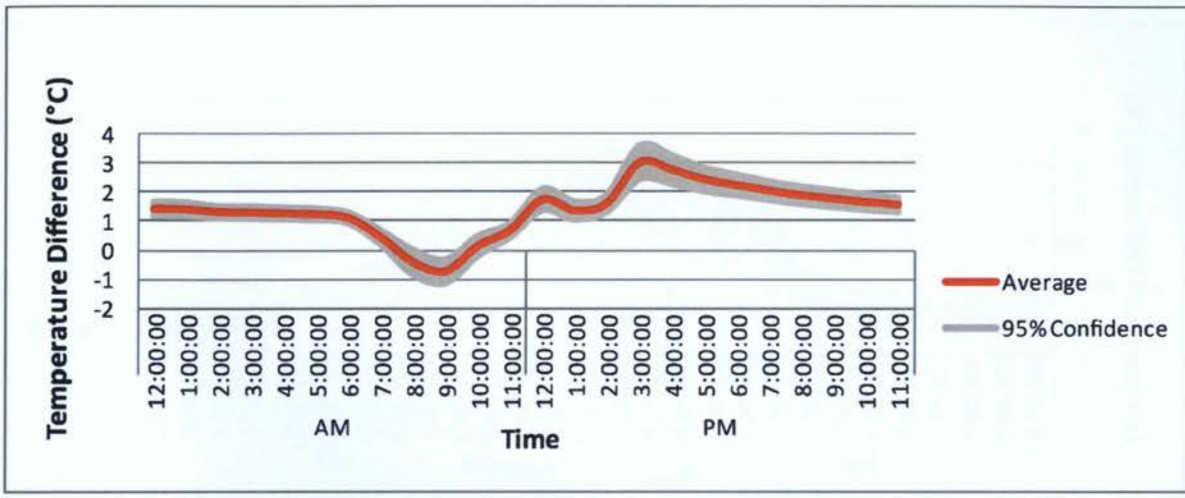
B1.29: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



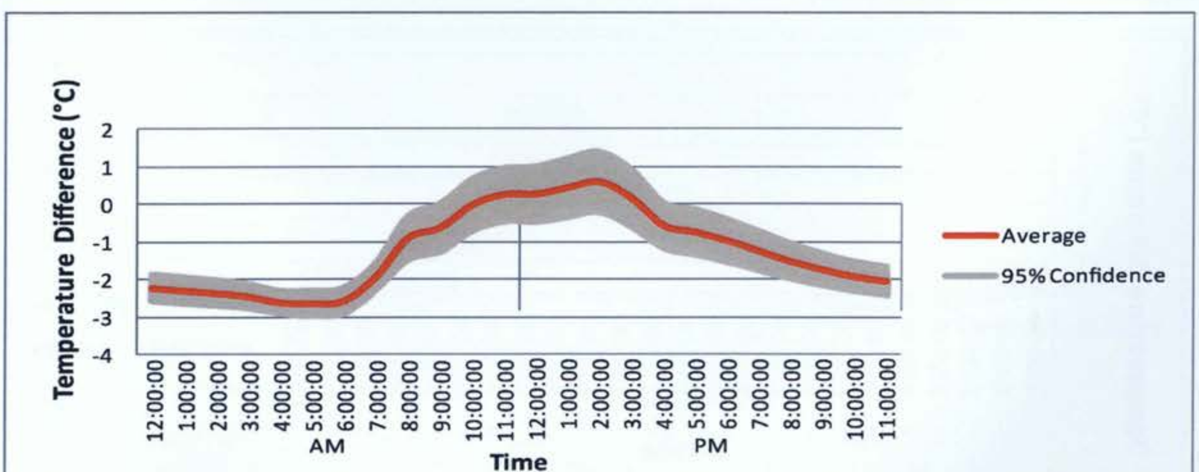
B1.30: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



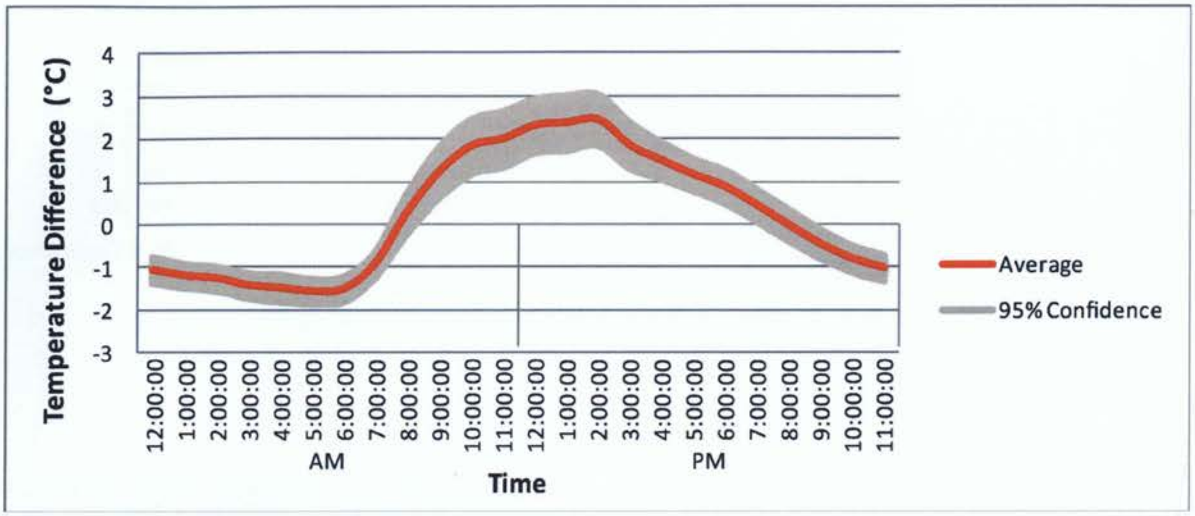
B1.31: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



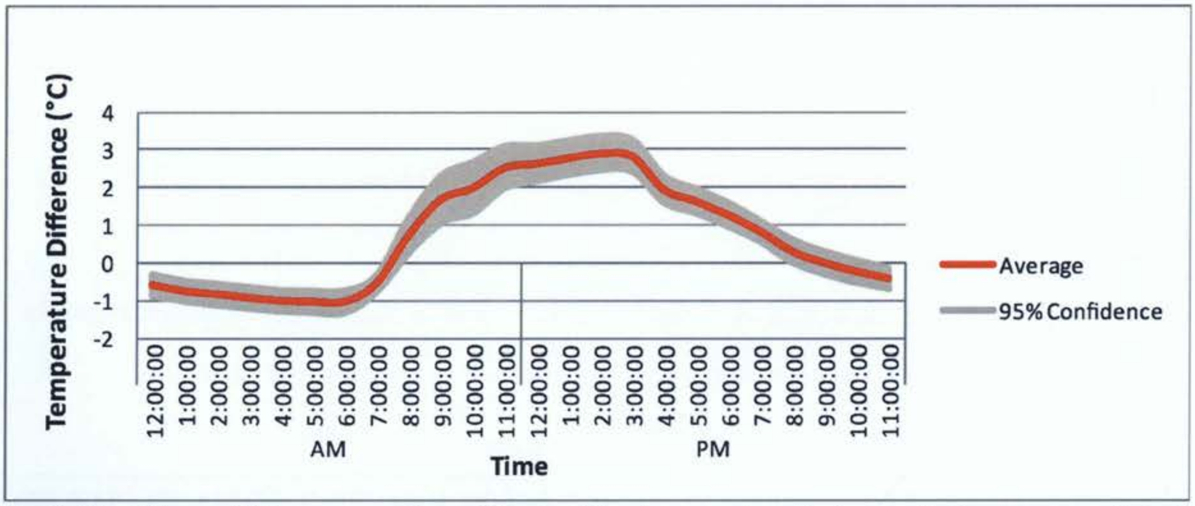
B1.32: University College (UC(2)) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



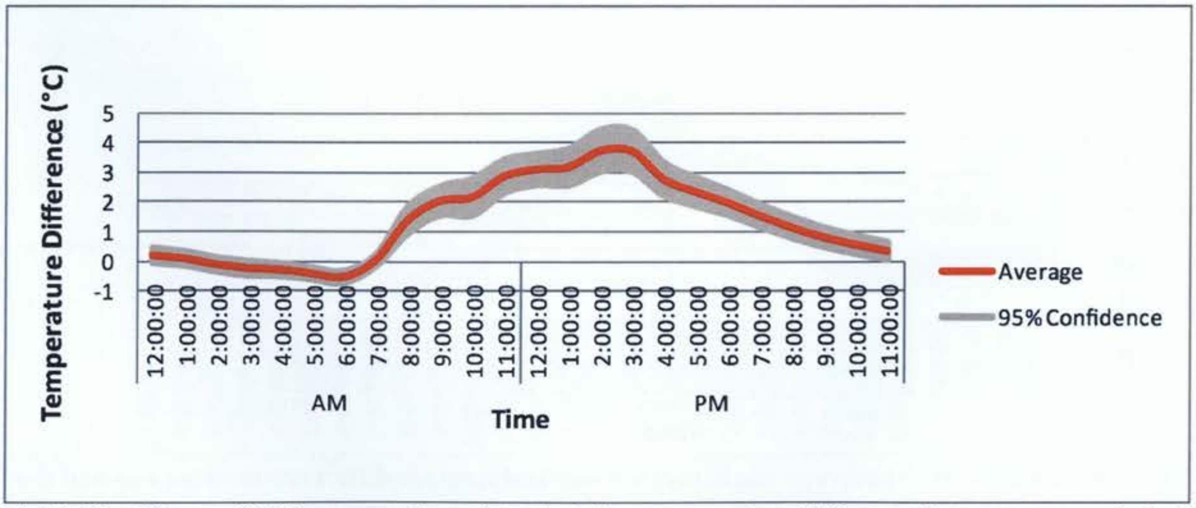
B1.33: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



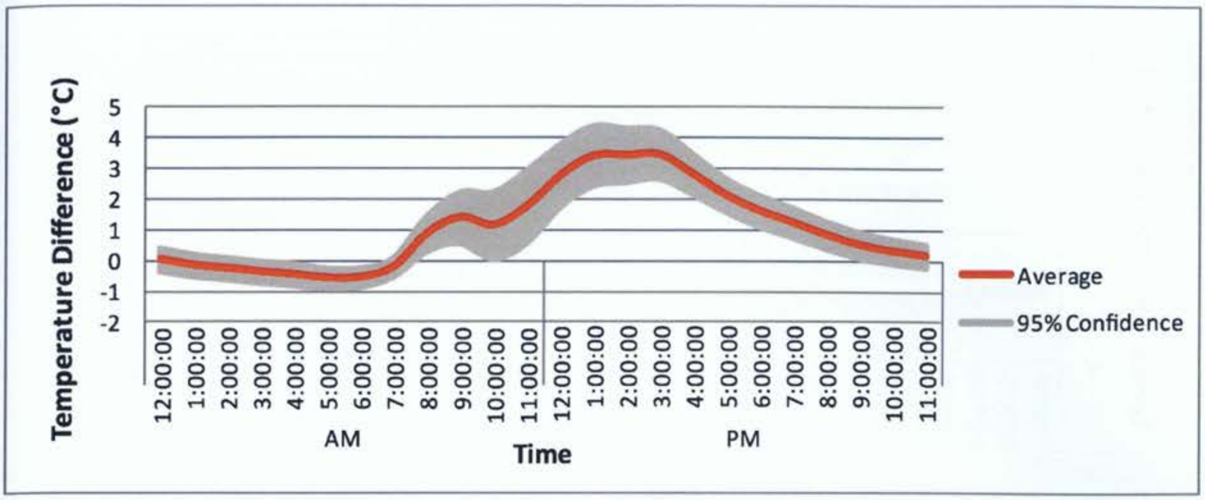
B1.34: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



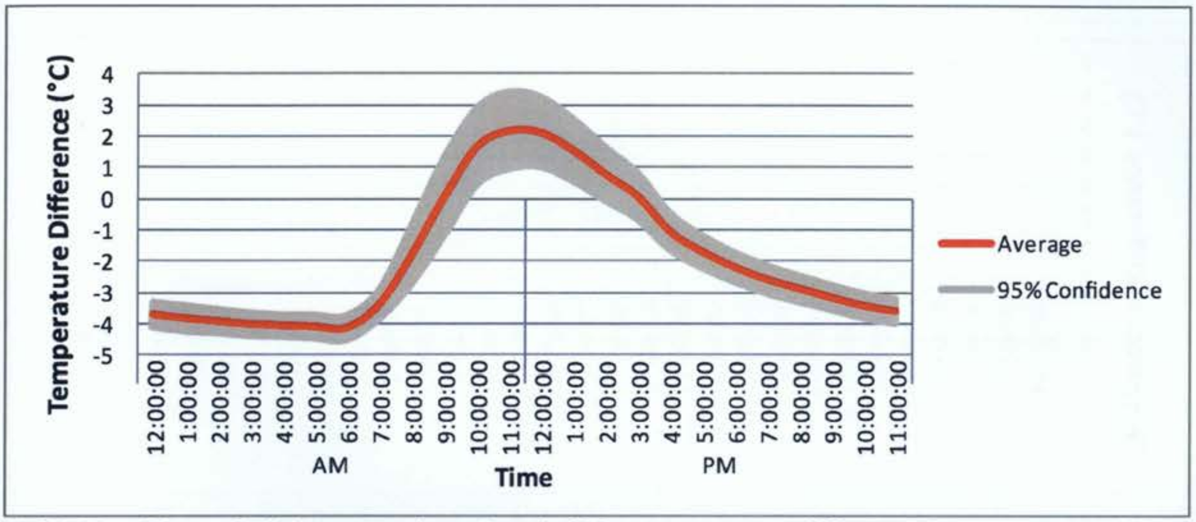
B1.35: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



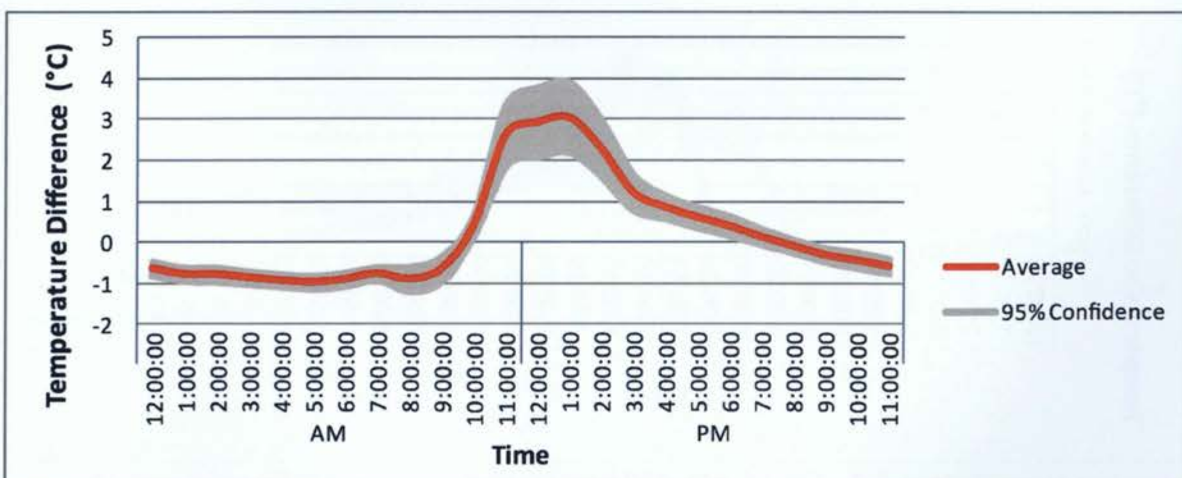
B1.36: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



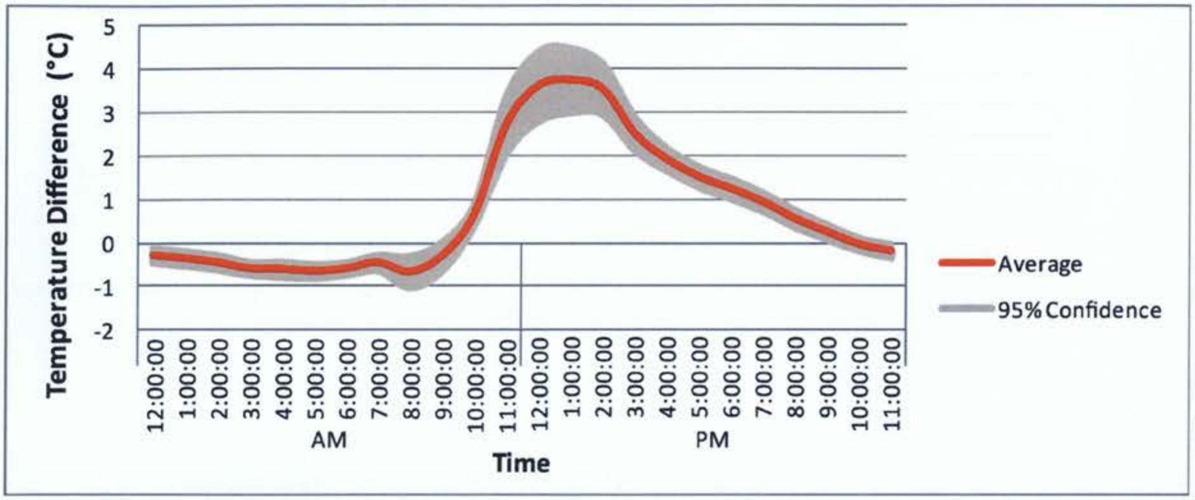
B1.37: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



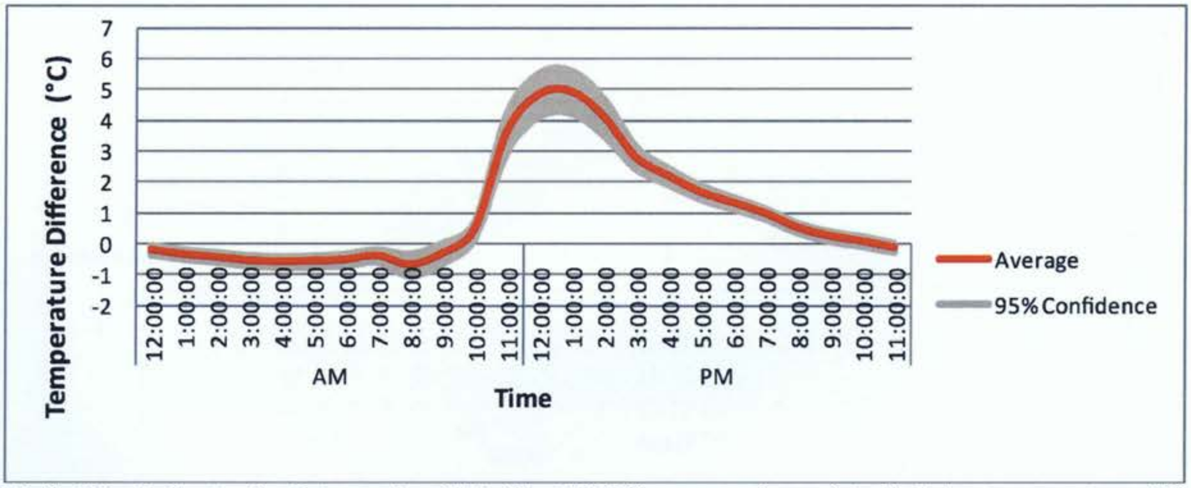
B1.38: Hart House (HHs) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



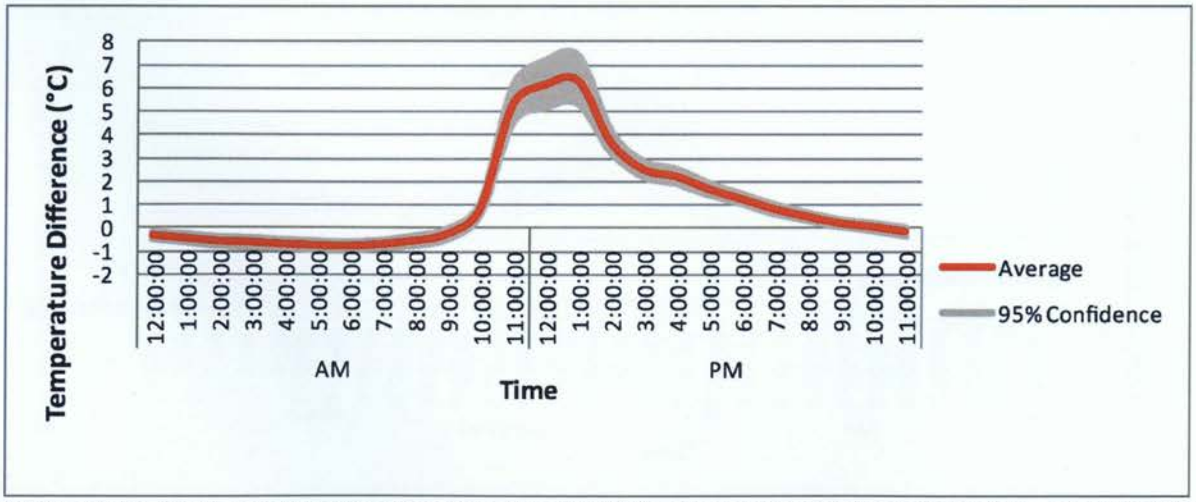
B1.39: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



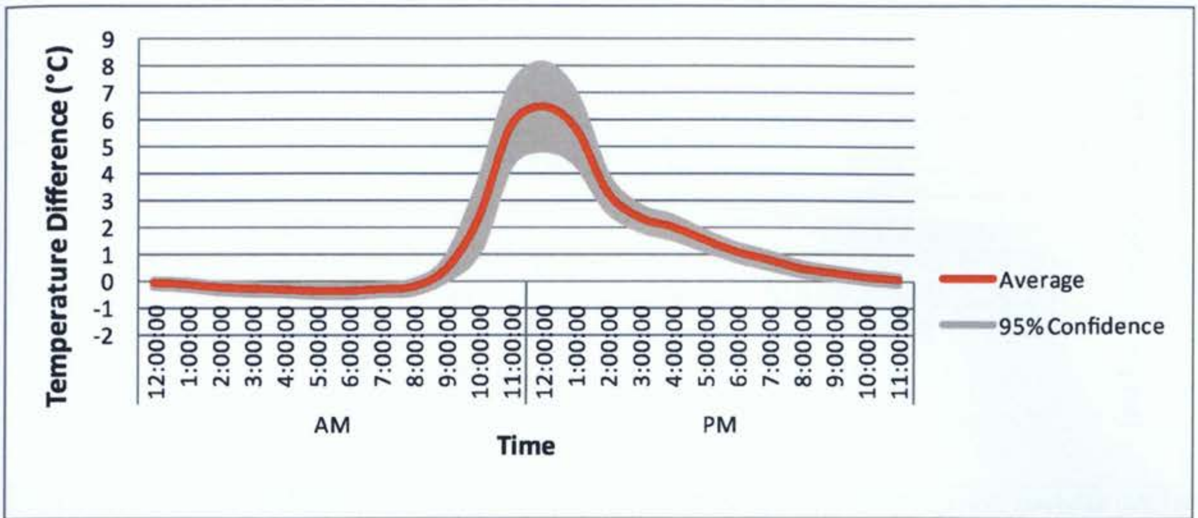
B1.40: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



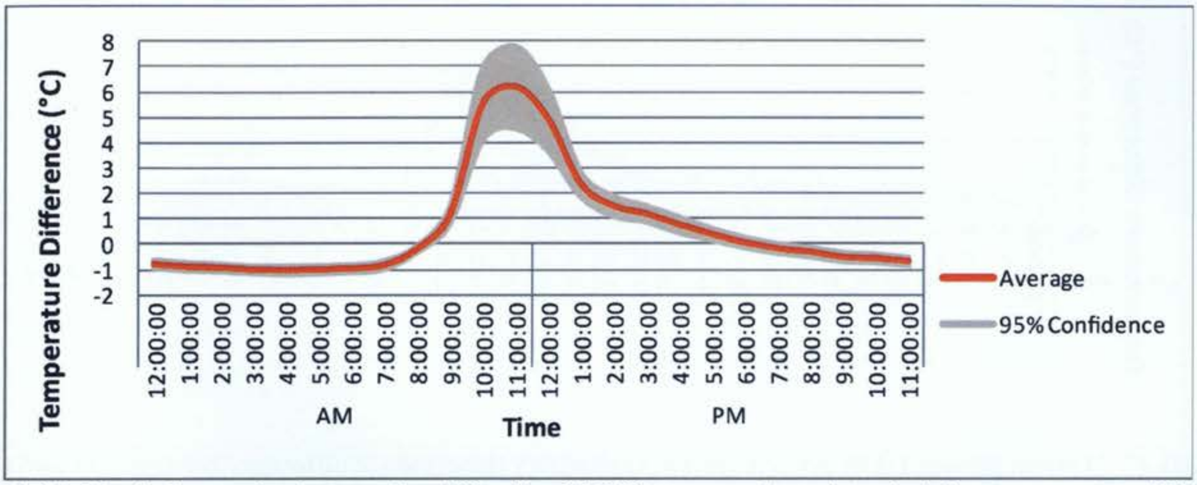
B1.41: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



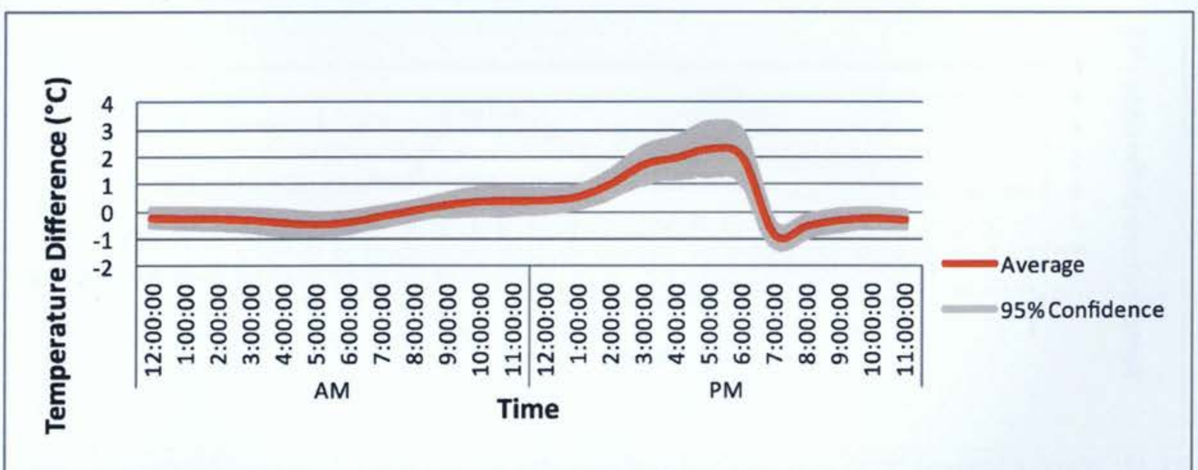
B1.42: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



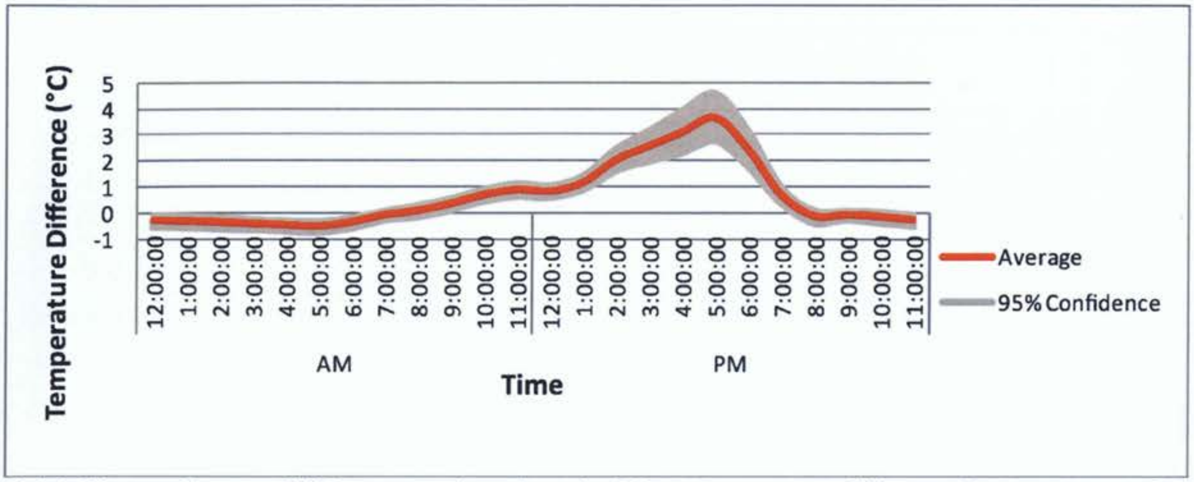
B1.43: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



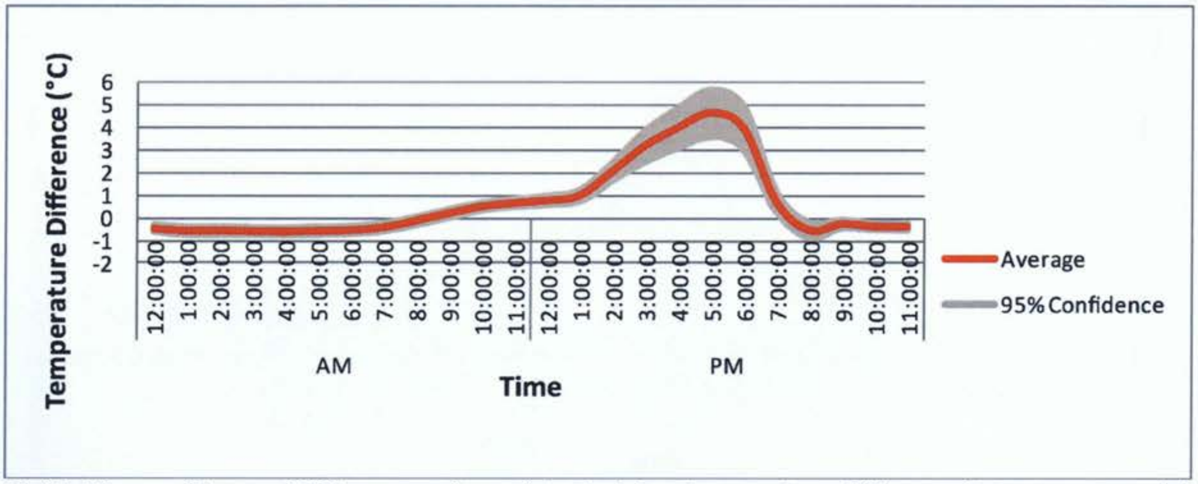
B1.44: Munk Center for International Studies (MCIS) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



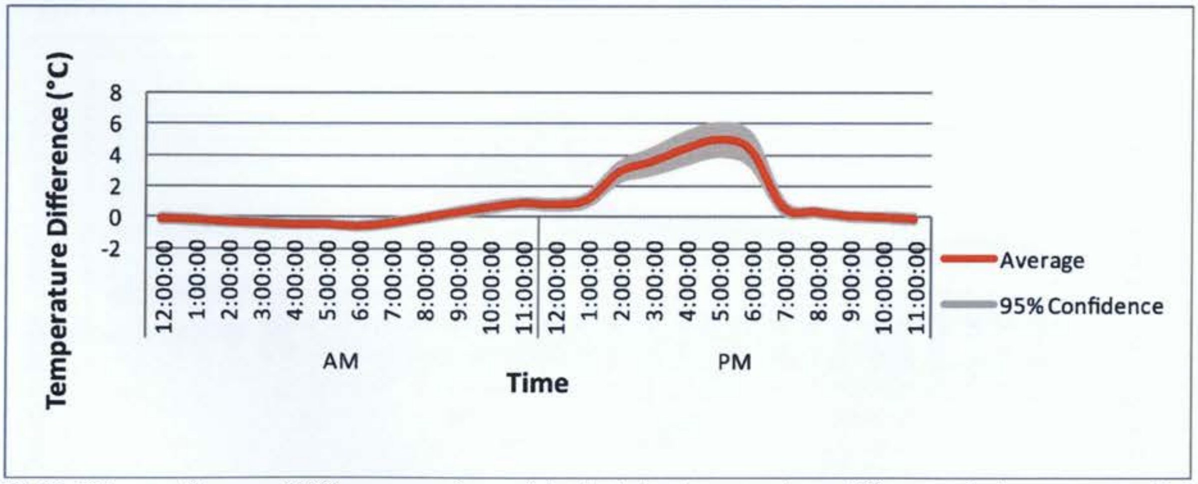
B1.45: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



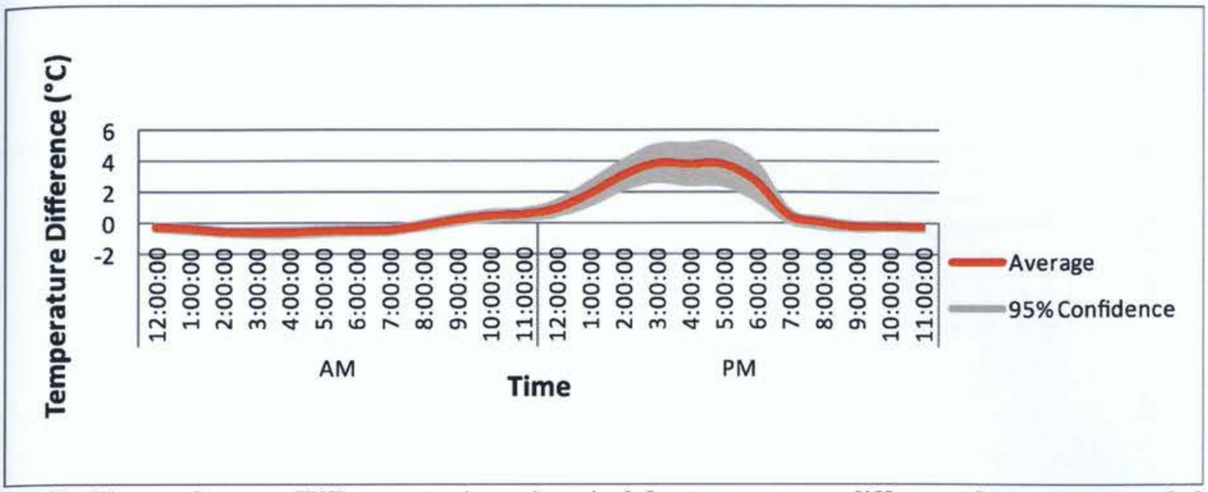
B1.46: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



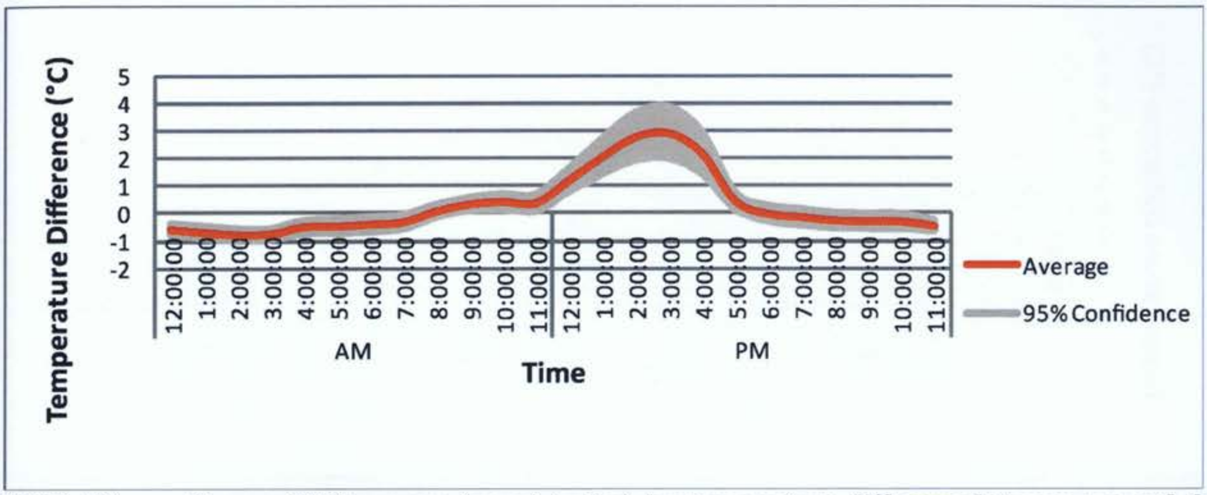
B1.47: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



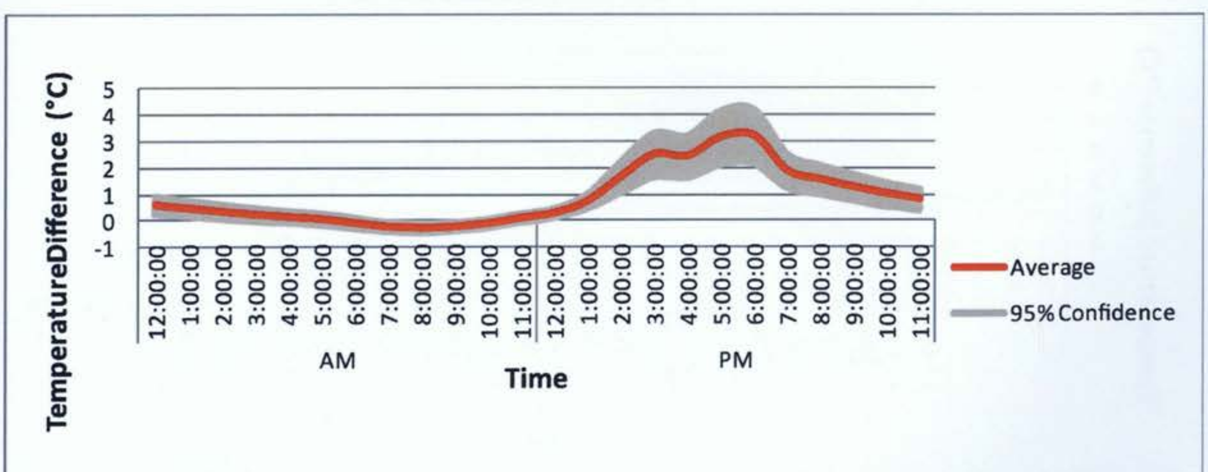
B1.48: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



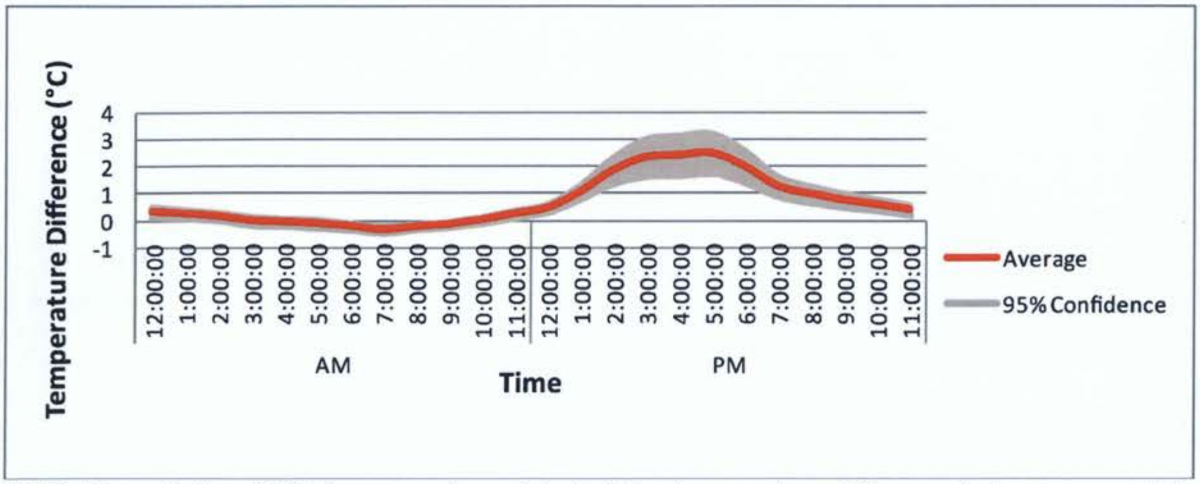
B1.49: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



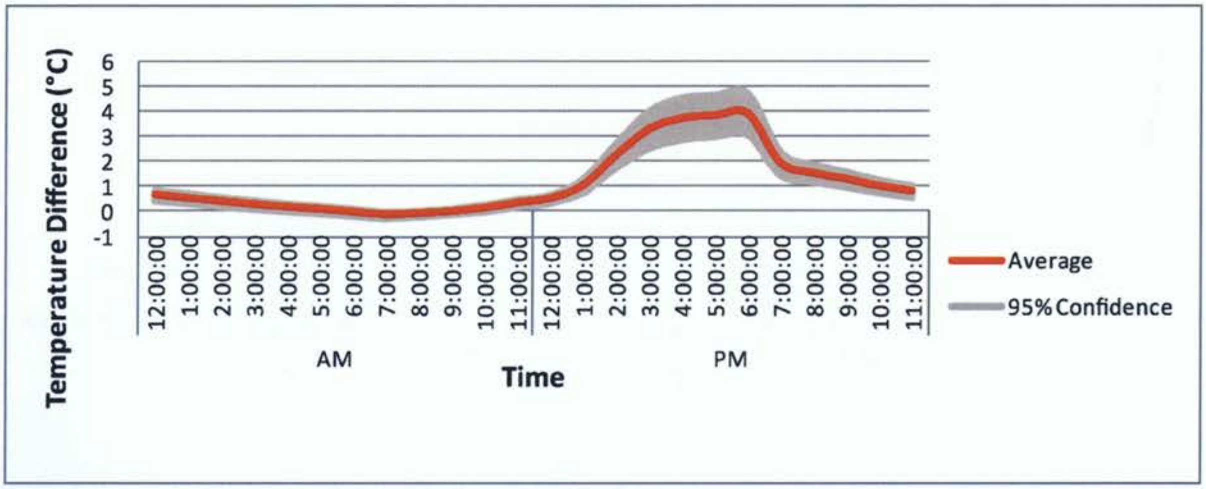
B1.50: Warren Stevens (WS) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



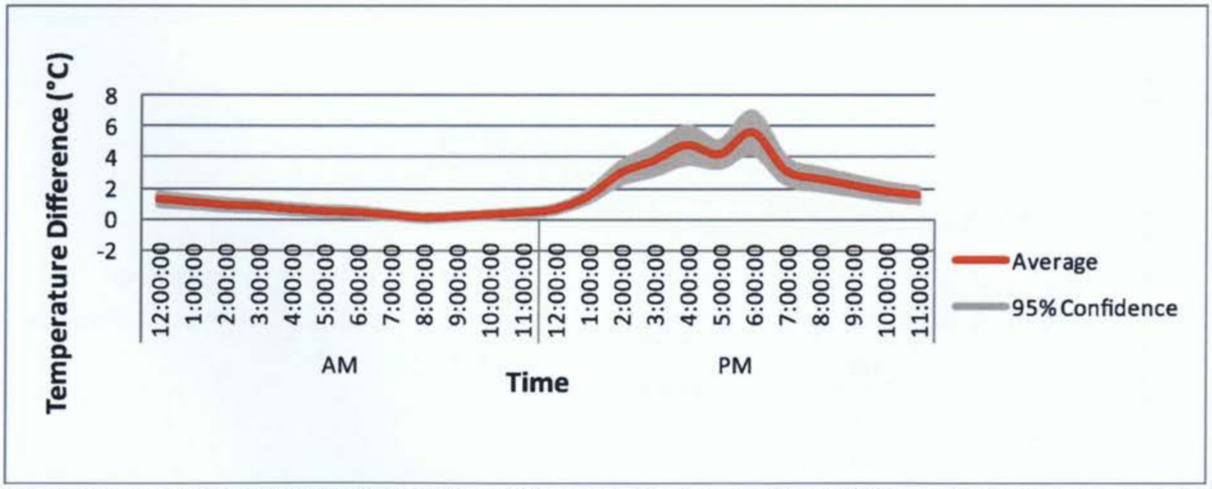
B1.51: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



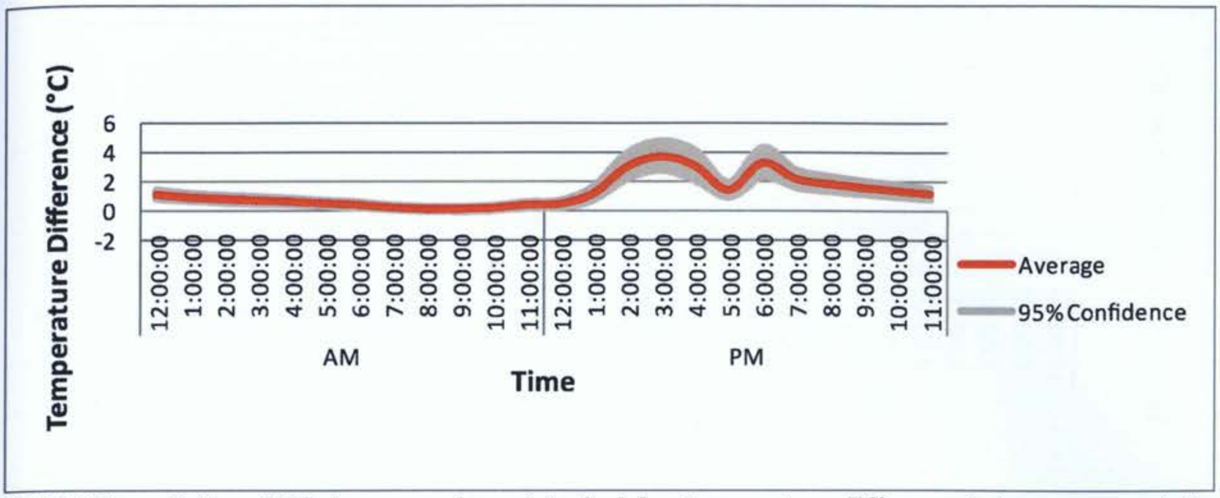
B1.52: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



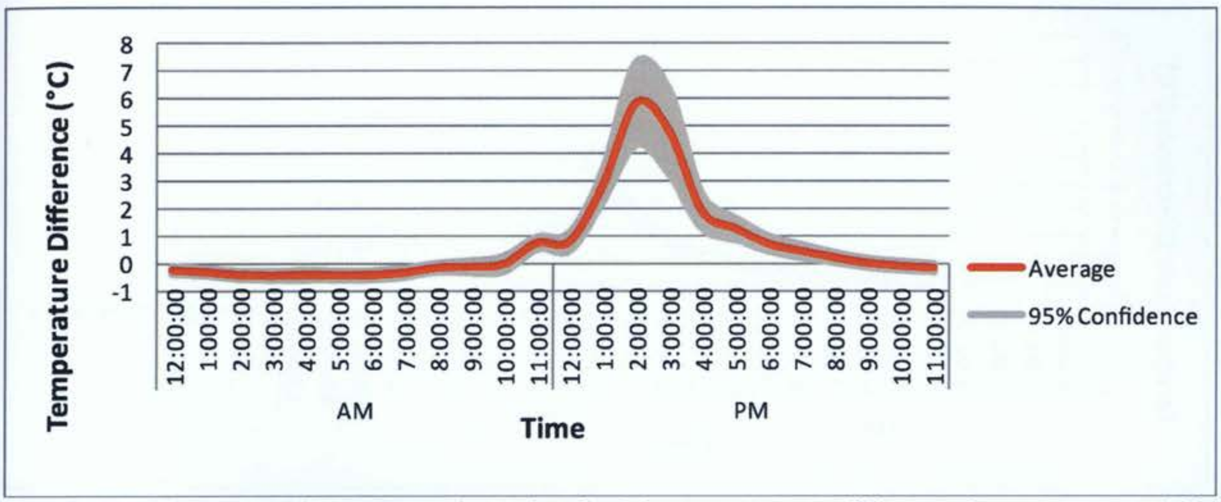
B1.53: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



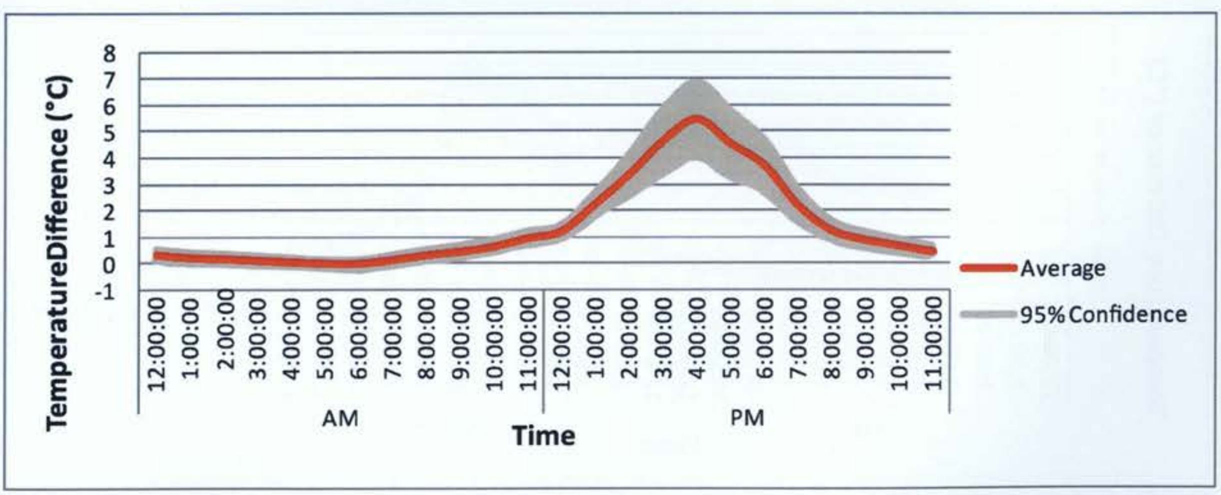
B1.54: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



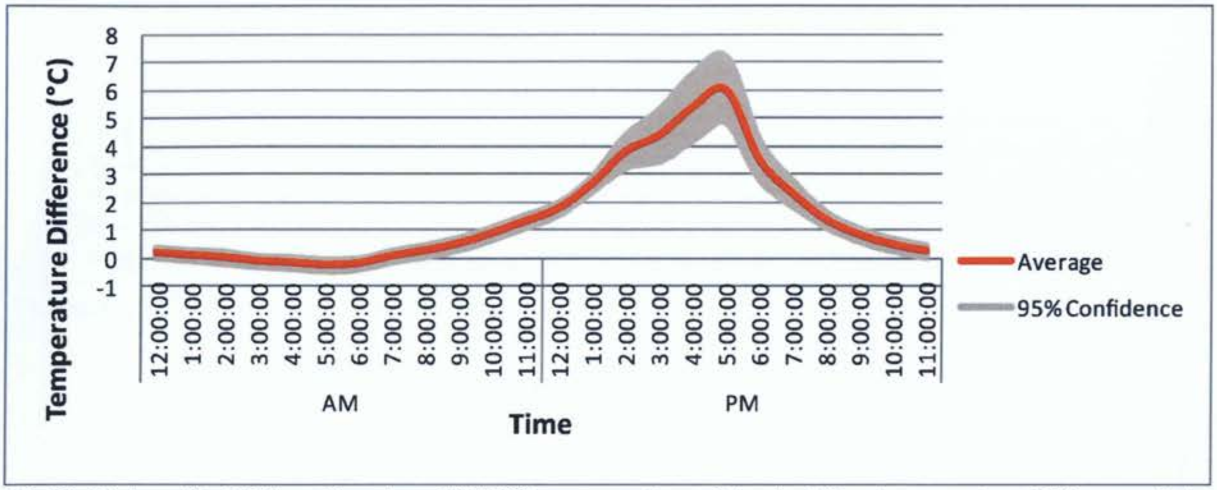
B1.55: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



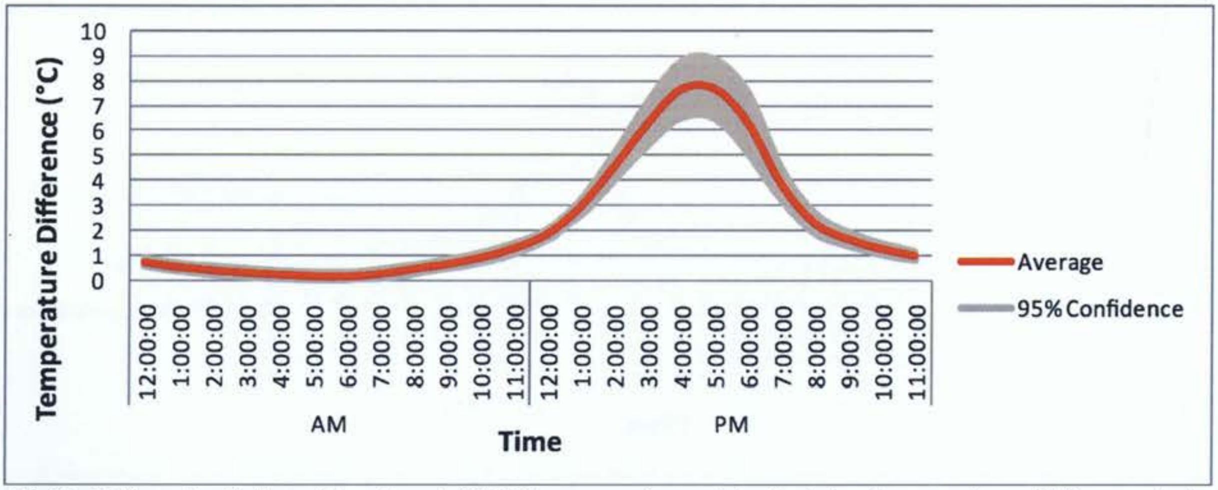
B1.56: Knox College (KCw) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



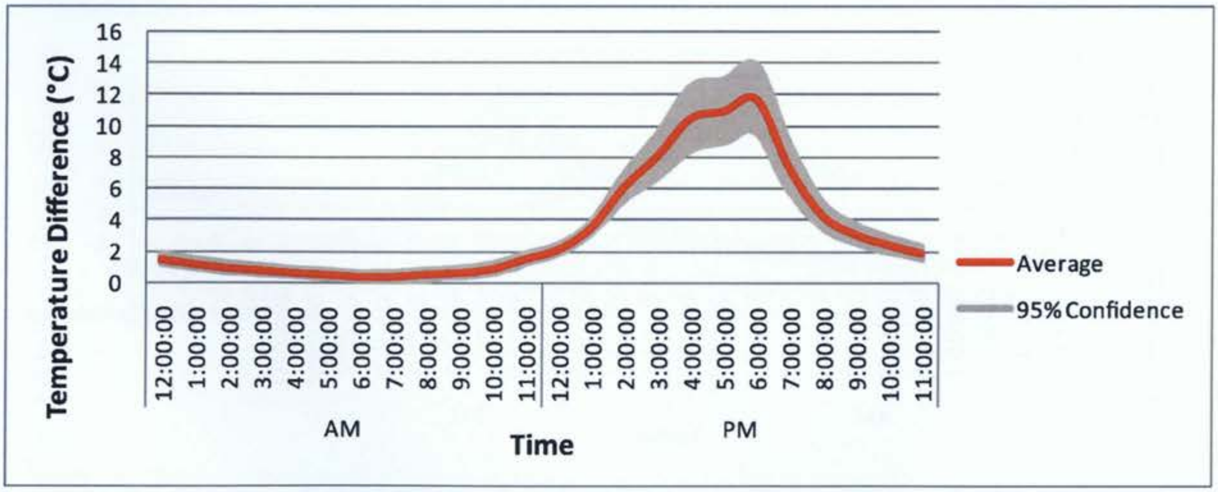
B1.57: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



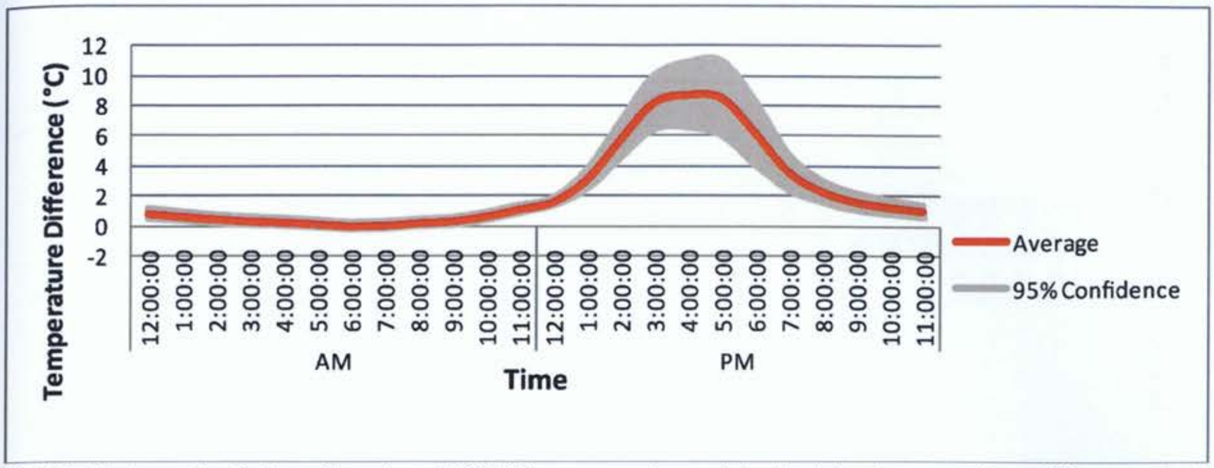
B1.58: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



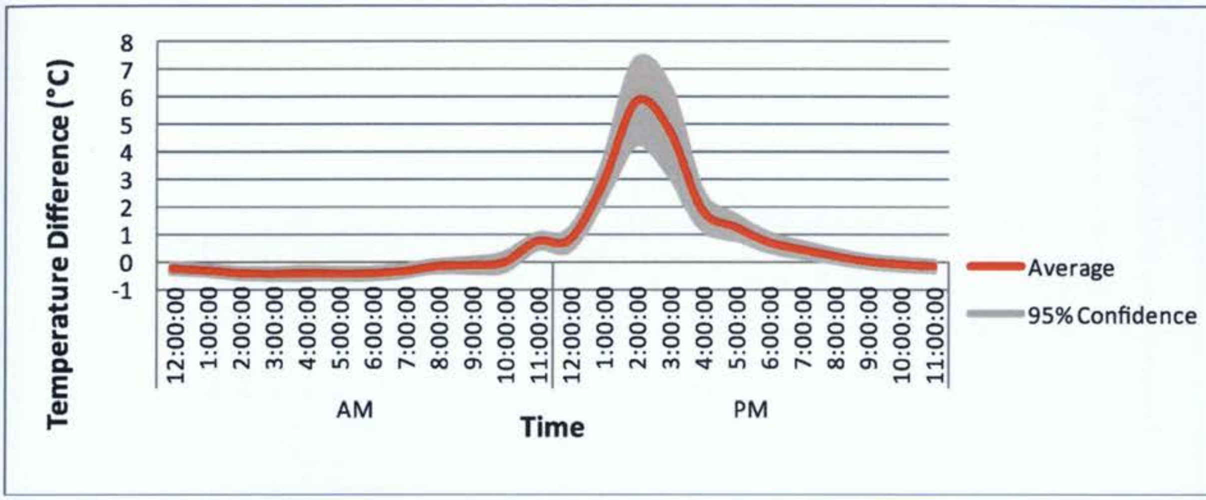
B1.59: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



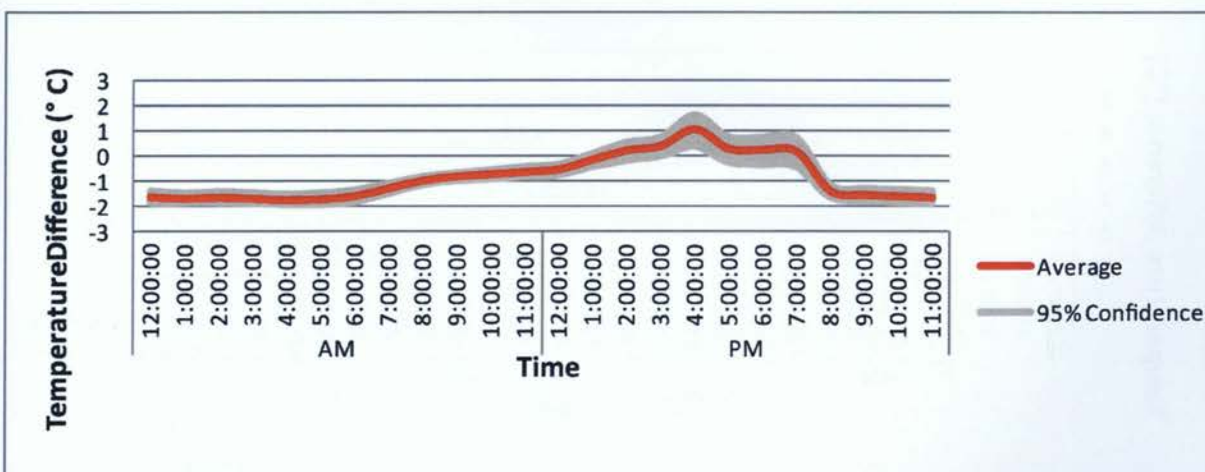
B1.60: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



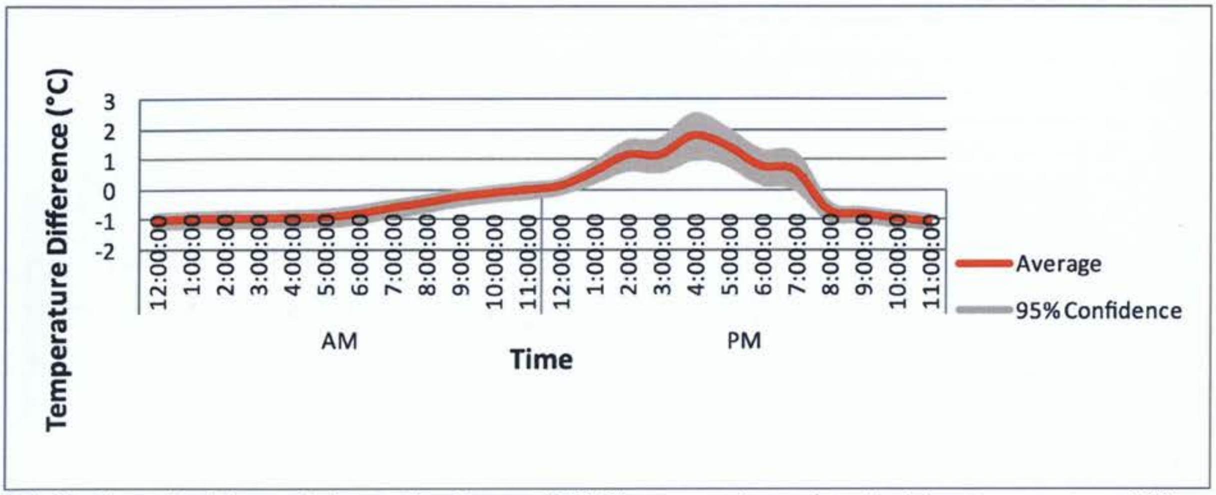
B1.61: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



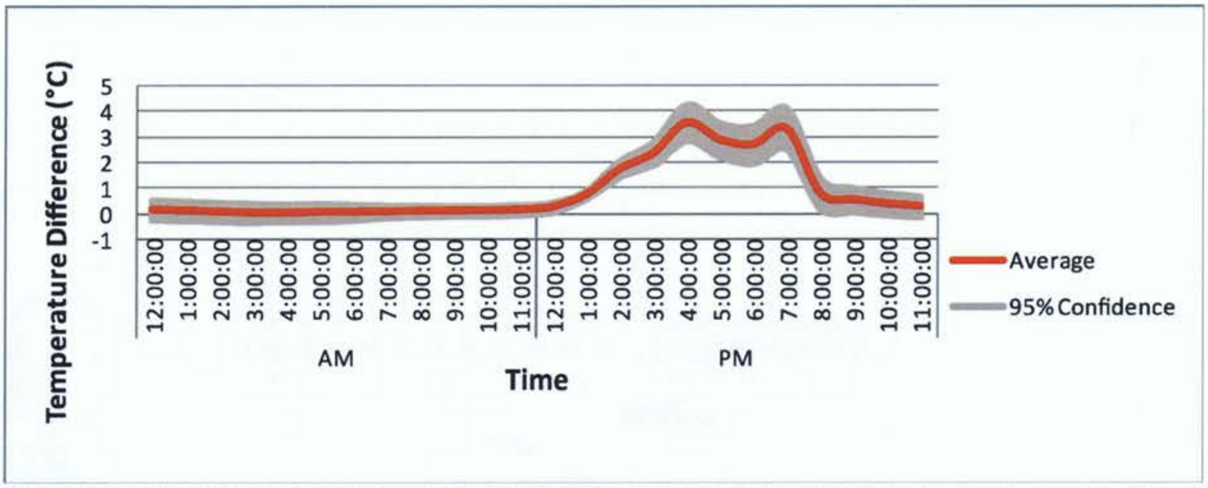
B1.62: University College Courtyard (UCC) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



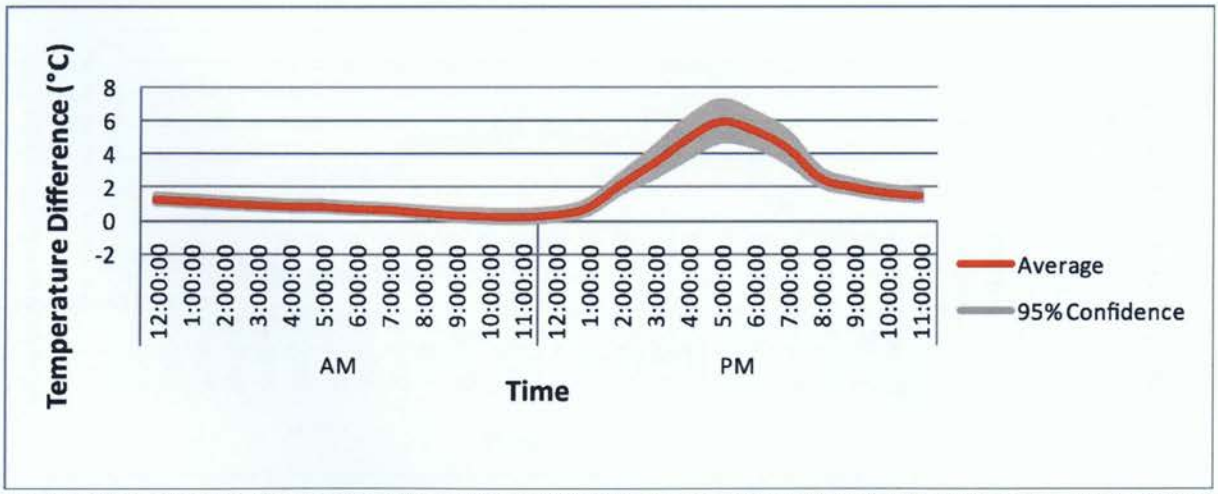
B1.63: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



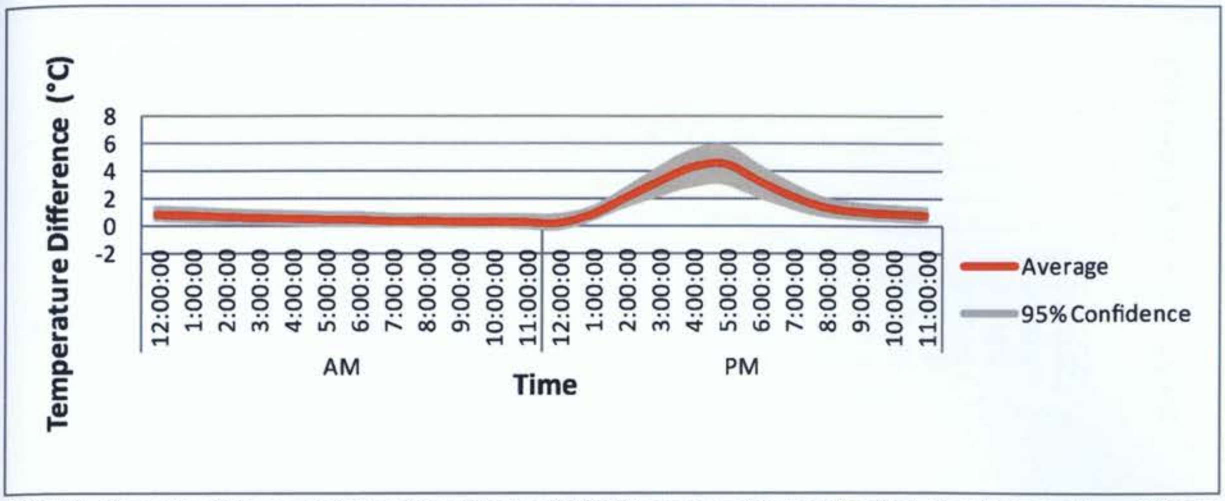
B1.64: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



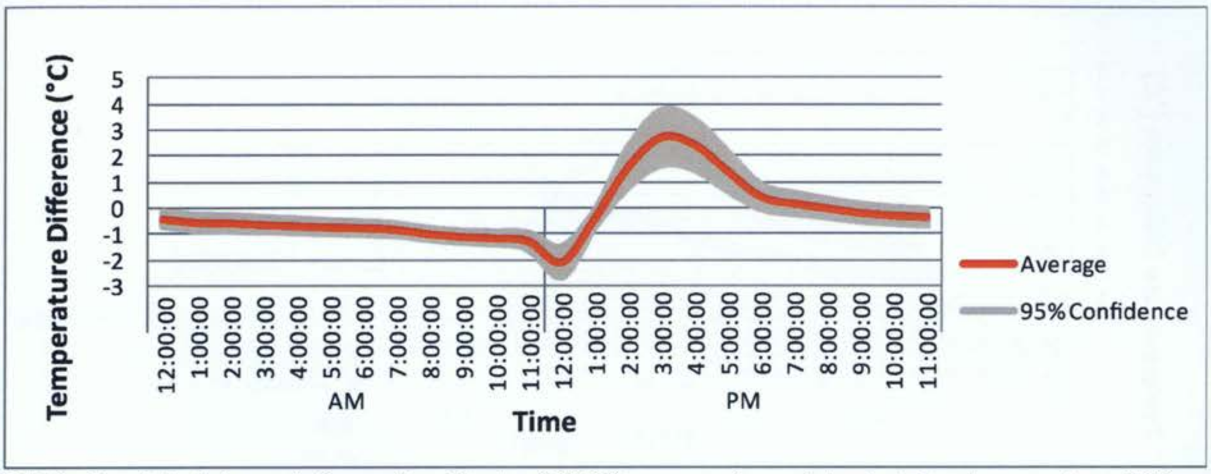
B1.65: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



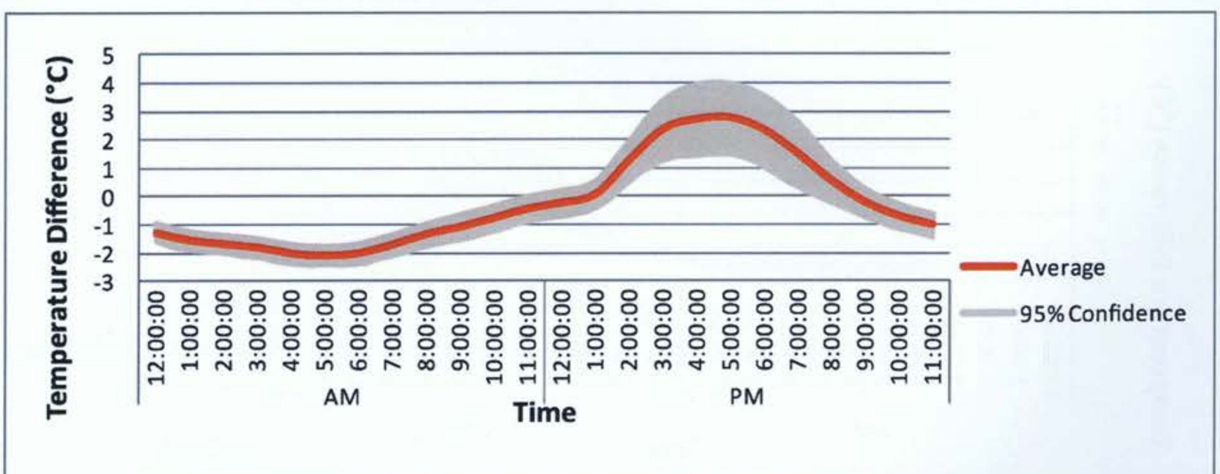
B1.66: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



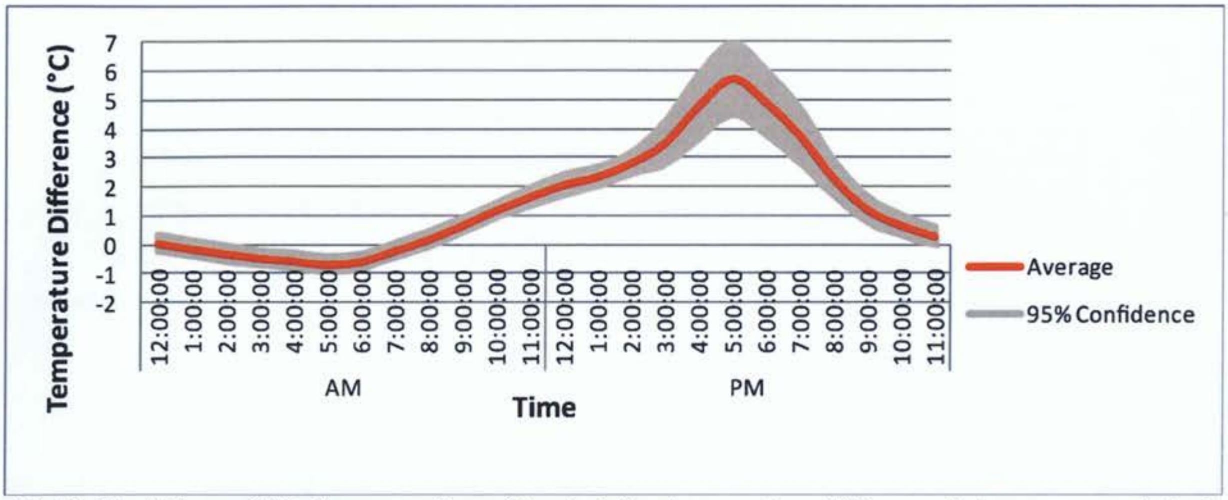
B1.67: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



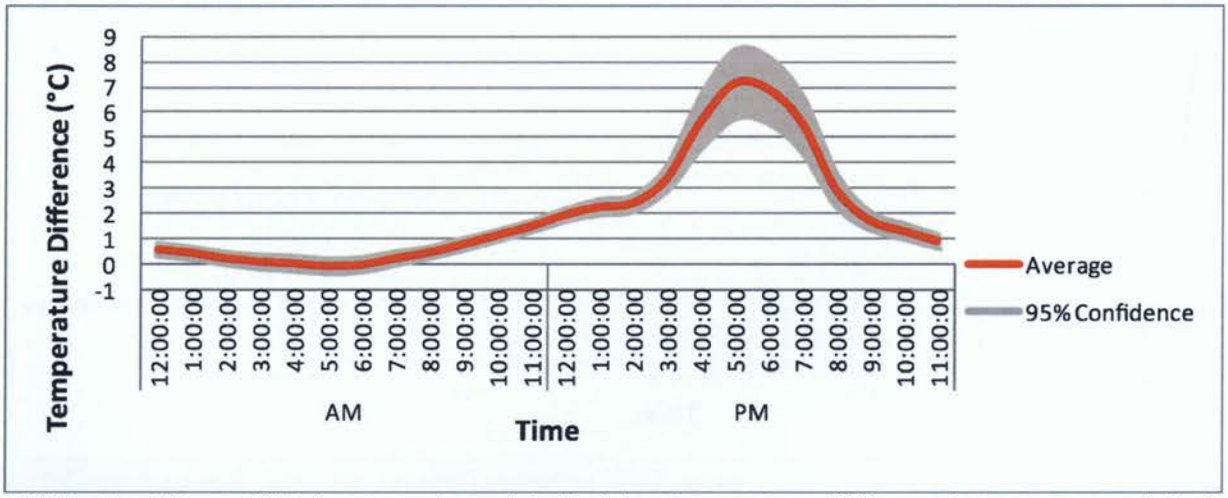
B1.68: Gerstein Science Information Center (GSIC) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008



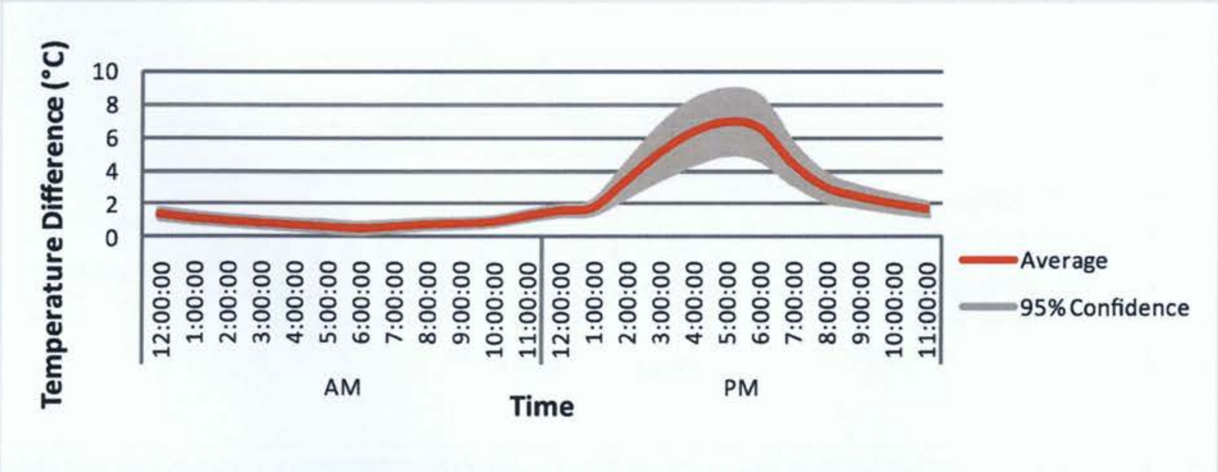
B1.69: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of May 2008



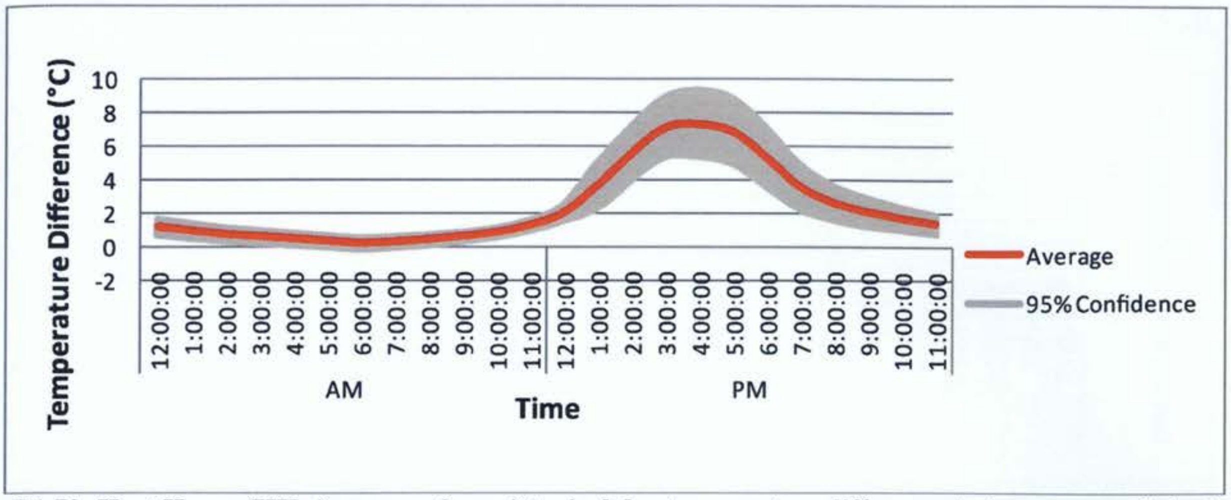
B1.70: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of June 2008



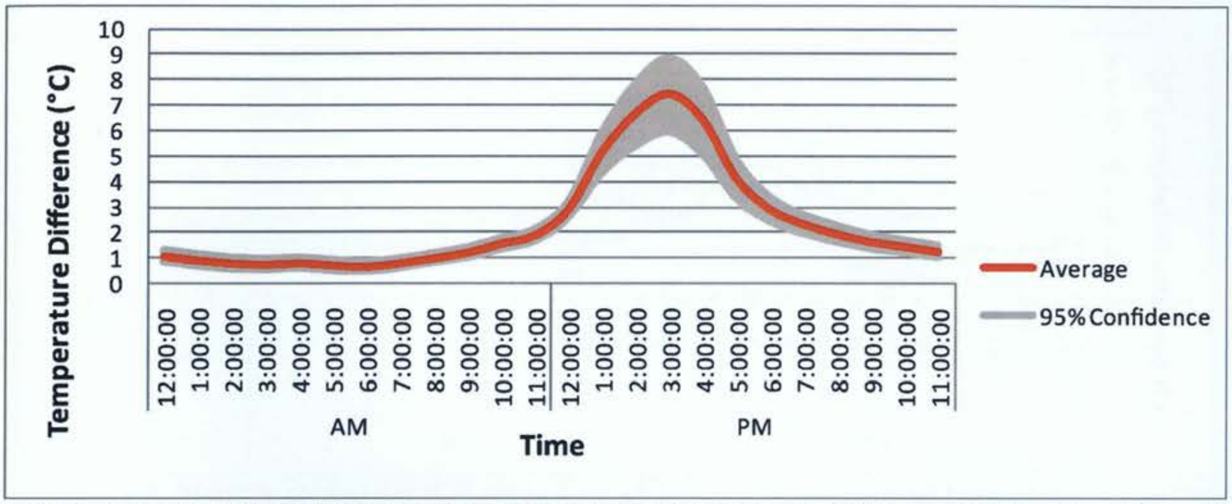
B1.71: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of July 2008



B1.72: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of August 2008



B1.73: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of September 2008



B1.74: Hart House (HHw) average (mean) typical day temperature difference between sun and shade loggers during the month of October 2008

Appendix B2 – Monthly typical day difference comparisons for each site

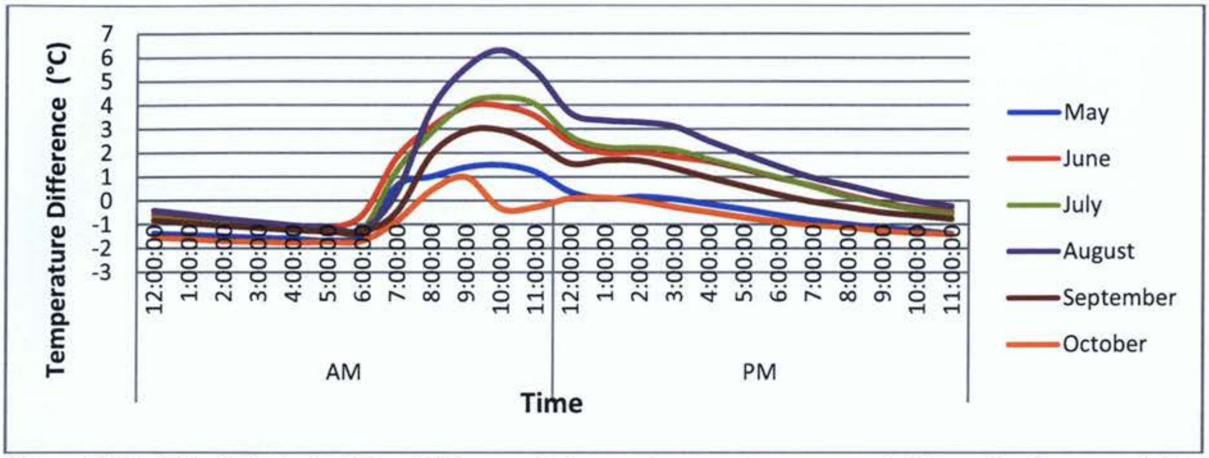


Figure B2.1: Monthly typical day difference between temperatures recorded from both sun and shade loggers at TCe for the duration of study May 1, 2008 – October 31, 2008.

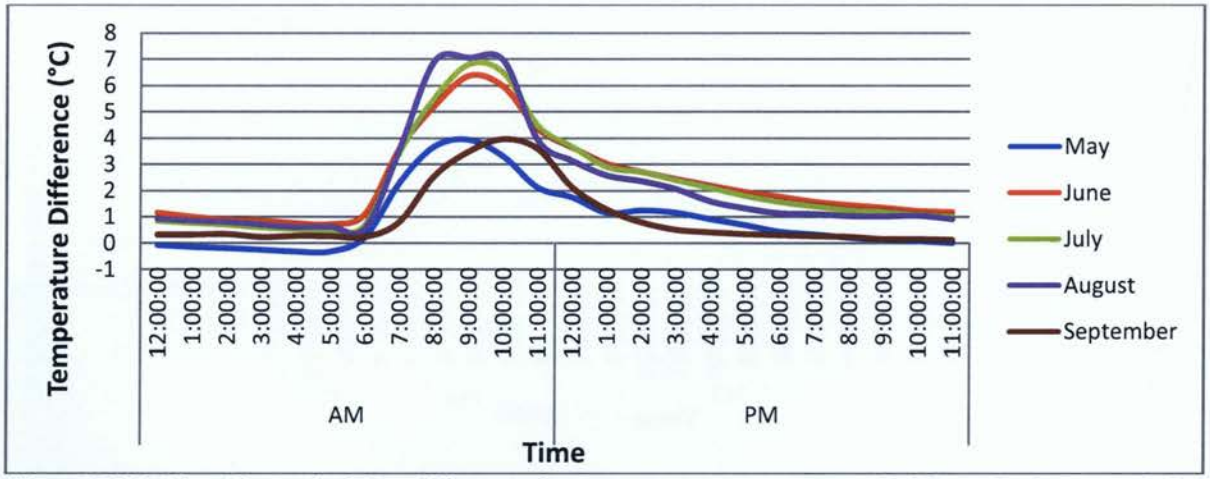


Figure B2.2: Monthly typical day difference between temperatures recorded from both sun and shade loggers at KCe for the duration of study May 1, 2008 – September 30, 2008.

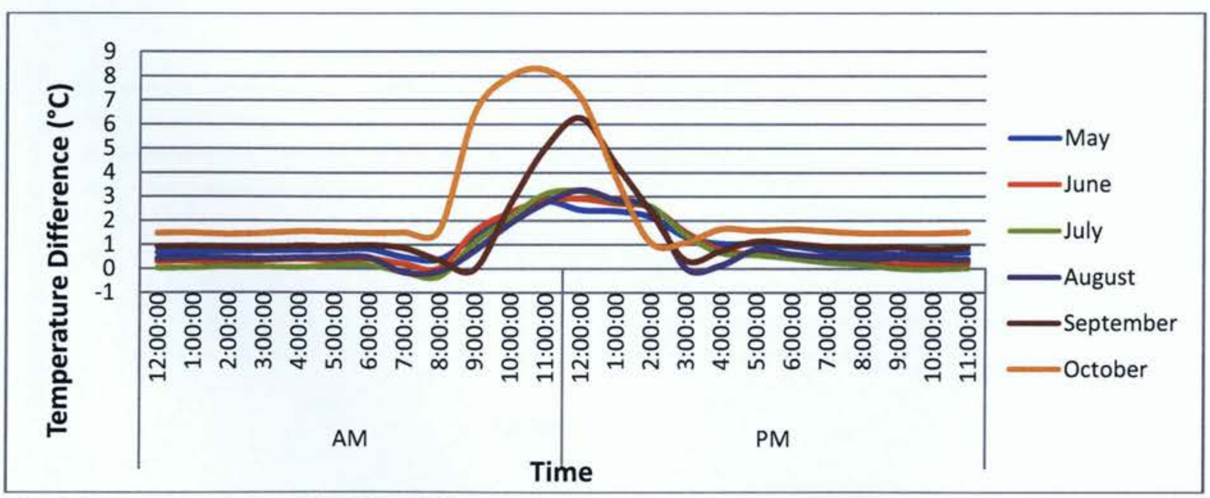


Figure B2.3: Monthly typical day difference between temperatures recorded from both sun and shade loggers at TC(1) for the duration of study May 1, 2008 – October 31, 2008.

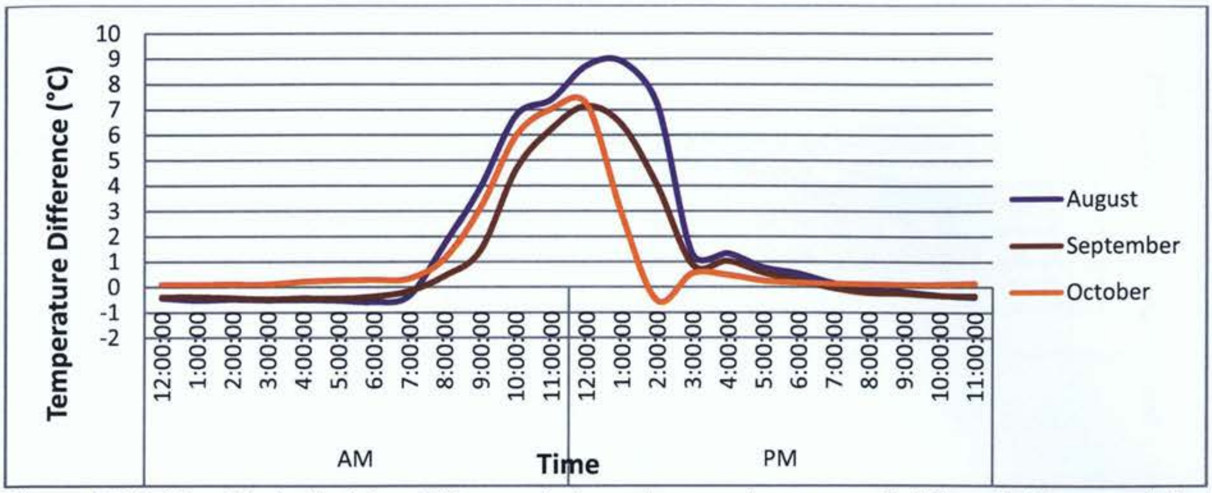


Figure B2.4: Monthly typical day difference between temperatures recorded from both sun and shade loggers at TC(2) for the duration of study May 1, 2008 – October 31, 2008.

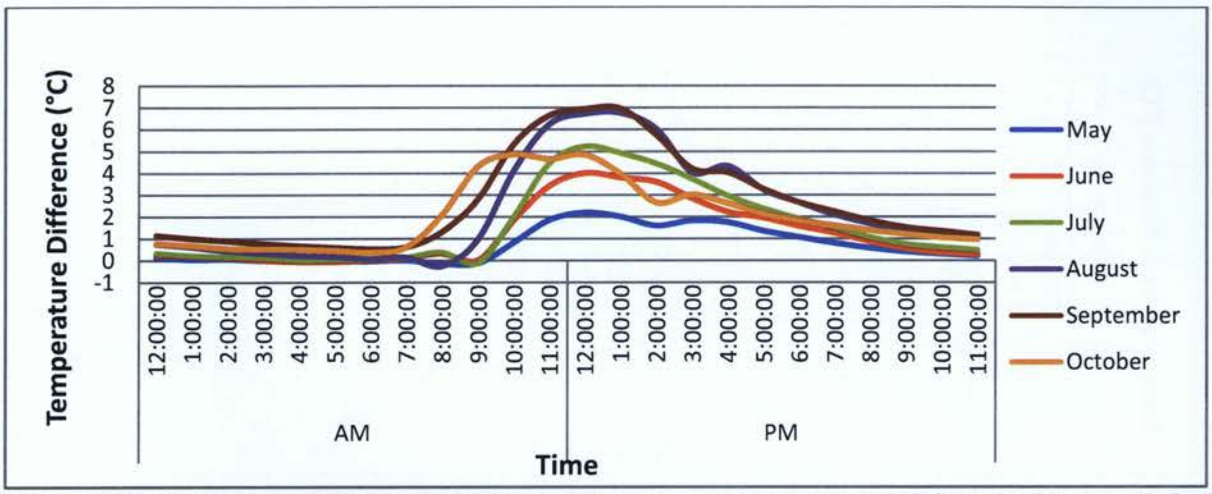


Figure B2.5: Monthly typical day difference between temperatures recorded from both sun and shade loggers at UC(1) for the duration of study May 1, 2008 – October 31, 2008.

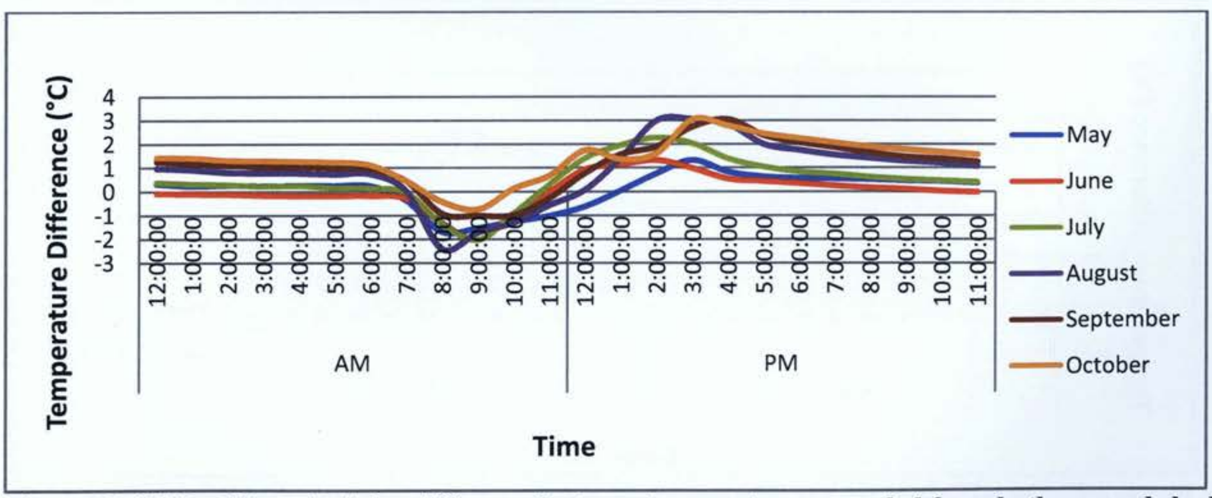


Figure B2.6: Monthly typical day difference between temperatures recorded from both sun and shade loggers at UC(2) for the duration of study May 1, 2008 – October 31, 2008.

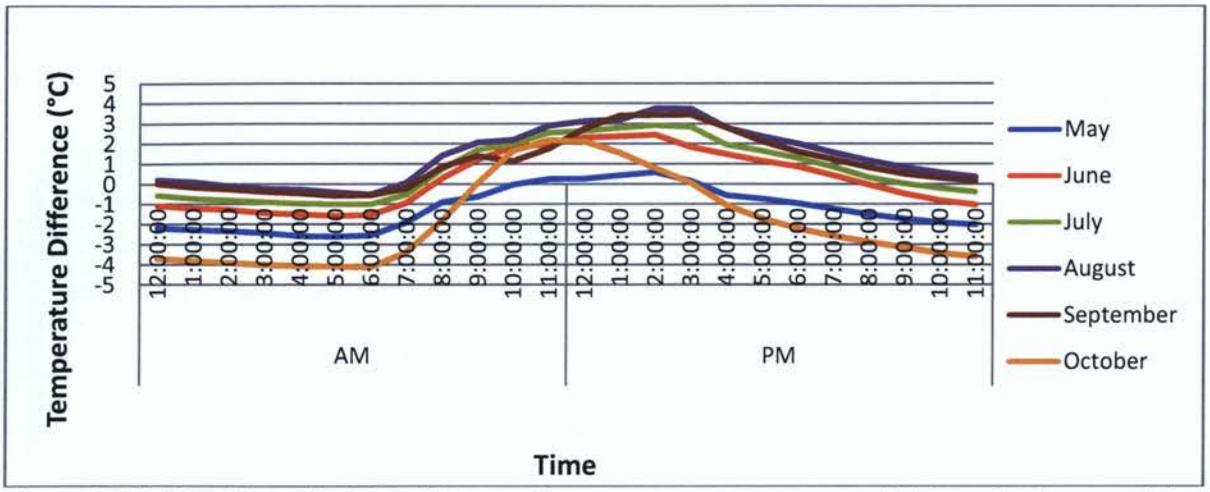


Figure B2.7: Monthly typical day difference between temperatures recorded from both sun and shade loggers at HHs for the duration of study May 1, 2008 – October 31, 2008.

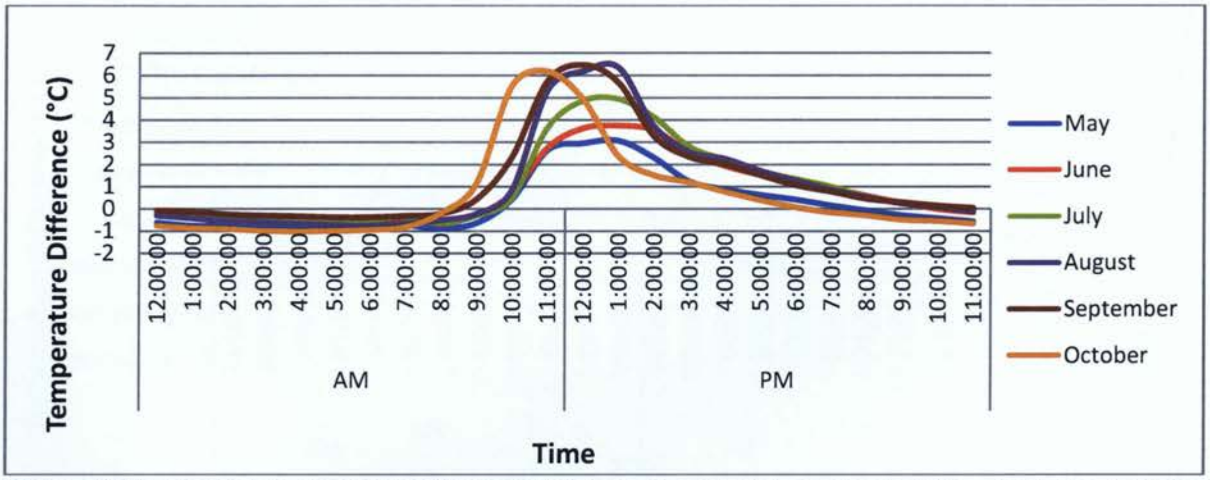


Figure B2.7: Monthly typical day difference between temperatures recorded from both sun and shade loggers at MCIS for the duration of study May 1, 2008 – October 31, 2008.

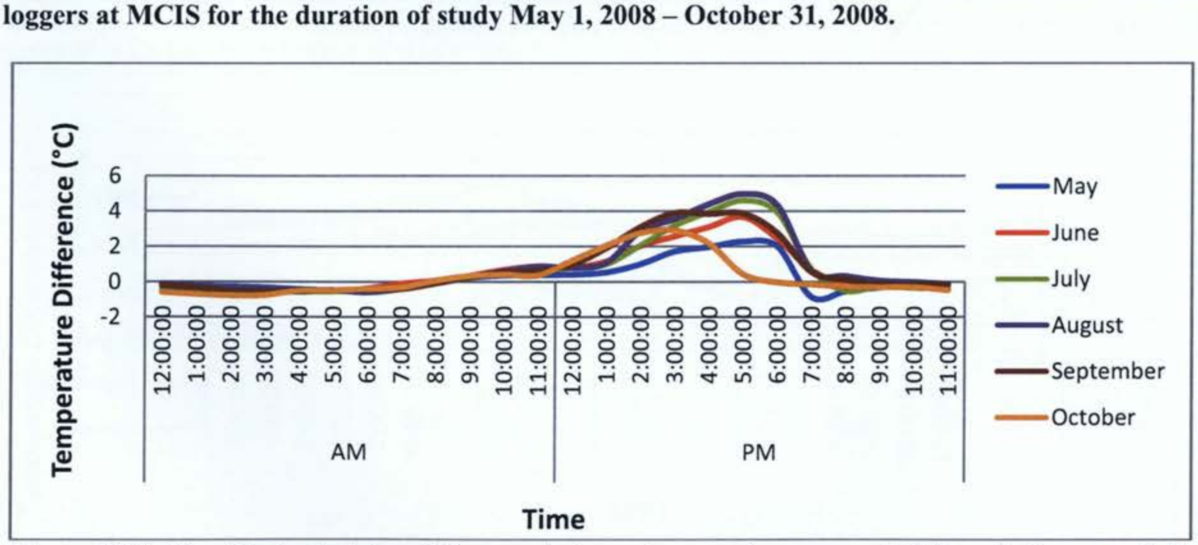


Figure B2.8: Monthly typical day difference between temperatures recorded from both sun and shade loggers at WS for the duration of study May 1, 2008 – October 31, 2008.

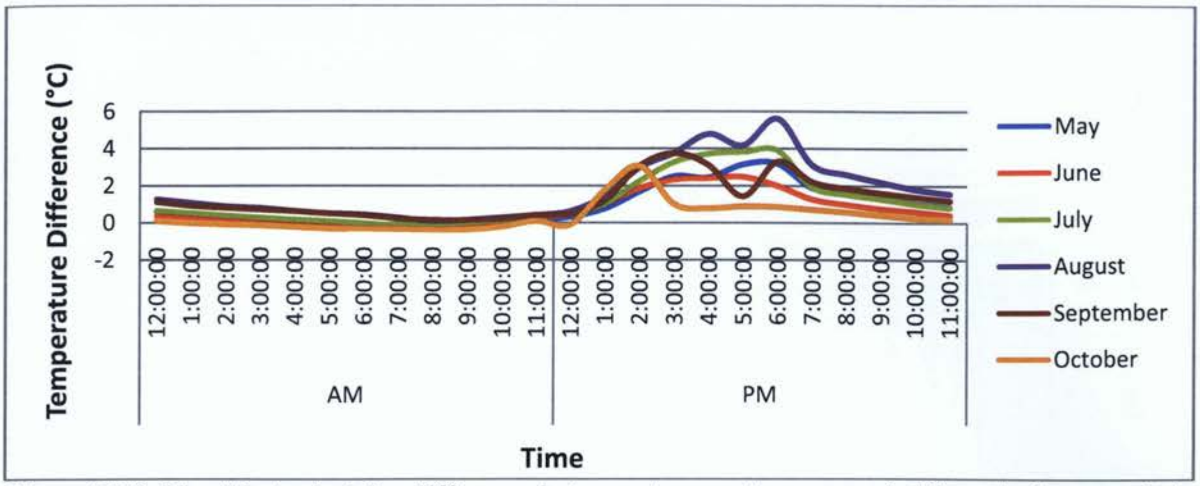


Figure B2.9: Monthly typical day difference between temperatures recorded from both sun and shade loggers at KCw for the duration of study May 1, 2008 – October 31, 2008.

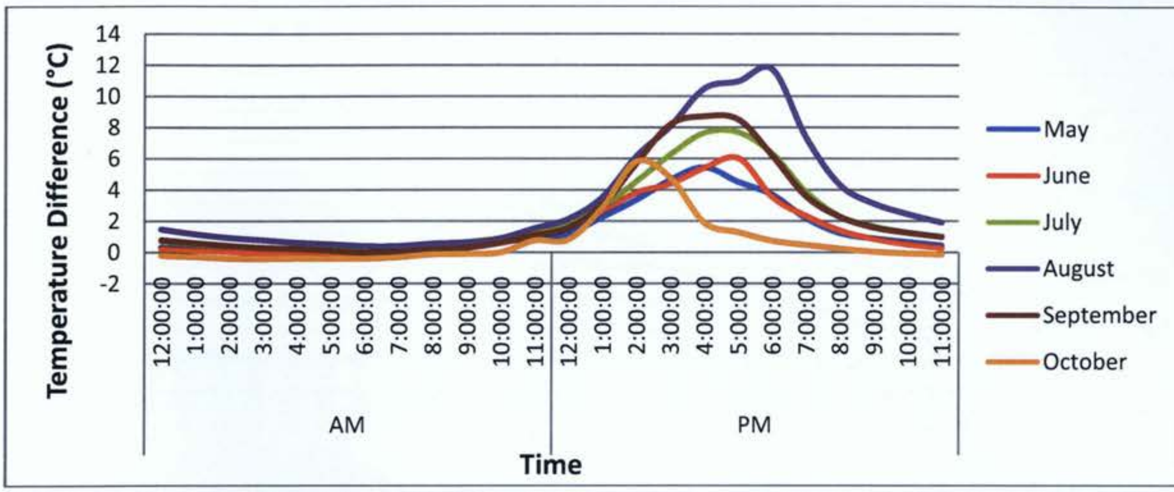


Figure B2.10: Monthly typical day difference between temperatures recorded from both sun and shade loggers at UCC for the duration of study May 1, 2008 – October 31, 2008.

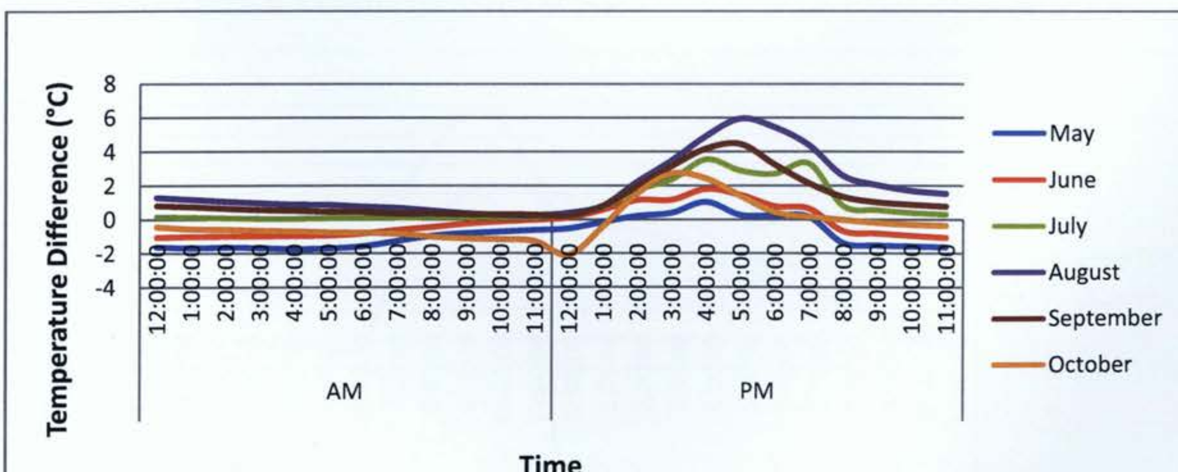


Figure B2.11: Monthly typical day difference between temperatures recorded from both sun and shade loggers at GSIC for the duration of study May 1, 2008 – October 31, 2008.

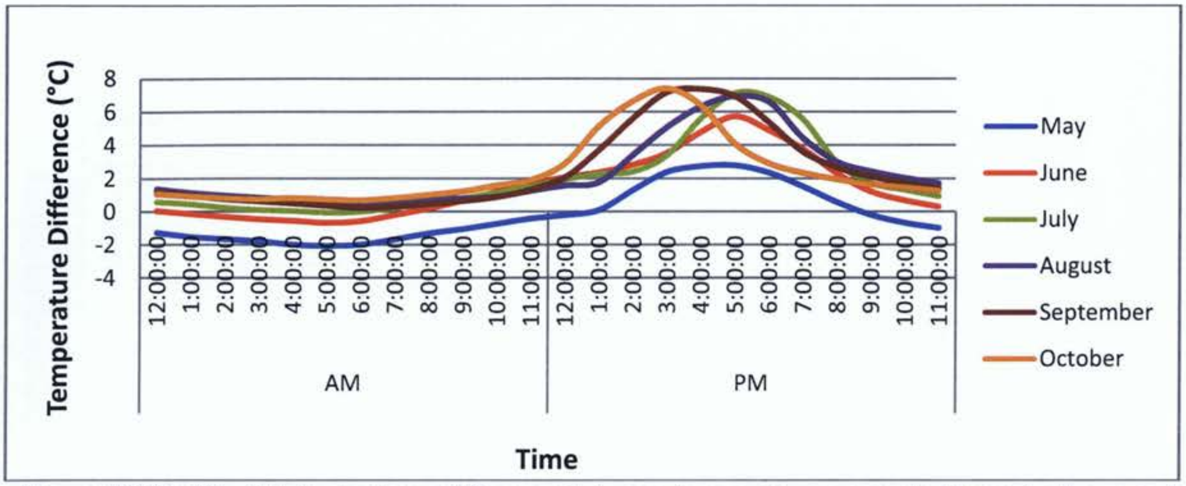


Figure B2.12: Monthly typical day difference between temperatures recorded from both sun and shade loggers at HHw for the duration of study May 1, 2008 – October 31, 2008.

Appendix B3 – Site-to-site typical day difference comparisons

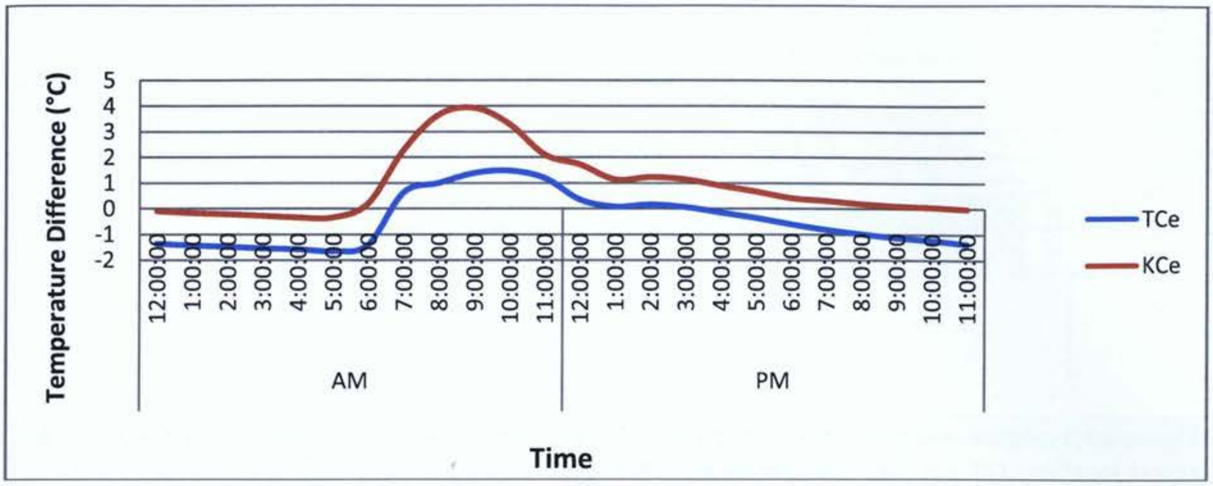


Figure B3.1: Site comparisons for typical day difference between sun and shade loggers for east facing aspect locations (TCe & KCe) for the month of May.

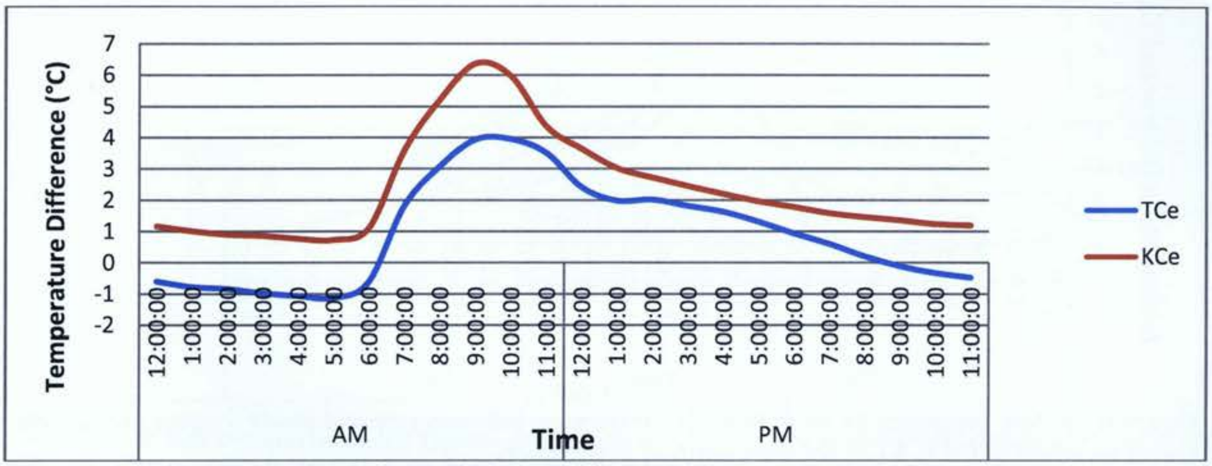


Figure B3.2: Site comparisons for typical day difference between sun and shade loggers for east facing aspect locations (TCe & KCe) for the month of June.

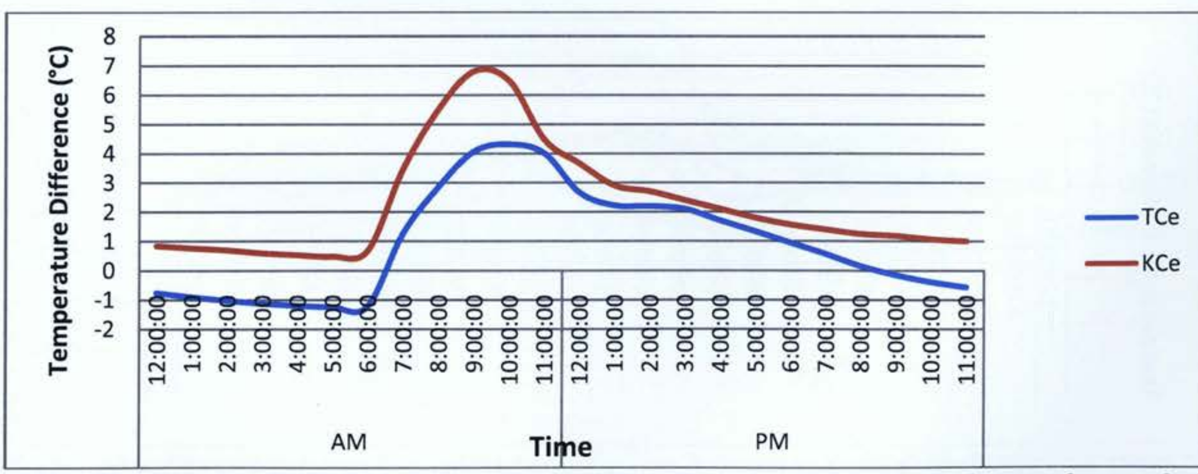


Figure B3.3: Site comparisons for typical day difference between sun and shade loggers for east facing aspect locations (TCe & KCe) for the month of July.

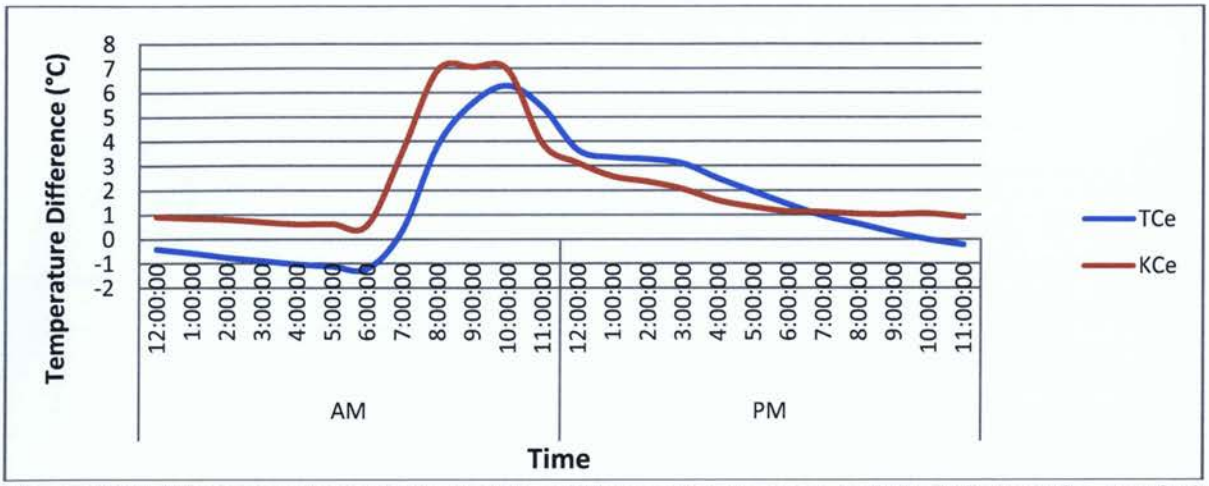


Figure B3.4: Site comparisons for typical day difference between sun and shade loggers for east facing aspect locations (TCe & KCe) for the month of August.

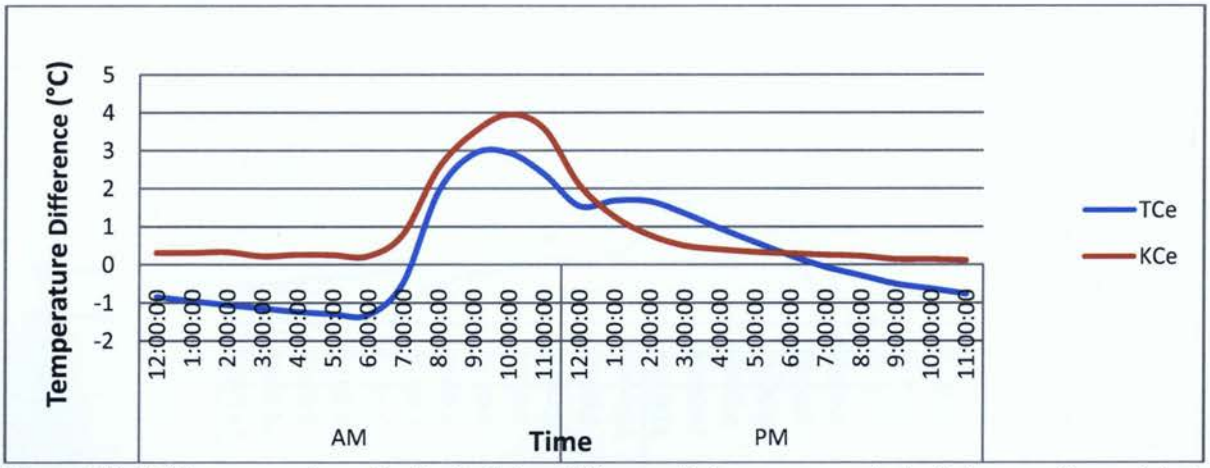


Figure B3.5: Site comparisons for typical day difference between sun and shade loggers for east facing aspect locations (TCe & KCe) for the month of September.

***Note: The month of October comparisons was omitted because of on-site construction at Knox College**

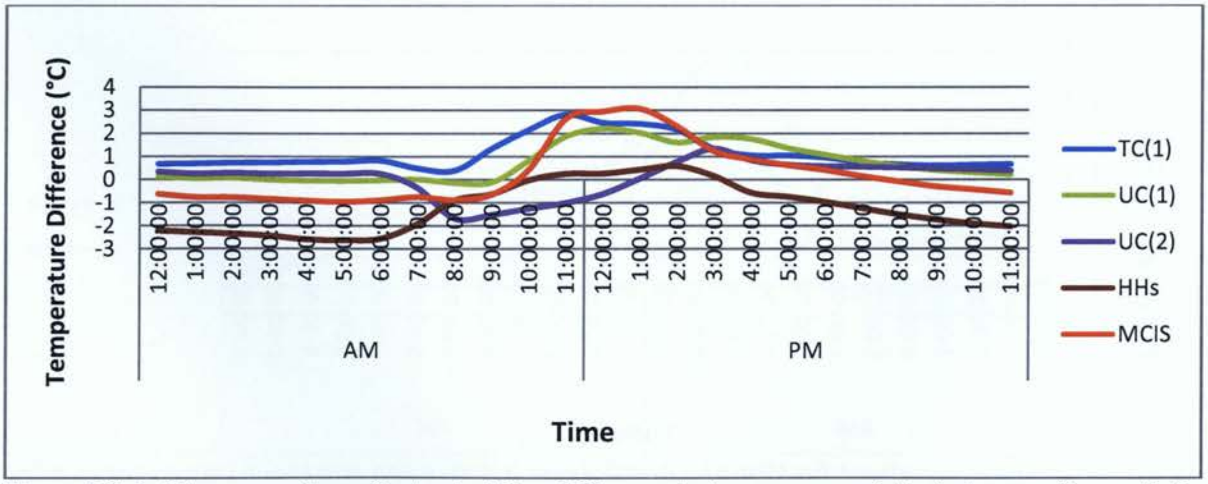


Figure B3.6: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of May.

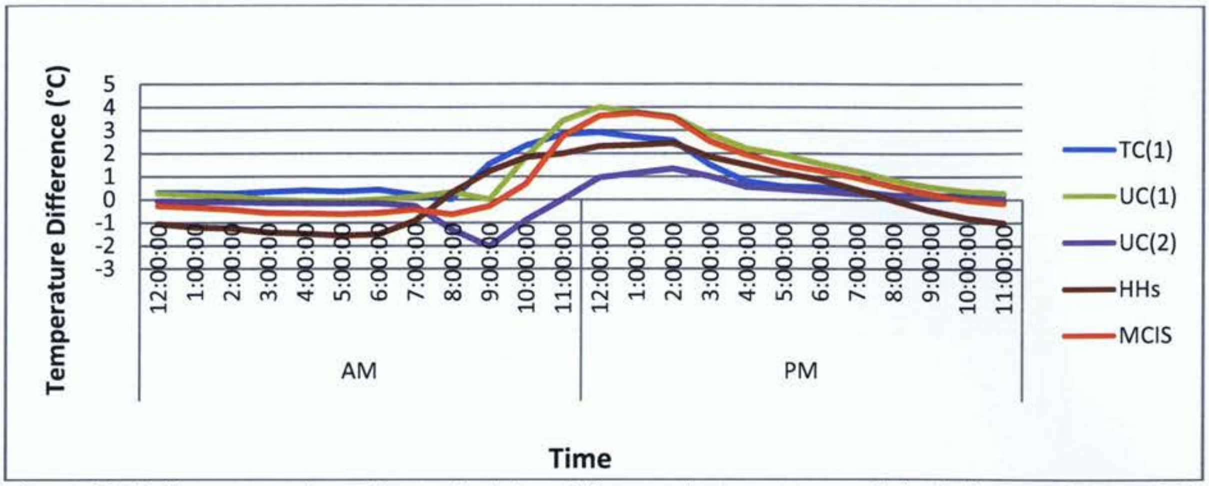


Figure B3.7: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of June.

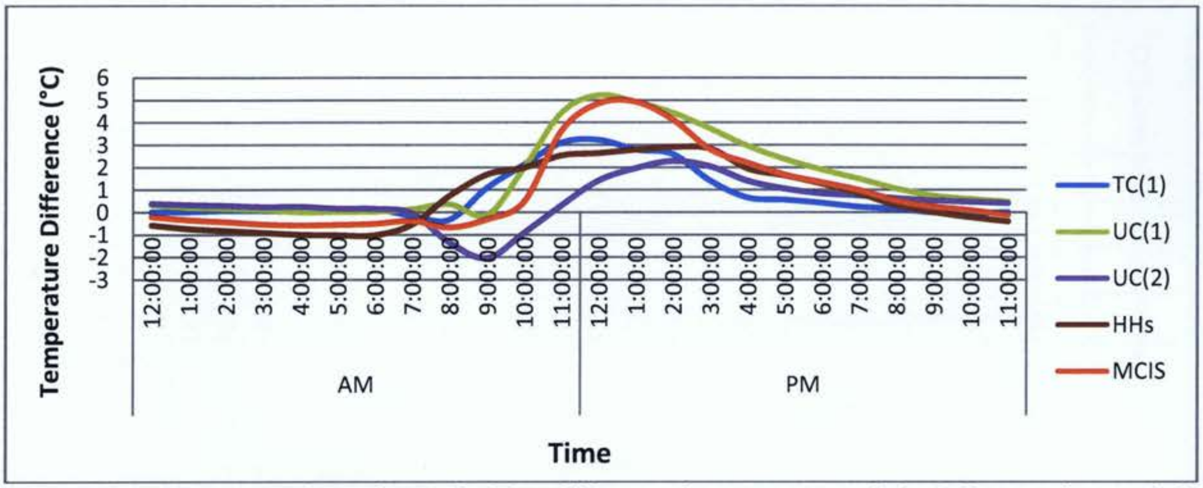


Figure B3.8: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of July.

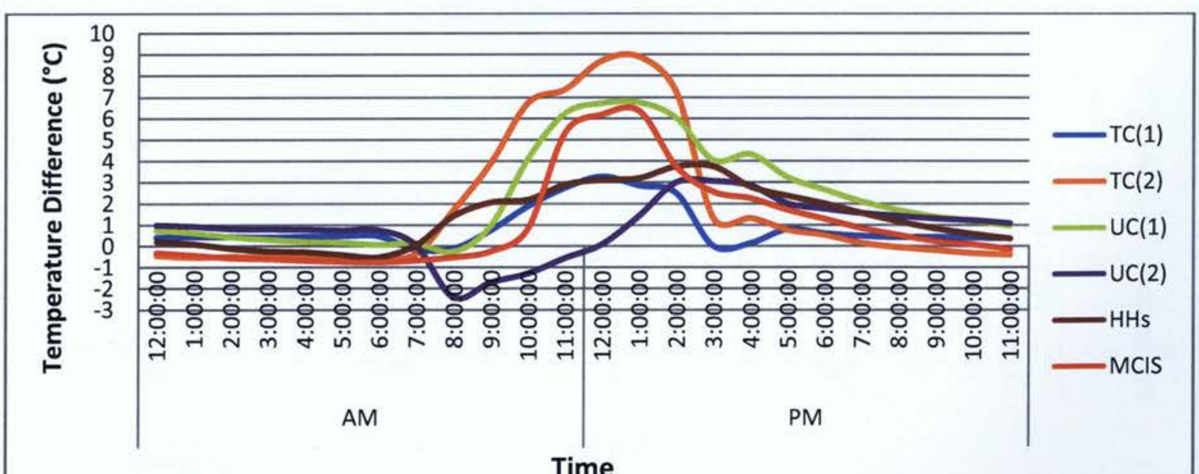


Figure B3.9: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of August.

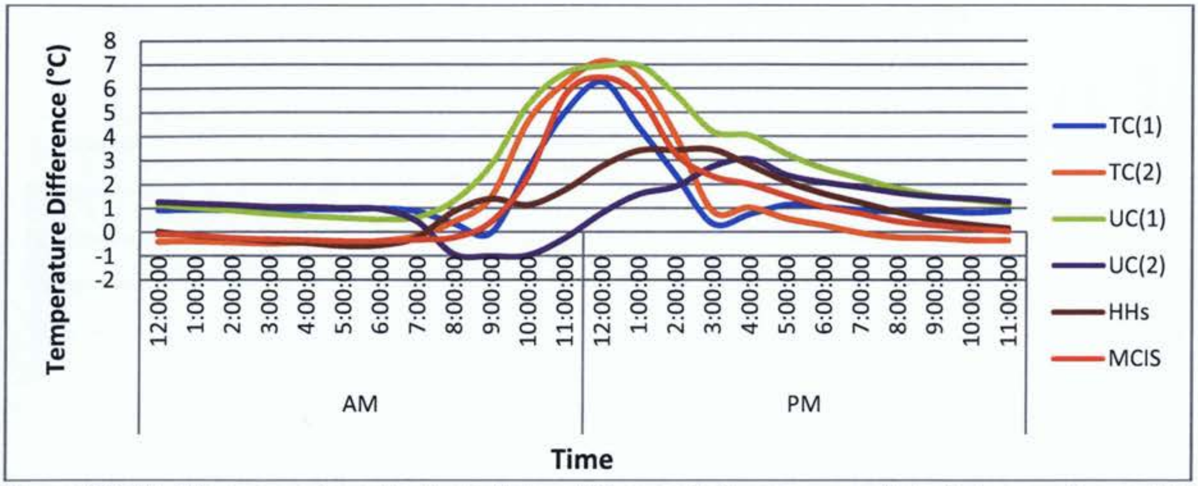


Figure B3.10: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of September.

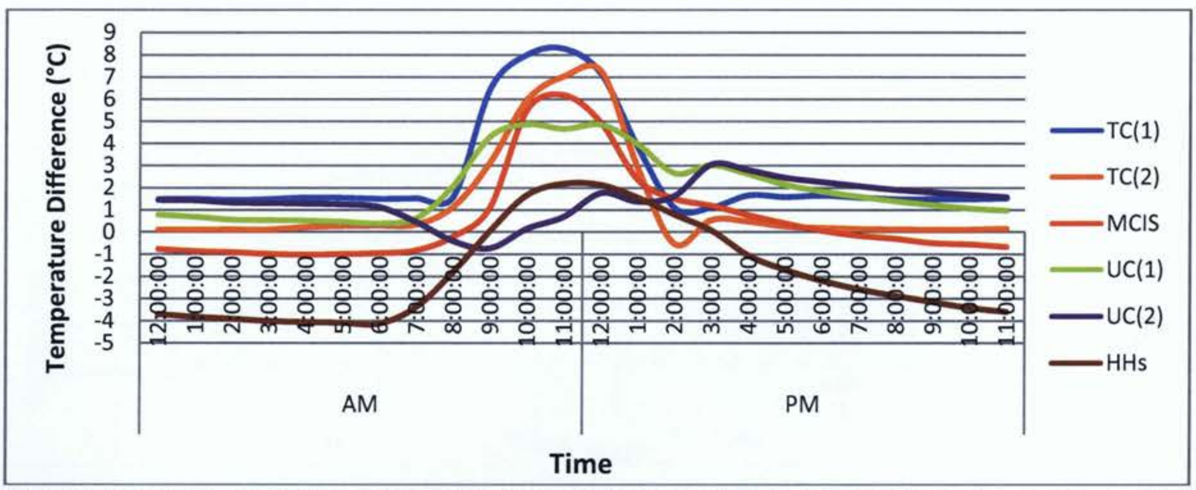


Figure B3.11: Site comparisons for typical day difference between sun and shade loggers for south facing aspect locations (TC(1), UC(1), UC(2), HHs, and MCIS) for the month of October.

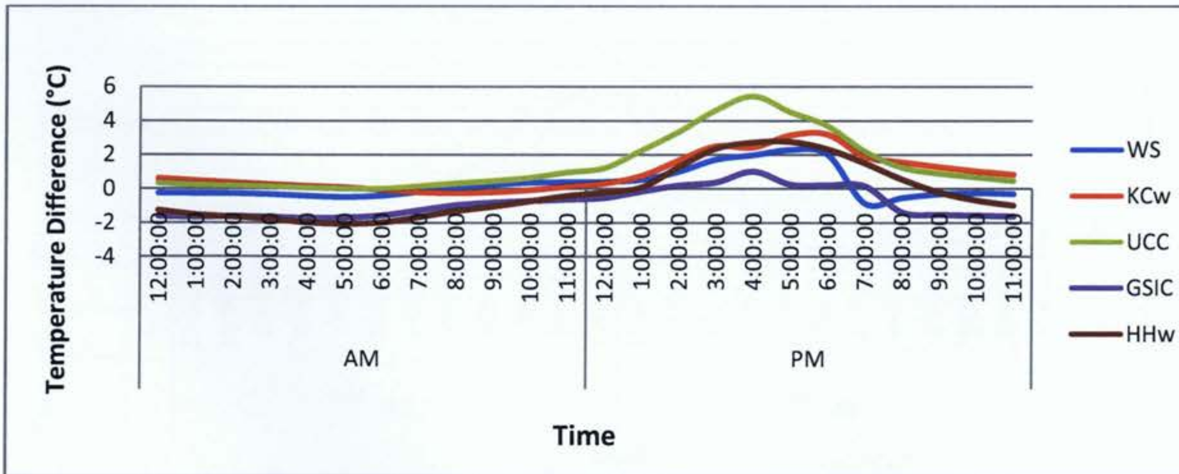


Figure B3.12: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of May.

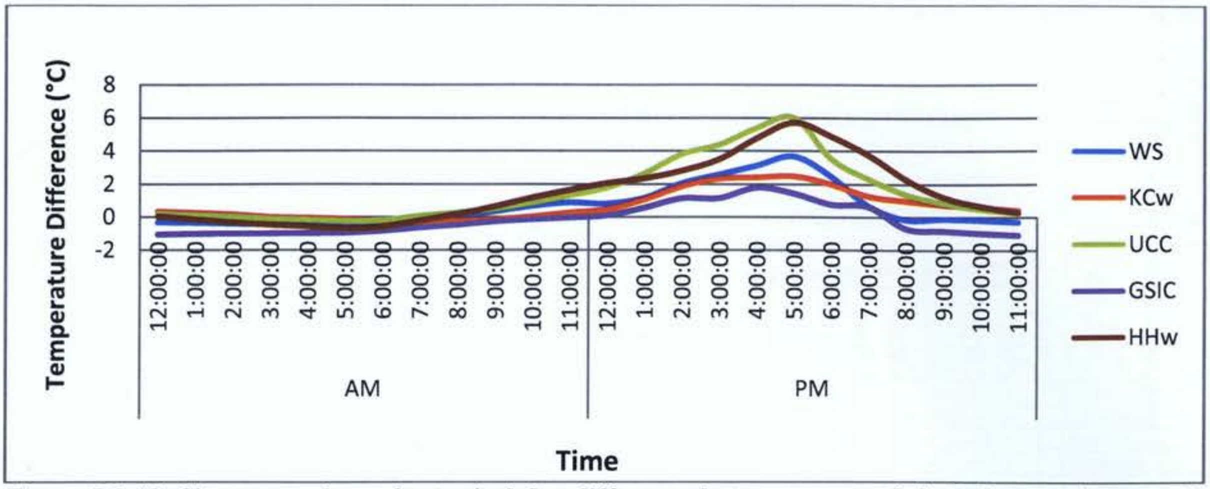


Figure B3.13: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of June.

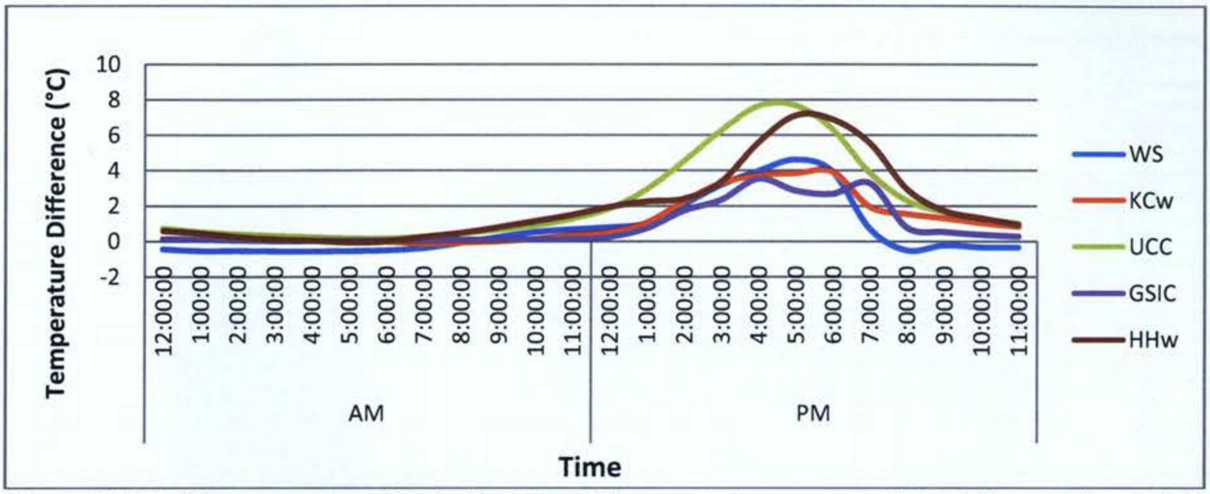


Figure B3.14: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of July.

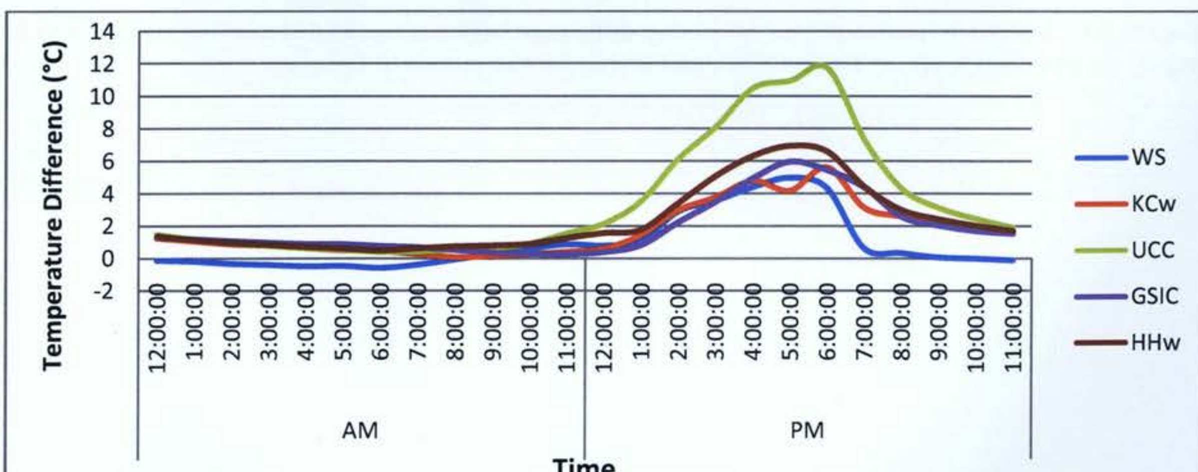


Figure B3.15: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of August.

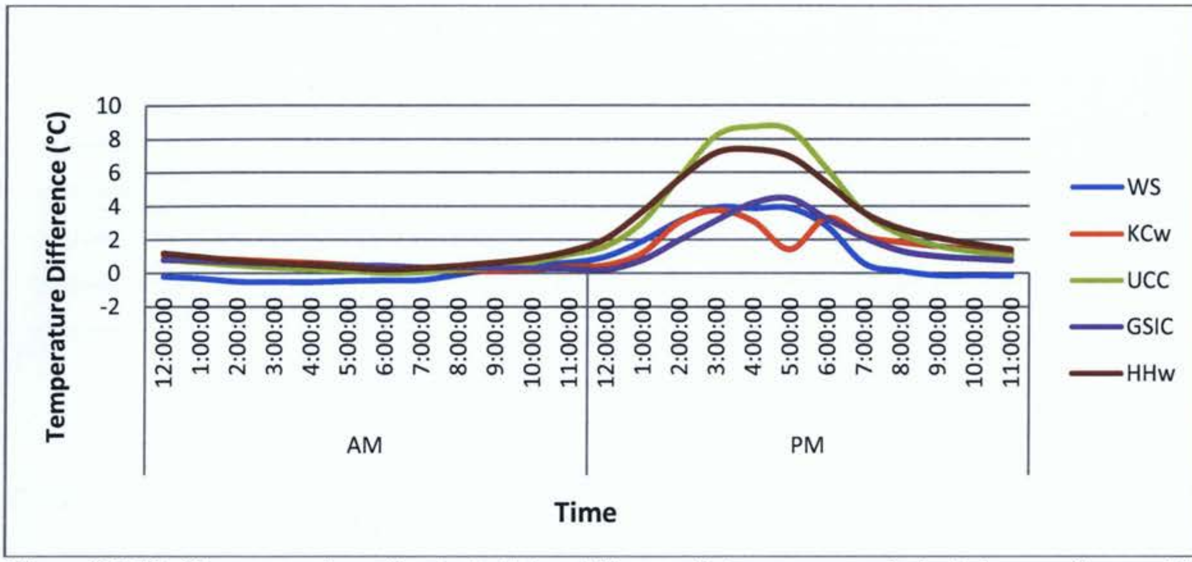


Figure B3.16: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of September.

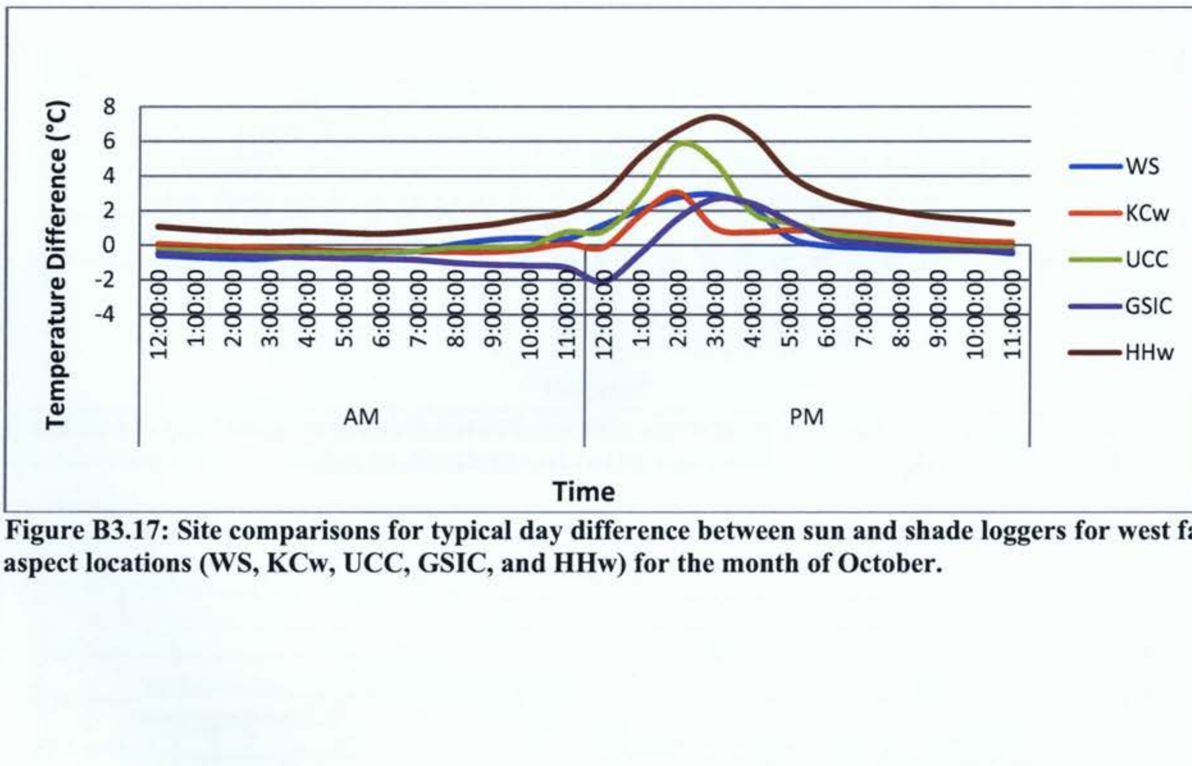


Figure B3.17: Site comparisons for typical day difference between sun and shade loggers for west facing aspect locations (WS, KCw, UCC, GSIC, and HHw) for the month of October.

Appendix C1 – Mixed model (SAS PROC MIXED) results for multiple tree temperatures to individual tree temperatures

	Month	Peak Time Period	N-Value	Building Variation	Observation B/W Correlations	Residual	Temperature	Warmer / Cooler	p-value	Significant
KCe to SDWRe	May	5:30-11:30	1173	0	0.9308	17.9173	1.5312	cooler	0.411	No
KCe to Tce	May	5:30-11:30	1173	0	0.9308	17.9173	0.1055	cooler	0.9957	No
SDWRe to Tce	May	5:30-11:30	1173	0	0.9308	17.9173	1.4257	warmer	0.4612	No
KCe to SDWRe	June	5:30-11:30	1128	0	0.9608	18.0145	0.6759	cooler	0.8994	No
KCe to Tce	June	5:30-11:30	1128	0	0.9608	18.0145	0.223	warmer	0.9885	No
SDWRe to Tce	June	5:30-11:30	1128	0	0.9608	18.0145	0.8989	warmer	0.8296	No
KCe to SDWRe	July	5:30-11:30	1170	0	0.9253	10.2033	0.6888	cooler	0.7142	No
KCe to Tce	July	5:30-11:30	1170	0	0.9253	10.2033	0.1886	warmer	0.9748	No
SDWRe to Tce	July	5:30-11:30	1170	0	0.9253	10.2033	0.8774	warmer	0.5812	No
KCe to SDWRe	August	5:30-11:30	936	0	0.9258	11.6615	0.3427	cooler	0.9585	No
KCe to Tce	August	5:30-11:30	936	0	0.9258	11.6615	0.1668	warmer	0.99	No
SDWRe to Tce	August	5:30-11:30	936	0	0.9258	11.6615	0.5095	warmer	0.8504	No
KCe to SDWRe	September	5:30-11:30	988	0	0.9361	13.7135	1.7992	cooler	0.325	No
KCe to Tce	September	5:30-11:30	988	0	0.9361	13.7135	1.2211	cooler	0.5886	No
SDWRe to Tce	September	5:30-11:30	988	0	0.9361	13.7135	0.5781	warmer	0.8584	No
SDWRe to TCe	October	5:30-11:30	806	0	0.9419	21.4672	0.6244	warmer	0.6566	No
KCe to SDWRe	May	11am-4pm	990	0	0.9742	14.6693	1.4546	cooler	0.6532	No
KCe to Tce	May	11am-4pm	990	0	0.9742	14.6693	0.599	warmer	0.9284	No
SDWRe to Tce	May	11am-4pm	990	0	0.9742	14.6693	2.0536	warmer	0.4398	No
KCe to SDWRe	June	11am-4pm	957	0	0.983	19.7369	0.4751	cooler	0.9758	No
KCe to Tce	June	11am-4pm	957	0	0.983	19.7369	1.0831	warmer	0.8817	No
SDWRe to Tce	June	11am-4pm	957	0	0.983	19.7369	1.5582	warmer	0.7739	No
KCe to SDWRe	July	11am-4pm	990	0	0.9461	5.9733	0.588	cooler	0.7266	No
KCe to Tce	July	11am-4pm	990	0	0.9461	5.9733	1.1487	warmer	0.3087	No
SDWRe to Tce	July	11am-4pm	990	0	0.9461	5.9733	1.7366	warmer	0.0792	No
KCe to SDWRe	August	11am-4pm	792	0	0.9462	8.4594	0.3147	warmer	0.9626	No
KCe to Tce	August	11am-4pm	792	0	0.9462	8.4594	1.3554	warmer	0.5045	No
SDWRe to Tce	August	11am-4pm	792	0	0.9462	8.4594	1.0407	warmer	0.4984	No
KCe to SDWRe	September	11am-4pm	836	0	0.981	11.266	1.4595	cooler	0.6906	No
KCe to Tce	September	11am-4pm	836	0	0.981	11.266	0.3405	cooler	0.9792	No
SDWRe to Tce	September	11am-4pm	836	0	0.981	11.266	1.119	warmer	0.7732	No
SDWRe to TCe	October	11am-4pm	682	0	0.9942	24.1006	0.814	warmer	0.8158	No
KCe to SDWRe	May	3pm-8pm	990	0	0.9821	13.7864	1.236	cooler	0.7801	No
KCe to Tce	May	3pm-8pm	990	0	0.9821	13.7864	0.1582	cooler	0.9958	No
SDWRe to Tce	May	3pm-8pm	990	0	0.9821	13.7864	1.0777	warmer	0.8268	No
KCe to SDWRe	June	3pm-8pm	957	0	0.9875	17.97224	0.2797	cooler	0.9925	No
KCe to Tce	June	3pm-8pm	957	0	0.9875	17.97224	0.4157	warmer	0.9835	No
SDWRe to Tce	June	3pm-8pm	957	0	0.9875	17.97224	0.6954	warmer	0.9547	No
KCe to SDWRe	July	3pm-8pm	990	0	0.9578	4.4686	0.3923	cooler	0.8553	No
KCe to Tce	July	3pm-8pm	990	0	0.9578	4.4686	0.3495	warmer	0.8831	No
SDWRe to Tce	July	3pm-8pm	990	0	0.9578	4.4686	0.7419	warmer	0.5783	No
KCe to SDWRe	August	3pm-8pm	792	0	0.9824	9.4577	0.1299	warmer	0.9974	No
KCe to Tce	August	3pm-8pm	792	0	0.9824	9.4577	0.4639	warmer	0.9679	No
SDWRe to Tce	August	3pm-8pm	792	0	0.9824	9.4577	0.3339	warmer	0.9726	No
KCe to SDWRe	September	3pm-8pm	836	0	0.9912	14.4464	2.0622	cooler	0.6819	No
KCe to Tce	September	3pm-8pm	836	0	0.9912	14.4464	1.4941	cooler	0.8066	No
SDWRe to Tce	September	3pm-8pm	836	0	0.9912	14.4464	0.5681	warmer	0.9634	No
SDWRe to TCe	October	3pm-8pm	682	0	0.9942	20.2366	0.7416	warmer	0.8177	No

	Month	Peak Time Period	N-Value	Building Variation	Observation B/W Correlations	Residual	Temperature	Warmer / Cooler	p-value	Significant
TC(1) to UC(1)	May	5:30am-11:30am	1955	0	0.9318	20.5217	0.6195	cooler	0.9888	No
TC(1) to UC(2)	May	5:30am-11:30am	1955	0	0.9318	20.5217	1.8907	cooler	0.5875	No
TC(1) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5217	0.173	cooler	0.9999	No
TC(1) to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5217	2.5005	cooler	0.3087	No
UC(1) to UC(2)	May	5:30am-11:30am	1955	0	0.9318	20.5217	1.2712	cooler	0.8601	No
UC(1) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5217	0.4465	warmer	0.9968	No
UC(1) to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5217	1.8809	cooler	0.5923	No
UC(2) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5217	1.7177	warmer	0.6719	No
UC(2) to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5217	0.6098	cooler	0.9895	No
MCIS to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5217	2.3274	cooler	0.3804	No
TC(1) to UC(1)	May	11pm-4pm	1650	0	0.9483	17.1288	0.4687	cooler	0.9966	No
TC(1) to UC(2)	May	11pm-4pm	1650	0	0.9483	17.1288	2.2947	cooler	0.4319	No
TC(1) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	0.6287	warmer	0.9895	No
TC(1) to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	1.8259	cooler	0.6499	No
UC(1) to UC(2)	May	11pm-4pm	1650	0	0.9483	17.1288	1.826	cooler	0.6499	No
UC(1) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	1.0973	warmer	0.9221	No
UC(1) to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	1.3572	cooler	0.8457	No
UC(2) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	2.9234	warmer	0.2015	No
UC(2) to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	0.4688	warmer	0.9966	No
MCIS to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	2.4546	cooler	0.3639	No
TC(1) to UC(1)	May	3pm-8pm	1650	0	0.9685	16.0367	0.4251	cooler	0.9988	No
TC(1) to UC(2)	May	3pm-8pm	1650	0	0.9685	16.0367	0.694	cooler	0.992	No
TC(1) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.1359	cooler	1	No
TC(1) to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.8713	cooler	0.7638	No
UC(1) to UC(2)	May	3pm-8pm	1650	0	0.9685	16.0367	0.269	cooler	0.9998	No
UC(1) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.2891	warmer	0.9997	No
UC(1) to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.4462	cooler	0.8905	No
UC(2) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.5581	warmer	0.9965	No
UC(2) to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.1772	cooler	0.9448	No
MCIS to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.7353	cooler	0.809	No
TC(1) to UC(1)	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.08681	warmer	1	No
TC(1) to UC(2)	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.749	cooler	0.7179	No
TC(1) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.3075	warmer	0.9994	No
TC(1) to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.0941	cooler	0.9329	No
UC(1) to UC(2)	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.8358	cooler	0.6805	No
UC(1) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.2207	warmer	0.9999	No
UC(1) to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.181	cooler	0.9133	No
UC(2) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	2.0566	warmer	0.5819	No
UC(2) to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.6549	warmer	0.9895	No
MCIS to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.4017	cooler	0.8501	No

TC(1) to UC(1)	June	11pm-4pm	1595	0	0.9662	18.1716	0.7172	warmer	0.9924	No
TC(1) to UC(2)	June	11pm-4pm	1595	0	0.9662	18.1716	1.6653	cooler	0.8529	No
TC(1) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	1.6648	warmer	0.9059	No
TC(1) to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	0.05705	cooler	1	No
UC(1) to UC(2)	June	11pm-4pm	1595	0	0.9662	18.1716	2.3825	cooler	0.6139	No
UC(1) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	0.7285	warmer	0.9919	No
UC(1) to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	0.7742	cooler	0.9898	No
UC(2) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	3.111	warmer	0.358	No
UC(2) to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	1.6083	warmer	0.8678	No
MCIS to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	1.5028	cooler	0.8933	No
TC(1) to UC(1)	June	3pm-8pm	1595	0	0.981	17.7145	0.4956	warmer	0.9992	No
TC(1) to UC(2)	June	3pm-8pm	1595	0	0.981	17.7145	0.752	cooler	0.996	No
TC(1) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	0.7776	warmer	0.9954	No
TC(1) to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.03225	cooler	1	No
UC(1) to UC(2)	June	3pm-8pm	1595	0	0.981	17.7145	1.2476	cooler	0.9733	No
UC(1) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	0.282	warmer	0.9999	No
UC(1) to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.5278	cooler	0.9999	No
UC(2) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	1.5296	warmer	0.9454	No
UC(2) to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.7198	warmer	0.9966	No
MCIS to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.8098	cooler	0.9947	No
TC(1) to UC(1)	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.4253	warmer	0.9889	No
TC(1) to UC(2)	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.655	cooler	0.3431	No
TC(1) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.9992	warmer	0.7906	No
TC(1) to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.512	cooler	0.9778	No
UC(1) to UC(2)	July	5:30am-11:30am	1950	0	0.9196	10.8655	2.0803	cooler	0.1419	No
UC(1) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.5739	warmer	0.9663	No
UC(1) to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.9373	cooler	0.8265	No
UC(2) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	2.6542	warmer	0.03	Yes
UC(2) to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.143	warmer	0.6972	No
MCIS to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.5112	cooler	0.4362	No
TC(1) to UC(1)	July	11pm-4pm	1650	0	0.8915	6.1806	1.3274	warmer	0.1979	No
TC(1) to UC(2)	July	11pm-4pm	1650	0	0.8915	6.1806	1.3426	cooler	0.1885	No
TC(1) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	2.4534	warmer	0.0012	Yes
TC(1) to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	0.6841	warmer	0.7938	No
UC(1) to UC(2)	July	11pm-4pm	1650	0	0.8915	6.1806	2.67	cooler	0.0003	Yes
UC(1) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	1.126	warmer	0.3533	No
UC(1) to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	0.6433	cooler	0.8281	No
UC(2) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	3.796	warmer	<0.0001	Yes
UC(2) to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	2.0267	warmer	0.0112	Yes
MCIS to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	1.7693	cooler	0.0371	Yes

TC(1) to UC(1)	July	3pm-8pm	1650	0	0.9327	4.9895	0.9351	warmer	0.6026	No
TC(1) to UC(2)	July	3pm-8pm	1650	0	0.9327	4.9895	0.1987	cooler	0.998	No
TC(1) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	1.5506	warmer	0.132	No
TC(1) to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.6796	warmer	0.8312	No
UC(1) to UC(2)	July	3pm-8pm	1650	0	0.9327	4.9895	1.1338	cooler	0.4123	No
UC(1) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	0.6155	warmer	0.8758	No
UC(1) to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.2555	cooler	0.9947	No
UC(2) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	1.7493	warmer	0.0665	No
UC(2) to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.8783	warmer	0.6578	No
MCIS to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.871	cooler	0.6648	No
TC(1) to UC(1)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.896	warmer	0.9696	No
TC(1) to UC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.1172	cooler	0.44	No
TC(1) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.2179	warmer	0.3868	No
TC(1) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.5312	warmer	0.902	No
TC(1) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.4431	cooler	0.9988	No
UC(1) to UC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	3.0132	cooler	0.1011	No
UC(1) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.3219	warmer	0.8563	No
UC(1) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.6352	warmer	0.998	No
UC(1) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.3391	cooler	0.8495	No
UC(2) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	4.3351	warmer	0.0038	Yes
UC(2) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	3.6484	warmer	0.1411	No
UC(2) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.6741	warmer	0.6883	No
MCIS to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.6867	cooler	0.9971	No
MCIS to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.661	cooler	0.196	No
TC(2) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.9743	cooler	0.7595	No
TC(1) to UC(1)	August	11pm-4pm	1793	0	0.8948	12.7846	2.5512	warmer	0.0539	No
TC(1) to UC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	1.6008	cooler	0.4655	No
TC(1) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	4.7382	warmer	<0.0001	Yes
TC(1) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	2.7338	warmer	0.1659	No
TC(1) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	0.9592	warmer	0.8866	No
UC(1) to UC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	4.152	cooler	0.0001	Yes
UC(1) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	2.187	warmer	0.1438	No
UC(1) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	0.1825	warmer	1	No
UC(1) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	1.592	cooler	0.4717	No
UC(2) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	6.339	warmer	<0.0001	Yes
UC(2) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	4.3345	warmer	0.0033	Yes
UC(2) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	2.56	warmer	0.0526	No
MCIS to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	2.0045	cooler	0.4949	No
MCIS to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	3.779	cooler	0.0007	Yes
TC(2) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	1.7746	cooler	0.6264	No

TC(1) to UC(1)	August	3pm-8pm	1793	0	0.9535	12.011	0.6822	warmer	0.9916	No
TC(1) to UC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.1466	cooler	1	No
TC(1) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	2.5126	warmer	0.281	No
TC(1) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.007836	warmer	1	No
TC(1) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.6032	warmer	0.9952	No
UC(1) to UC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.8288	cooler	0.9797	No
UC(1) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	1.8304	warmer	0.6234	No
UC(1) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.6744	cooler	0.9975	No
UC(1) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.079	cooler	1	No
UC(2) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	2.6592	warmer	0.2253	No
UC(2) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.1544	warmer	1	No
UC(2) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.7498	warmer	0.987	No
MCIS to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	2.5048	cooler	0.5514	No
MCIS to HHs	August	3pm-8pm	1793	0	0.9535	12.011	1.9094	cooler	0.5803	No
TC(2) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.5954	warmer	0.9986	No
TC(1) to UC(1)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.4372	cooler	0.9994	No
TC(1) to UC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.49	cooler	0.086	No
TC(1) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	0.9515	warmer	0.9766	No
TC(1) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.1051	cooler	1	No
TC(1) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.5792	cooler	0.3528	No
UC(1) to UC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.0528	cooler	0.1815	No
UC(1) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	1.3888	warmer	0.8895	No
UC(1) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.3321	warmer	0.9998	No
UC(1) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.142	cooler	0.5624	No
UC(2) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	4.4415	warmer	0.0116	Yes
UC(2) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.3849	warmer	0.104	No
UC(2) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	0.9108	warmer	0.9807	No
MCIS to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	1.0566	cooler	0.9633	No
MCIS to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	3.5307	cooler	0.0797	No
TC(2) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.4741	cooler	0.3999	No
TC(1) to UC(1)	September	11am-4pm	1914	0	0.9329	19.1535	0.836	warmer	0.9869	No
TC(1) to UC(2)	September	11am-4pm	1914	0	0.9329	19.1535	3.2393	cooler	0.1382	No
TC(1) to MCIS	September	11am-4pm	1914	0	0.9329	19.1535	3.1688	warmer	0.155	No
TC(1) to TC(2)	September	11am-4pm	1914	0	0.9329	19.1535	1.166	warmer	0.9446	No
TC(1) to HHs	September	11am-4pm	1914	0	0.9329	19.1535	1.2632	cooler	0.9236	No
UC(1) to UC(2)	September	11am-4pm	1914	0	0.9329	19.1535	4.0753	cooler	0.0286	Yes
UC(1) to MCIS	September	11am-4pm	1914	0	0.9329	19.1535	2.3328	warmer	0.4705	No
UC(1) to TC(2)	September	11am-4pm	1914	0	0.9329	19.1535	0.33	warmer	0.9998	No
UC(1) to HHs	September	11am-4pm	1914	0	0.9329	19.1535	2.0992	cooler	0.5864	No
UC(2) to MCIS	September	11am-4pm	1914	0	0.9329	19.1535	6.4081	warmer	<0.0001	Yes
UC(2) to TC(2)	September	11am-4pm	1914	0	0.9329	19.1535	4.4053	warmer	0.014	Yes
UC(2) to HHs	September	11am-4pm	1914	0	0.9329	19.1535	1.9761	warmer	0.6475	No
MCIS to TC(2)	September	11am-4pm	1914	0	0.9329	19.1535	2.0028	cooler	0.6344	No
MCIS to HHs	September	11am-4pm	1914	0	0.9329	19.1535	4.4319	cooler	0.0132	Yes
TC(2) to HHs	September	11am-4pm	1914	0	0.9329	19.1535	2.4292	cooler	0.4246	No

TC(1) to UC(1)	September	3pm-8pm	1914	0	0.9687	17.7282	0.03637	cooler	1	No
TC(1) to UC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.9401	cooler	0.9932	No
TC(1) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	2.1698	warmer	0.795	No
TC(1) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.1783	cooler	1	No
TC(1) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.2525	cooler	1	No
UC(1) to UC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.9038	cooler	0.9943	No
UC(1) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	2.2062	warmer	0.7837	No
UC(1) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.1419	cooler	1	No
UC(1) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.2161	cooler	1	No
UC(2) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	3.1099	warmer	0.4658	No
UC(2) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.7619	warmer	0.9975	No
UC(2) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.6877	warmer	0.9984	No
MCIS to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	2.3481	cooler	0.7377	No
MCIS to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	2.4223	cooler	0.7124	No
TC(2) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.0742	cooler	1	No
TC(1) to UC(1)	October	5:30am-11:30am	2418	0	0.9371	27.7683	2.0566	cooler	0.7677	No
TC(1) to UC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.8103	cooler	0.1509	No
TC(1) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.5888	cooler	0.9989	No
TC(1) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.2249	cooler	0.968	No
TC(1) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	5.3953	cooler	0.011	Yes
UC(1) to UC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.7537	cooler	0.8655	No
UC(1) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.4679	warmer	0.932	No
UC(1) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.8318	warmer	0.9944	No
UC(1) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.3387	cooler	0.2718	No
UC(2) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.2216	warmer	0.3095	No
UC(2) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	2.5854	warmer	0.5555	No
UC(2) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.585	cooler	0.908	No
MCIS to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.6361	cooler	0.9984	No
MCIS to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	4.8065	cooler	0.0322	Yes
TC(2) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	4.1704	cooler	0.0902	No
TC(1) to UC(1)	October	11am-4pm	2046	0	0.944	28.8386	2.0518	cooler	0.8191	No
TC(1) to UC(2)	October	11am-4pm	2046	0	0.944	28.8386	-4.087	cooler	0.1557	No
TC(1) to MCIS	October	11am-4pm	2046	0	0.944	28.8386	0.4157	warmer	0.9999	No
TC(1) to TC(2)	October	11am-4pm	2046	0	0.944	28.8386	1.2049	cooler	0.9782	No
TC(1) to HHs	October	11am-4pm	2046	0	0.944	28.8386	4.7503	cooler	0.0636	No
UC(1) to UC(2)	October	11am-4pm	2046	0	0.944	28.8386	2.0352	cooler	0.8241	No
UC(1) to MCIS	October	11am-4pm	2046	0	0.944	28.8386	2.4676	warmer	0.6768	No
UC(1) to TC(2)	October	11am-4pm	2046	0	0.944	28.8386	0.8469	warmer	0.9956	No
UC(1) to HHs	October	11am-4pm	2046	0	0.944	28.8386	2.6984	cooler	0.5886	No
UC(2) to MCIS	October	11am-4pm	2046	0	0.944	28.8386	4.5027	warmer	0.0904	No
UC(2) to TC(2)	October	11am-4pm	2046	0	0.944	28.8386	2.8821	warmer	0.5177	No
UC(2) to HHs	October	11am-4pm	2046	0	0.944	28.8386	0.6633	cooler	0.9986	No
MCIS to TC(2)	October	11am-4pm	2046	0	0.944	28.8386	1.6207	cooler	0.9244	No
MCIS to HHs	October	11am-4pm	2046	0	0.944	28.8386	5.166	cooler	0.0339	Yes
TC(1) to UC(1)	October	3pm-8pm	2046	0	0.9802	24.1892	1.1898	cooler	0.9956	No
TC(1) to UC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	1.0378	cooler	0.9977	No
TC(1) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	0.3726	warmer	1	No
TC(1) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.9822	cooler	0.9982	No
TC(1) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	3.7826	cooler	0.6137	No
UC(1) to UC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.1521	warmer	1	No
UC(1) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	1.5624	warmer	0.9848	No
UC(1) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.2076	warmer	1	No
UC(1) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.5928	cooler	0.8801	No
UC(2) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	1.4104	warmer	0.9904	No
UC(2) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.05556	warmer	1	No
UC(2) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.7449	cooler	0.8532	No
MCIS to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	1.3548	cooler	0.992	No
MCIS to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	4.1552	cooler	0.5186	No
TC(2) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.8004	cooler	0.8427	No

	Month	Peak Time Period	N-Value	Building Variation	Observation B/W Correlations	Residual	Temperature	Warmer / Cooler	p-value	Significant
SDWRw to HHw	May	5:30-11:30	2346	0	0.9702	12.2144	1.7863	cooler	0.797	No
SDWRw to UCC	May	5:30-11:30	2346	0	0.9702	12.2144	0.4166	warmer	0.9996	No
SDWRw to WS	May	5:30-11:30	2346	0	0.9702	12.2144	0.5464	warmer	0.9987	No
SDWRw to KCw	May	5:30-11:30	2346	0	0.9702	12.2144	0.3435	warmer	0.9999	No
SDWRw to GSIC	May	5:30-11:30	2346	0	0.9702	12.2144	0.2808	cooler	0.9999	No
HHw to UCC	May	5:30-11:30	2346	0	0.9702	12.2144	2.2028	warmer	0.6262	No
HHw to WS	May	5:30-11:30	2346	0	0.9702	12.2144	2.3326	warmer	0.5695	No
HHw to KCw	May	5:30-11:30	2346	0	0.9702	12.2144	2.1298	warmer	0.6579	No
HHw to GSIC	May	5:30-11:30	2346	0	0.9702	12.2144	1.5055	warmer	0.8876	No
UCC to WS	May	5:30-11:30	2346	0	0.9702	12.2144	0.1298	warmer	1	No
UCC to KCw	May	5:30-11:30	2346	0	0.9702	12.2144	0.07306	cooler	1	No
UCC to GSIC	May	5:30-11:30	2346	0	0.9702	12.2144	0.6874	cooler	0.9958	No
WS to KCw	May	5:30-11:30	2346	0	0.9702	12.2144	0.2028	cooler	1	No
WS to GSIC	May	5:30-11:30	2346	0	0.9702	12.2144	0.8272	cooler	0.9908	No
KCw to GSIC	May	5:30-11:30	2346	0	0.9702	12.2144	0.6243	cooler	0.9975	No
SDWRw to HHw	May	11pm-4pm	1980	0	0.9588	16.4244	1.7799	cooler	0.8154	No
SDWRw to UCC	May	11pm-4pm	1980	0	0.9588	16.4244	0.5951	warmer	0.9983	No
SDWRw to WS	May	11pm-4pm	1980	0	0.9588	16.4244	0.129	warmer	1	No
SDWRw to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.4109	warmer	0.9997	No
SDWRw to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.1114	cooler	1	No
HHw to UCC	May	11pm-4pm	1980	0	0.9588	16.4244	2.375	warmer	0.5698	No
HHw to WS	May	11pm-4pm	1980	0	0.9588	16.4244	1.9089	warmer	0.7678	No
HHw to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	2.1909	warmer	0.651	No
HHw to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	1.6686	warmer	0.8524	No
UCC to WS	May	11pm-4pm	1980	0	0.9588	16.4244	0.4661	cooler	0.9995	No
UCC to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.1842	cooler	1	No
UCC to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.7065	cooler	0.9962	No
WS to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.2819	warmer	1	No
WS to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.2404	cooler	1	No
KCw to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.5223	cooler	0.9991	No
SDWRw to HHw	May	3pm-8pm	1980	0	0.9248	21.2085	2.0237	cooler	0.6153	No
SDWRw to UCC	May	3pm-8pm	1980	0	0.9248	21.2085	0.947	warmer	0.9764	No
SDWRw to WS	May	3pm-8pm	1980	0	0.9248	21.2085	0.2783	warmer	0.9999	No
SDWRw to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.861	warmer	0.9845	No
SDWRw to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	0.4633	cooler	0.9992	No
HHw to UCC	May	3pm-8pm	1980	0	0.9248	21.2085	2.9707	warmer	0.2004	No
HHw to WS	May	3pm-8pm	1980	0	0.9248	21.2085	2.302	warmer	0.4751	No
HHw to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	2.8847	warmer	0.2281	No
HHw to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.5604	warmer	0.8273	No
UCC to WS	May	3pm-8pm	1980	0	0.9248	21.2085	0.6687	cooler	0.9952	No
UCC to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.08599	cooler	1	No
UCC to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.4103	cooler	0.88	No
WS to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.5827	warmer	0.9975	No

KCw to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.3243	cooler	0.9054	No
SDWRw to HHw	June	5:30-11:30	2256	0	0.9801	12.4681	0.4995	cooler	0.9997	No
SDWRw to UCC	June	5:30-11:30	2256	0	0.9801	12.4681	0.4223	warmer	0.9999	No
SDWRw to WS	June	5:30-11:30	2256	0	0.9801	12.4681	0.6005	warmer	0.9992	No
SDWRw to KCw	June	5:30-11:30	2256	0	0.9801	12.4681	0.158	warmer	1	No
SDWRw to GSIC	June	5:30-11:30	2256	0	0.9801	12.4681	0.09638	cooler	1	No
HHw to UCC	June	5:30-11:30	2256	0	0.9801	12.4681	0.9217	warmer	0.994	No
HHw to WS	June	5:30-11:30	2256	0	0.9801	12.4681	1.1	warmer	0.9865	No
HHw to KCw	June	5:30-11:30	2256	0	0.9801	12.4681	0.6575	warmer	0.9988	No
HHw to GSIC	June	5:30-11:30	2256	0	0.9801	12.4681	0.4031	warmer	0.9999	No
UCC to WS	June	5:30-11:30	2256	0	0.9801	12.4681	0.1783	warmer	1	No
UCC to KCw	June	5:30-11:30	2256	0	0.9801	12.4681	0.2643	cooler	1	No
UCC to GSIC	June	5:30-11:30	2256	0	0.9801	12.4681	0.5186	cooler	0.9996	No
WS to KCw	June	5:30-11:30	2256	0	0.9801	12.4681	0.4425	cooler	0.9998	No
WS to GSIC	June	5:30-11:30	2256	0	0.9801	12.4681	0.6969	cooler	0.9984	No
KCw to GSIC	June	5:30-11:30	2256	0	0.9801	12.4681	0.2544	cooler	1	No
SDWRw to HHw	June	11pm-4pm	1914	0	0.9704	17.9236	0.2906	warmer	1	No
SDWRw to UCC	June	11pm-4pm	1914	0	0.9704	17.9236	0.7471	warmer	0.998	No
SDWRw to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.6087	warmer	0.9993	No
SDWRw to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.102	warmer	1	No
SDWRw to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.04669	warmer	1	No
HHw to UCC	June	11pm-4pm	1914	0	0.9704	17.9236	0.4565	warmer	0.9998	No
HHw to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.3181	warmer	1	No
HHw to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.1886	cooler	1	No
HHw to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.2439	cooler	1	No
UCC to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.1384	cooler	1	No
UCC to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.6451	cooler	0.999	No
UCC to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.7004	cooler	0.9985	No
WS to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.5067	cooler	0.9997	No
WS to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.562	cooler	0.9995	No
KCw to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.05534	cooler	1	No
SDWRw to HHw	June	3pm-8pm	1914	0	0.9436	20.742	0.5069	warmer	0.9993	No
SDWRw to UCC	June	3pm-8pm	1914	0	0.9436	20.742	1.6095	warmer	0.8723	No
SDWRw to WS	June	3pm-8pm	1914	0	0.9436	20.742	1.1385	warmer	0.9681	No
SDWRw to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.9805	warmer	0.9834	No
SDWRw to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.1792	warmer	1	No
HHw to UCC	June	3pm-8pm	1914	0	0.9436	20.742	1.1026	warmer	0.9722	No
HHw to WS	June	3pm-8pm	1914	0	0.9436	20.742	0.6317	warmer	0.9978	No
HHw to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.4736	warmer	0.9995	No
HHw to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.3277	cooler	0.9999	No
UCC to WS	June	3pm-8pm	1914	0	0.9436	20.742	0.471	cooler	0.9995	No
UCC to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.629	cooler	0.9979	No
UCC to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	1.4303	cooler	0.9184	No
WS to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.158	cooler	1	No
WS to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.9594	cooler	0.9849	No
KCw to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.8013	cooler	0.9934	No

SDWRw to HHw	July	5:30-11:30	2340	0	0.9652	5.3364	0.2439	cooler	0.9998	No
SDWRw to UCC	July	5:30-11:30	2340	0	0.9652	5.3364	0.4195	warmer	0.9966	No
SDWRw to WS	July	5:30-11:30	2340	0	0.9652	5.3364	0.6421	warmer	0.9764	No
SDWRw to KCw	July	5:30-11:30	2340	0	0.9652	5.3364	0.1733	warmer	1	No
SDWRw to GSIC	July	5:30-11:30	2340	0	0.9652	5.3364	0.2125	warmer	0.9999	No
HHw to UCC	July	5:30-11:30	2340	0	0.9652	5.3364	0.6634	warmer	0.9729	No
HHw to WS	July	5:30-11:30	2340	0	0.9652	5.3364	0.886	warmer	0.9113	No
HHw to KCw	July	5:30-11:30	2340	0	0.9652	5.3364	0.4172	warmer	0.9967	No
HHw to GSIC	July	5:30-11:30	2340	0	0.9652	5.3364	0.4564	warmer	0.995	No
UCC to WS	July	5:30-11:30	2340	0	0.9652	5.3364	0.2226	warmer	0.9998	No
UCC to KCw	July	5:30-11:30	2340	0	0.9652	5.3364	0.2462	cooler	0.9997	No
UCC to GSIC	July	5:30-11:30	2340	0	0.9652	5.3364	0.207	cooler	0.9999	No
WS to KCw	July	5:30-11:30	2340	0	0.9652	5.3364	0.4688	cooler	0.9943	No
WS to GSIC	July	5:30-11:30	2340	0	0.9652	5.3364	0.4296	cooler	0.9962	No
KCw to GSIC	July	5:30-11:30	2340	0	0.9652	5.3364	0.0392	warmer	1	No
SDWRw to HHw	July	11pm-4pm	1980	0	0.9236	6.32	0.4447	warmer	0.9876	No
SDWRw to UCC	July	11pm-4pm	1980	0	0.9236	6.32	0.7753	warmer	0.8737	No
SDWRw to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.4808	warmer	0.9824	No
SDWRw to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.1727	warmer	0.9999	No
SDWRw to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.5185	warmer	0.9754	No
HHw to UCC	July	11pm-4pm	1980	0	0.9236	6.32	0.3306	warmer	0.9969	No
HHw to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.03616	warmer	1	No
HHw to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.2719	cooler	0.9988	No
HHw to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.0786	warmer	1	No
UCC to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.2944	cooler	0.9982	No
UCC to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.6025	cooler	0.9532	No
UCC to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.2567	cooler	0.9991	No
WS to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.3081	cooler	0.9978	No
WS to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.03771	warmer	1	No
KCw to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.3458	warmer	0.9961	No
SDWRw to HHw	July	3pm-8pm	1980	0	0.7568	6.1316	0.6878	warmer	0.7276	No
SDWRw to UCC	July	3pm-8pm	1980	0	0.7568	6.1316	1.8133	warmer	0.0039	Yes
SDWRw to WS	July	3pm-8pm	1980	0	0.7568	6.1316	1.1035	warmer	0.222	No
SDWRw to KCw	July	3pm-8pm	1980	0	0.7568	6.1316	1.1137	warmer	0.2131	No
SDWRw to GSIC	July	3pm-8pm	1980	0	0.7568	6.1316	0.6772	warmer	0.7405	No
HHw to UCC	July	3pm-8pm	1980	0	0.7568	6.1316	1.1256	warmer	0.203	No
HHw to WS	July	3pm-8pm	1980	0	0.7568	6.1316	0.4157	warmer	0.9585	No
HHw to KCw	July	3pm-8pm	1980	0	0.7568	6.1316	0.4259	warmer	0.9541	No
HHw to GSIC	July	3pm-8pm	1980	0	0.7568	6.1316	0.01057	cooler	1	No
UCC to WS	July	3pm-8pm	1980	0	0.7568	6.1316	0.7098	cooler	0.7001	No
UCC to KCw	July	3pm-8pm	1980	0	0.7568	6.1316	0.6997	cooler	0.7129	No
UCC to GSIC	July	3pm-8pm	1980	0	0.7568	6.1316	1.1361	cooler	0.1943	No
WS to KCw	July	3pm-8pm	1980	0	0.7568	6.1316	0.01016	warmer	1	No
WS to GSIC	July	3pm-8pm	1980	0	0.7568	6.1316	0.4263	cooler	0.9539	No
KCw to GSIC	July	3pm-8pm	1980	0	0.7568	6.1316	0.4365	cooler	0.9491	No
SDWRw to HHw	August	5:30-11:30	2236	0	0.9644	7.3228	0.4118	cooler	0.9989	No

SDWRw to UCC	August	5:30-11:30	2236	0	0.9644	7.3228	0.2629	warmer	0.9998	No
SDWRw to WS	August	5:30-11:30	2236	0	0.9644	7.3228	0.4501	warmer	0.9977	No
SDWRw to KCw	August	5:30-11:30	2236	0	0.9644	7.3228	0.03204	warmer	1	No
SDWRw to GSIC	August	5:30-11:30	2236	0	0.9644	7.3228	0.1493	warmer	1	No
HHw to UCC	August	5:30-11:30	2236	0	0.9644	7.3228	0.6747	warmer	0.9889	No
HHw to WS	August	5:30-11:30	2236	0	0.9644	7.3228	0.8619	warmer	0.9674	No
HHw to KCw	August	5:30-11:30	2236	0	0.9644	7.3228	0.4438	warmer	0.9984	No
HHw to GSIC	August	5:30-11:30	2236	0	0.9644	7.3228	0.5611	warmer	0.9953	No
UCC to WS	August	5:30-11:30	2236	0	0.9644	7.3228	0.1873	warmer	1	No
UCC to KCw	August	5:30-11:30	2236	0	0.9644	7.3228	0.2308	cooler	0.9999	No
UCC to GSIC	August	5:30-11:30	2236	0	0.9644	7.3228	0.1136	cooler	1	No
WS to KCw	August	5:30-11:30	2236	0	0.9644	7.3228	0.4181	cooler	0.9984	No
WS to GSIC	August	5:30-11:30	2236	0	0.9644	7.3228	0.3008	cooler	0.9997	No
KCw to GSIC	August	5:30-11:30	2236	0	0.9644	7.3228	0.1173	warmer	1	No
SDWRw to HHw	August	11pm-4pm	1892	0	0.9385	9.8459	0.00656	cooler	1	No
SDWRw to UCC	August	11pm-4pm	1892	0	0.9385	9.8459	0.8297	warmer	0.9499	No
SDWRw to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.5307	warmer	0.993	No
SDWRw to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.1381	warmer	1	No
SDWRw to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.7268	warmer	0.9714	No
HHw to UCC	August	11pm-4pm	1892	0	0.9385	9.8459	0.8363	warmer	0.9627	No
HHw to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.5372	warmer	0.9949	No
HHw to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.1447	warmer	1	No
HHw to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.7334	warmer	0.9789	No
UCC to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.2991	cooler	0.9996	No
UCC to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.6916	cooler	0.977	No
UCC to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.1029	cooler	1	No
WS to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.3926	cooler	0.9983	No
WS to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.1961	warmer	0.9999	No
KCw to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.5887	warmer	0.9888	No
SDWRw to HHw	August	3pm-8pm	1892	0	0.8928	11.6683	0.07961	warmer	1	No
SDWRw to UCC	August	3pm-8pm	1892	0	0.8928	11.6683	1.3115	warmer	0.6268	No
SDWRw to WS	August	3pm-8pm	1892	0	0.8928	11.6683	1.0855	warmer	0.7894	No
SDWRw to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.5978	warmer	0.9802	No
SDWRw to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.7291	warmer	0.9534	No
HHw to UCC	August	3pm-8pm	1892	0	0.8928	11.6683	1.2319	warmer	0.7567	No
HHw to WS	August	3pm-8pm	1892	0	0.8928	11.6683	1.0059	warmer	0.8796	No
HHw to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.5182	warmer	0.9929	No
HHw to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.6495	warmer	0.9802	No
UCC to WS	August	3pm-8pm	1892	0	0.8928	11.6683	0.226	cooler	0.9998	No
UCC to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.7137	cooler	0.9574	No
UCC to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.5823	cooler	0.9824	No
WS to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.4876	cooler	0.9921	No
WS to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.3563	cooler	0.9982	No
KCw to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.1313	warmer	1	No
SDWRw to HHw	September	5:30-11:30	2093	0	0.9779	10.5131	0.599	warmer	0.9991	No
SDWRw to UCC	September	5:30-11:30	2093	0	0.9779	10.5131	0.4457	warmer	0.9997	No

SDWRw to WS	September	5:30-11:30	2093	0	0.9779	10.5131	0.623	warmer	0.9983	No
SDWRw to KCw	September	5:30-11:30	2093	0	0.9779	10.5131	0.2722	warmer	1	No
SDWRw to GSIC	September	5:30-11:30	2093	0	0.9779	10.5131	0.2416	warmer	1	No
HHw to UCC	September	5:30-11:30	2093	0	0.9779	10.5131	0.1533	cooler	1	No
HHw to WS	September	5:30-11:30	2093	0	0.9779	10.5131	0.02391	warmer	1	No
HHw to KCw	September	5:30-11:30	2093	0	0.9779	10.5131	0.3268	cooler	1	No
HHw to GSIC	September	5:30-11:30	2093	0	0.9779	10.5131	0.3574	cooler	0.9999	No
UCC to WS	September	5:30-11:30	2093	0	0.9779	10.5131	0.1772	warmer	1	No
UCC to KCw	September	5:30-11:30	2093	0	0.9779	10.5131	0.1735	cooler	1	No
UCC to GSIC	September	5:30-11:30	2093	0	0.9779	10.5131	0.2041	cooler	1	No
WS to KCw	September	5:30-11:30	2093	0	0.9779	10.5131	0.3508	cooler	0.9999	No
WS to GSIC	September	5:30-11:30	2093	0	0.9779	10.5131	0.3813	cooler	0.9988	No
KCw to GSIC	September	5:30-11:30	2093	0	0.9779	10.5131	0.03056	cooler	1	No
SDWRw to HHw	September	11pm-4pm	1771	0	0.9461	14.0606	0.6189	warmer	0.9977	No
SDWRw to UCC	September	11pm-4pm	1771	0	0.9461	14.0606	0.9591	warmer	0.9673	No
SDWRw to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.6471	warmer	0.9944	No
SDWRw to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.1252	warmer	1	No
SDWRw to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.6195	warmer	0.9954	No
HHw to UCC	September	11pm-4pm	1771	0	0.9461	14.0606	0.3403	warmer	0.9999	No
HHw to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.02828	warmer	1	No
HHw to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.4936	cooler	0.9992	No
HHw to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.000638	warmer	1	No
UCC to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.312	cooler	0.9998	No
UCC to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.8339	cooler	0.9822	No
UCC to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.3397	cooler	0.9997	No
WS to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.5219	cooler	0.998	No
WS to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.02764	cooler	1	No
KCw to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.4943	warmer	0.9984	No
SDWRw to HHw	September	3pm-8pm	1771	0	0.9289	14.596	0.4929	warmer	0.9989	No
SDWRw to UCC	September	3pm-8pm	1771	0	0.9289	14.596	1.6211	warmer	0.6847	No
SDWRw to WS	September	3pm-8pm	1771	0	0.9289	14.596	1.3563	warmer	0.8207	No
SDWRw to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.4153	warmer	0.999	No
SDWRw to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.3006	warmer	0.9998	No
HHw to UCC	September	3pm-8pm	1771	0	0.9289	14.596	1.1282	warmer	0.9508	No
HHw to WS	September	3pm-8pm	1771	0	0.9289	14.596	0.8634	warmer	0.9845	No
HHw to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.07759	cooler	1	No
HHw to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.1923	cooler	1	No
UCC to WS	September	3pm-8pm	1771	0	0.9289	14.596	0.2648	cooler	0.9999	No
UCC to KCw	September	3pm-8pm	1771	0	0.9289	14.596	1.2058	cooler	0.8823	No
UCC to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	1.3205	cooler	0.8366	No
WS to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.941	cooler	0.956	No
WS to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	1.0557	cooler	0.9295	No
KCw to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.1147	cooler	1	No
SDWRw to HHw	October	5:30-11:30	2418	0	0.9842	18.8744	0.8237	warmer	0.999	No
SDWRw to UCC	October	5:30-11:30	2418	0	0.9842	18.8744	0.4591	warmer	0.9999	No
SDWRw to WS	October	5:30-11:30	2418	0	0.9842	18.8744	0.898	warmer	0.9986	No

SDWRw to KCw	October	5:30-11:30	2418	0	0.9842	18.8744	0.4861	warmer	0.9999	No
SDWRw to GSIC	October	5:30-11:30	2418	0	0.9842	18.8744	0.01301	warmer	1	No
HHw to UCC	October	5:30-11:30	2418	0	0.9842	18.8744	0.3736	cooler	1	No
HHw to WS	October	5:30-11:30	2418	0	0.9842	18.8744	0.06526	warmer	1	No
HHw to KCw	October	5:30-11:30	2418	0	0.9842	18.8744	0.3466	cooler	1	No
HHw to GSIC	October	5:30-11:30	2418	0	0.9842	18.8744	0.8197	cooler	0.9991	No
UCC to WS	October	5:30-11:30	2418	0	0.9842	18.8744	0.4389	warmer	1	No
UCC to KCw	October	5:30-11:30	2418	0	0.9842	18.8744	0.02687	warmer	1	No
UCC to GSIC	October	5:30-11:30	2418	0	0.9842	18.8744	0.4461	cooler	1	No
WS to KCw	October	5:30-11:30	2418	0	0.9842	18.8744	0.4119	cooler	1	No
WS to GSIC	October	5:30-11:30	2418	0	0.9842	18.8744	0.885	cooler	0.9987	No
KCw to GSIC	October	5:30-11:30	2418	0	0.9842	18.8744	0.4731	cooler	0.9999	No
SDWRw to HHw	October	11pm-4pm	682	0	0.9942	24.1006	0.9782	warmer	0.9892	No
SDWRw to UCC	October	11pm-4pm	682	0	0.9942	24.1006	0.9738	warmer	0.9894	No
SDWRw to WS	October	11pm-4pm	682	0	0.9942	24.1006	1.1938	warmer	0.9738	No
SDWRw to KCw	October	11pm-4pm	682	0	0.9942	24.1006	0.8913	warmer	0.993	No
SDWRw to GSIC	October	11pm-4pm	682	0	0.9942	24.1006	0.446	warmer	0.9997	No
HHw to UCC	October	11pm-4pm	682	0	0.9942	24.1006	0.00431	cooler	1	No
HHw to WS	October	11pm-4pm	682	0	0.9942	24.1006	0.2156	warmer	1	No
HHw to KCw	October	11pm-4pm	682	0	0.9942	24.1006	0.08691	cooler	1	No
HHw to GSIC	October	11pm-4pm	682	0	0.9942	24.1006	0.5322	cooler	0.9994	No
UCC to WS	October	11pm-4pm	682	0	0.9942	24.1006	0.2199	warmer	1	No
UCC to KCw	October	11pm-4pm	682	0	0.9942	24.1006	0.08261	cooler	1	No
UCC to GSIC	October	11pm-4pm	682	0	0.9942	24.1006	0.5279	cooler	0.9994	No
WS to KCw	October	11pm-4pm	682	0	0.9942	24.1006	0.3025	cooler	1	No
WS to GSIC	October	11pm-4pm	682	0	0.9942	24.1006	0.7478	cooler	0.9969	No
KCw to GSIC	October	11pm-4pm	682	0	0.9942	24.1006	0.4453	cooler	0.9997	No
SDWRw to HHw	October	3pm-8pm	2046	0	0.9673	24.9757	1.1966	warmer	0.9893	No
SDWRw to UCC	October	3pm-8pm	2046	0	0.9673	24.9757	1.9147	warmer	0.9208	No
SDWRw to WS	October	3pm-8pm	2046	0	0.9673	24.9757	1.9383	warmer	0.9169	No
SDWRw to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	0.2374	warmer	1	No
SDWRw to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.7567	warmer	0.9988	No
HHw to UCC	October	3pm-8pm	2046	0	0.9673	24.9757	0.7181	warmer	0.999	No
HHw to WS	October	3pm-8pm	2046	0	0.9673	24.9757	0.7417	warmer	0.9989	No
HHw to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	0.9591	cooler	0.9962	No
HHw to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.4399	cooler	0.9999	No
UCC to WS	October	3pm-8pm	2046	0	0.9673	24.9757	0.02359	warmer	1	No
UCC to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	1.6772	cooler	0.9535	No
UCC to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	1.158	cooler	0.9908	No
WS to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	1.7008	cooler	0.9507	No
WS to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	1.1816	cooler	0.9899	No
KCw to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.5192	warmer	0.9998	No

Appendix C2 – Average (mean) typical day temperature differences between loggers shaded by multiple trees minus those shaded by an individual tree

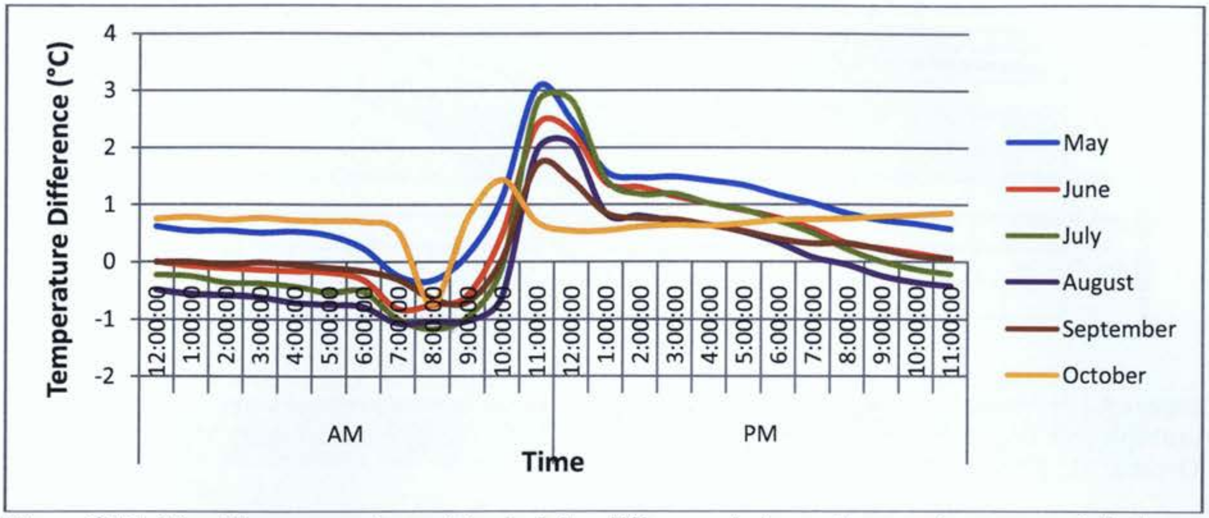


Figure C2.1: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRe minus individual tree site TCe for the duration of study May 1, 2008 – October 31, 2008.

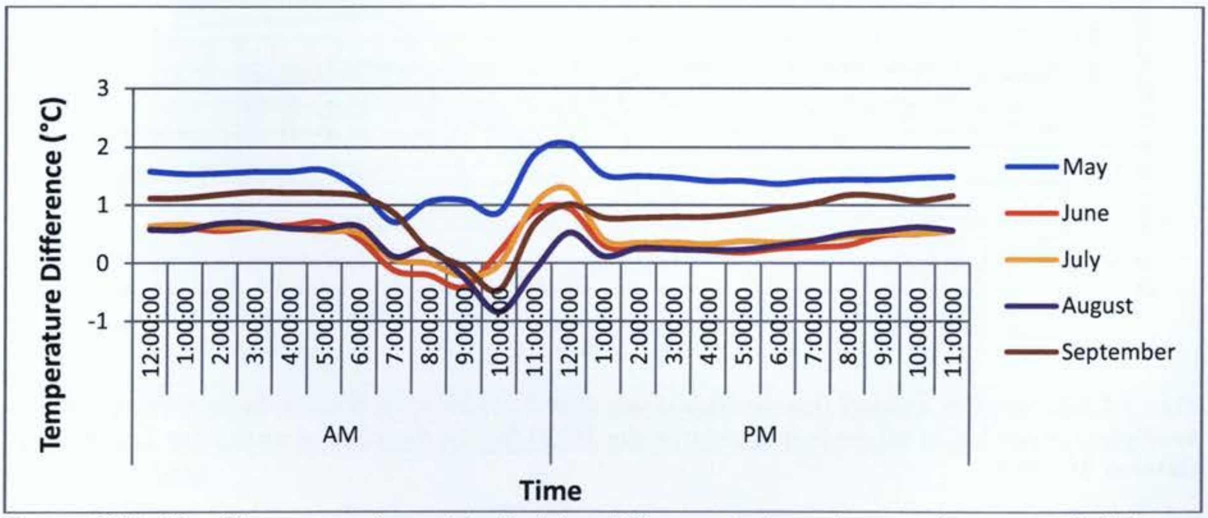


Figure C2.2: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRe minus individual tree site KCe for the duration of study May 1, 2008 – September 30, 2008.

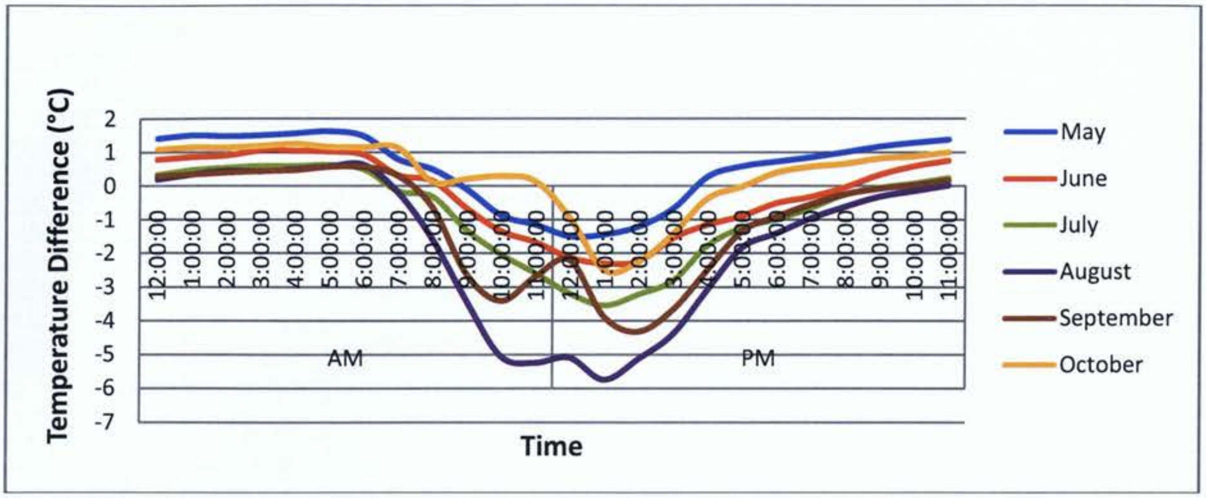


Figure C2.3: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site MCIS minus individual tree site TC(1) for the duration of study May 1, 2008 – October 31, 2008.

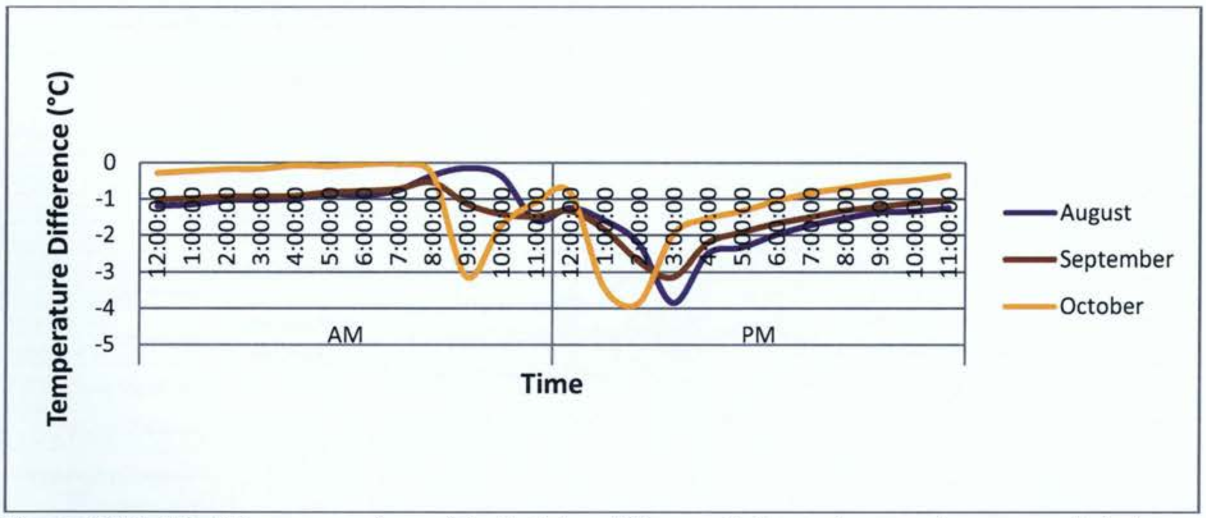


Figure C2.4: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site MCIS minus individual tree site TC(2) for the duration of study May 1, 2008 – October 31, 2008.

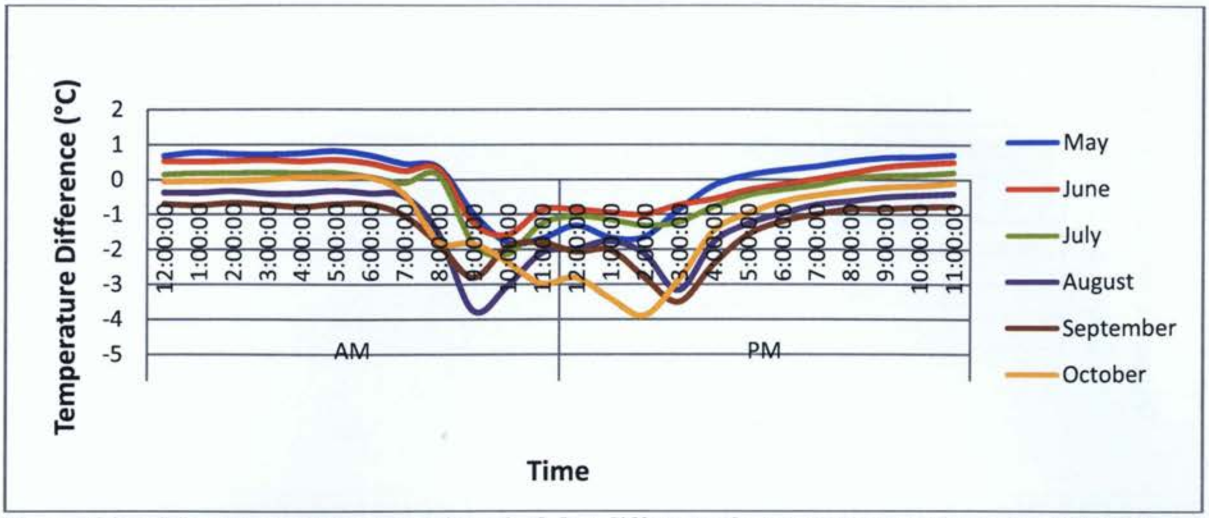


Figure C2.5: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site MCIS minus individual tree site UC(1) for the duration of study May 1, 2008 – October 31, 2008.

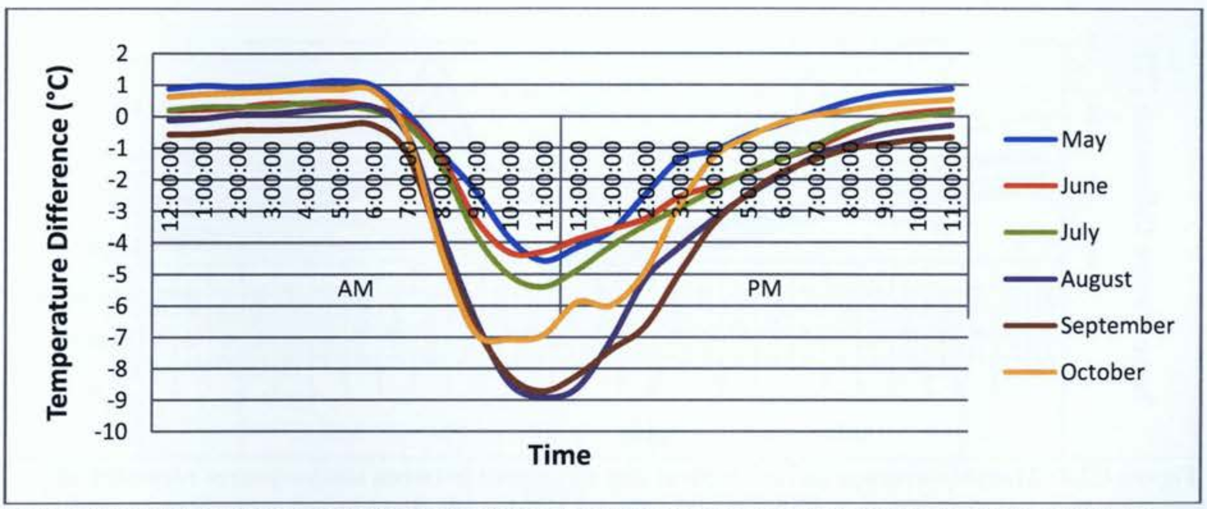


Figure C2.6: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site MCIS minus individual tree site UC(2) for the duration of study May 1, 2008 – October 31, 2008.

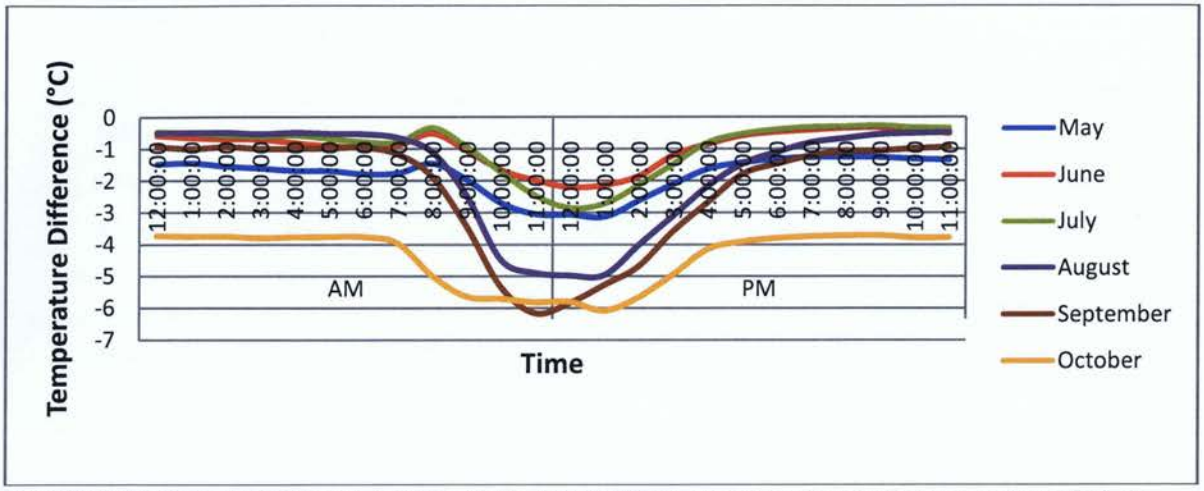


Figure C2.7: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site MCIS minus individual tree site HHs for the duration of study May 1, 2008 – October 31, 2008.

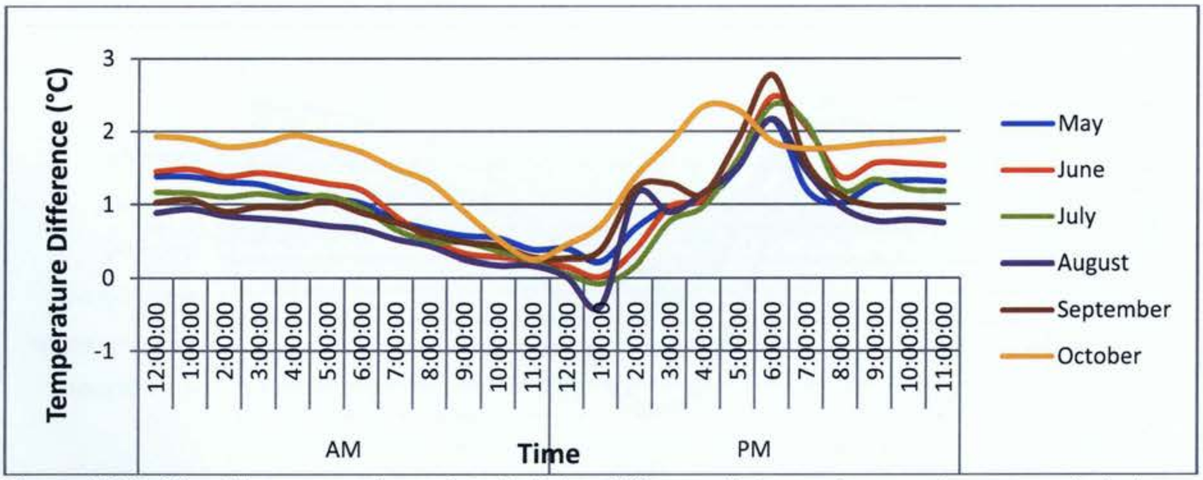


Figure C2.8: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRw minus individual tree site WS for the duration of study May 1, 2008 – October 31, 2008.

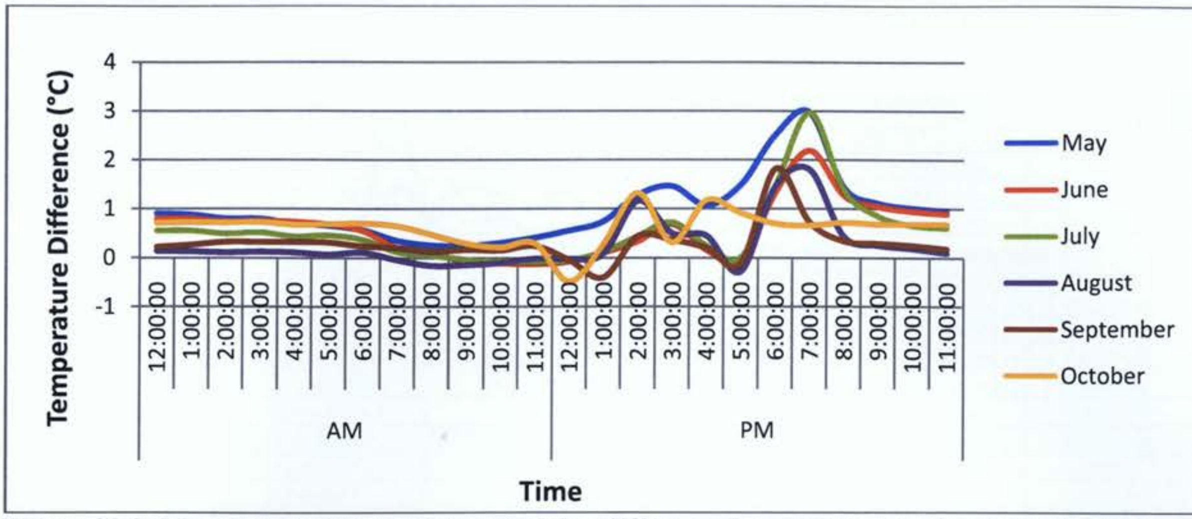


Figure C2.9: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRw minus individual tree site KCw for the duration of study May 1, 2008 – October 31, 2008.

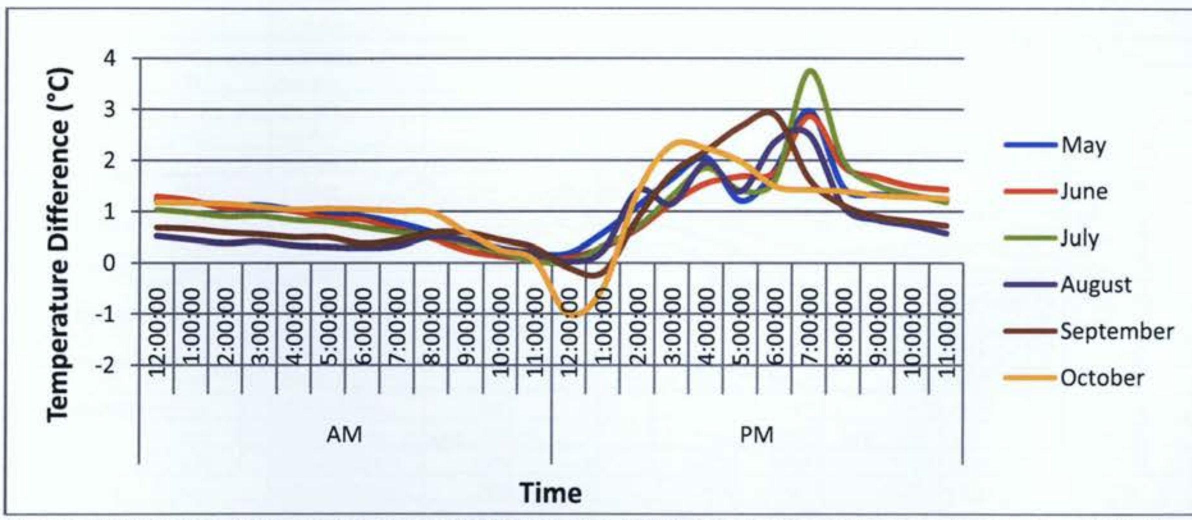


Figure C2.10: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRw minus individual tree site UCC for the duration of study May 1, 2008 – October 31, 2008.

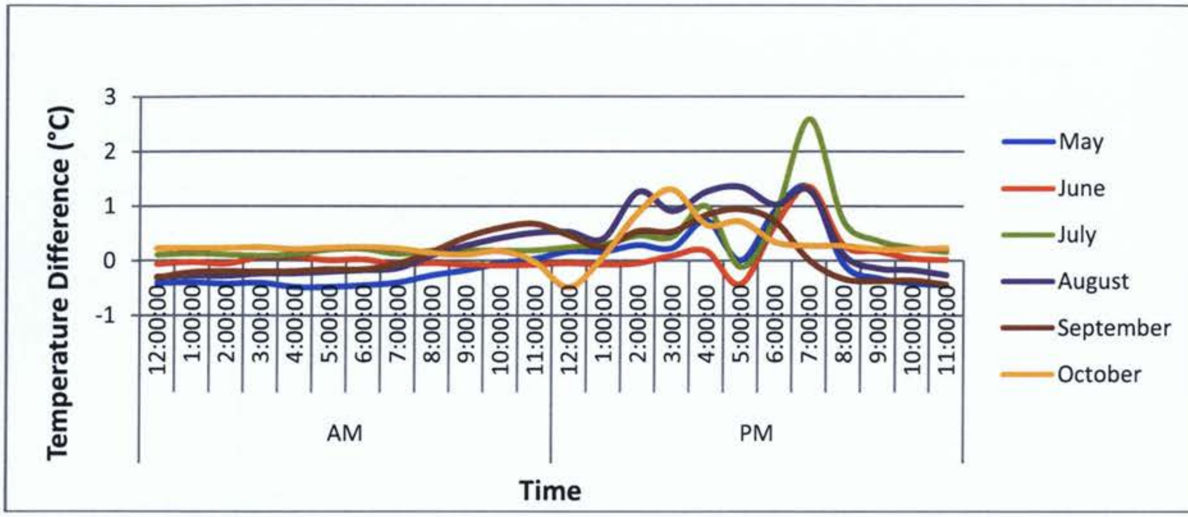


Figure C2.11: Monthly average(mean) typical day difference between temperatures recorded at multiple tree site SDWRw minus single tree site GSIC for the duration of study May 1, 2008 – October 31, 2008.

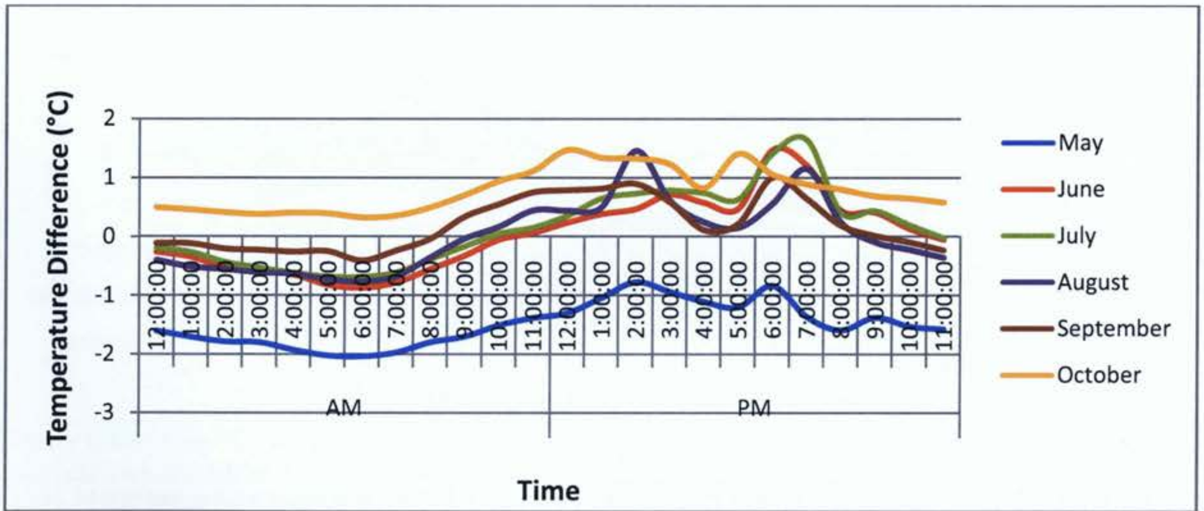


Figure C2.12: Monthly average (mean) typical day difference between temperatures recorded at multiple tree site SDWRw minus individual tree site HHw for the duration of study May 1, 2008 – October 31, 2008.

Appendix D – Mixed model (SAS PROC MIXED) results for vine temperature comparison with individual tree temperatures

	Month	Peak Time Period	N-Value	Building Variation	Observation B/W Correlations	Residual	Temperature	Warmer / Cooler	p-value	Significant
TC(1) to UC(1)	May	5:30am-11:30am	1955	0	0.9318	20.5248	0.6195	cooler	0.9888	No
TC(1) to UC(2)	May	5:30am-11:30am	1955	0	0.9318	20.5248	1.8907	cooler	0.5875	No
TC(1) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5248	0.173	cooler	0.9999	No
TC(1) HHs	May	5:30am-11:30am	1955	0	0.9318	20.5248	2.5005	cooler	0.3087	No
UC(1) to UC(2)	May	5:30am-11:30am	1955	0	0.9318	20.5248	1.2712	cooler	0.8601	No
UC(1) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5248	0.4465	warmer	0.9968	No
UC(1) to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5248	1.8809	cooler	0.5923	No
UC(2) to MCIS	May	5:30am-11:30am	1955	0	0.9318	20.5248	1.7177	warmer	0.6719	No
UC(2) to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5248	0.6098	cooler	0.9895	No
MCIS to HHs	May	5:30am-11:30am	1955	0	0.9318	20.5248	2.3274	cooler	0.3804	No
TC(1) to UC(1)	May	11pm-4pm	1650	0	0.9483	17.1288	0.4687	cooler	0.9966	No
TC(1) to UC(2)	May	11pm-4pm	1650	0	0.9483	17.1288	2.2947	cooler	0.4319	No
TC(1) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	0.6287	warmer	0.9895	No
TC(1) HHs	May	11pm-4pm	1650	0	0.9483	17.1288	1.8259	cooler	0.6499	No
UC(1) to UC(2)	May	11pm-4pm	1650	0	0.9483	17.1288	1.826	cooler	0.6499	No
UC(1) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	1.0973	warmer	0.9221	No
UC(1) to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	1.3572	cooler	0.8457	No
UC(2) to MCIS	May	11pm-4pm	1650	0	0.9483	17.1288	2.9234	warmer	0.2015	No
UC(2) to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	0.4688	warmer	0.9966	No
MCIS to HHs	May	11pm-4pm	1650	0	0.9483	17.1288	2.4546	cooler	0.3639	No
TC(1) to UC(1)	May	3pm-8pm	1650	0	0.9685	16.0367	0.4251	cooler	0.9988	No
TC(1) to UC(2)	May	3pm-8pm	1650	0	0.9685	16.0367	0.694	cooler	0.992	No
TC(1) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.1359	cooler	1	No
TC(1) HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.8713	cooler	0.7638	No
UC(1) to UC(2)	May	3pm-8pm	1650	0	0.9685	16.0367	0.269	cooler	0.9998	No
UC(1) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.2891	warmer	0.9997	No
UC(1) to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.4462	cooler	0.8905	No
UC(2) to MCIS	May	3pm-8pm	1650	0	0.9685	16.0367	0.5581	warmer	0.9965	No
UC(2) to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.1772	cooler	0.9448	No
MCIS to HHs	May	3pm-8pm	1650	0	0.9685	16.0367	1.7353	cooler	0.809	No
TC(1) to UC(1)	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.08681	warmer	1	No
TC(1) to UC(2)	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.749	cooler	0.7179	No
TC(1) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.3075	warmer	0.9994	No
TC(1) HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.0941	cooler	0.9329	No
UC(1) to UC(2)	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.8358	cooler	0.6805	No
UC(1) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.2207	warmer	0.9999	No
UC(1) to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.181	cooler	0.9133	No
UC(2) to MCIS	June	5:30am-11:30am	1880	0	0.9522	17.0877	2.0566	warmer	0.5819	No
UC(2) to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	0.6549	warmer	0.9895	No
MCIS to HHs	June	5:30am-11:30am	1880	0	0.9522	17.0877	1.4017	cooler	0.8501	No
TC(1) to UC(1)	June	11pm-4pm	1595	0	0.9662	18.1716	0.7172	warmer	0.9924	No
TC(1) to UC(2)	June	11pm-4pm	1595	0	0.9662	18.1716	1.6653	cooler	0.8529	No
TC(1) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	1.4457	warmer	0.9059	No
TC(1) HHs	June	11pm-4pm	1595	0	0.9662	18.1716	0.05705	cooler	1	No

UC(1) to UC(2)	June	11pm-4pm	1595	0	0.9662	18.1716	2.3825	cooler	0.6139	No
UC(1) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	0.7285	warmer	0.9919	No
UC(1) to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	0.7742	cooler	0.9898	No
UC(2) to MCIS	June	11pm-4pm	1595	0	0.9662	18.1716	3.111	warmer	0.358	No
UC(2) to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	1.6083	warmer	0.8678	No
MCIS to HHs	June	11pm-4pm	1595	0	0.9662	18.1716	1.5028	cooler	0.8933	No
TC(1) to UC(1)	June	3pm-8pm	1595	0	0.981	17.7145	0.4956	warmer	0.9992	No
TC(1) to UC(2)	June	3pm-8pm	1595	0	0.981	17.7145	0.752	cooler	0.996	No
TC(1) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	0.7776	warmer	0.9954	No
TC(1) HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.03225	cooler	1	No
UC(1) to UC(2)	June	3pm-8pm	1595	0	0.981	17.7145	1.2476	cooler	0.9733	No
UC(1) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	0.282	warmer	0.9999	No
UC(1) to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.5278	cooler	0.999	No
UC(2) to MCIS	June	3pm-8pm	1595	0	0.981	17.7145	1.5296	warmer	0.9454	No
UC(2) to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.7198	warmer	0.9966	No
MCIS to HHs	June	3pm-8pm	1595	0	0.981	17.7145	0.8098	cooler	0.9947	No
TC(1) to UC(1)	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.4253	warmer	0.9889	No
TC(1) to UC(2)	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.655	cooler	0.3431	No
TC(1) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.9992	warmer	0.7906	No
TC(1) HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.512	cooler	0.9778	No
UC(1) to UC(2)	July	5:30am-11:30am	1950	0	0.9196	10.8655	2.0803	cooler	0.1419	No
UC(1) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.5739	warmer	0.9663	No
UC(1) to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	0.9373	cooler	0.8265	No
UC(2) to MCIS	July	5:30am-11:30am	1950	0	0.9196	10.8655	2.6542	warmer	0.03	Yes
UC(2) to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.143	warmer	0.6972	No
MCIS to HHs	July	5:30am-11:30am	1950	0	0.9196	10.8655	1.5112	cooler	0.4362	No
TC(1) to UC(1)	July	11pm-4pm	1650	0	0.8915	6.1806	1.3274	warmer	0.1979	No
TC(1) to UC(2)	July	11pm-4pm	1650	0	0.8915	6.1806	1.3426	cooler	0.1885	No
TC(1) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	2.4534	warmer	0.0012	Yes
TC(1) HHs	July	11pm-4pm	1650	0	0.8915	6.1806	0.6841	warmer	0.7938	No
UC(1) to UC(2)	July	11pm-4pm	1650	0	0.8915	6.1806	2.67	cooler	0.0003	Yes
UC(1) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	1.126	warmer	0.3533	No
UC(1) to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	0.6433	cooler	0.8281	No
UC(2) to MCIS	July	11pm-4pm	1650	0	0.8915	6.1806	3.796	warmer	<0.0001	Yes
UC(2) to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	2.0267	warmer	0.0112	Yes
MCIS to HHs	July	11pm-4pm	1650	0	0.8915	6.1806	1.7693	cooler	0.0371	No
TC(1) to UC(1)	July	3pm-8pm	1650	0	0.9327	4.9895	0.9351	warmer	0.6026	No
TC(1) to UC(2)	July	3pm-8pm	1650	0	0.9327	4.9895	0.1987	cooler	0.998	No
TC(1) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	1.5506	warmer	0.132	No
TC(1) HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.6796	warmer	0.8312	No
UC(1) to UC(2)	July	3pm-8pm	1650	0	0.9327	4.9895	1.1338	cooler	0.4123	No
UC(1) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	0.6155	warmer	0.8758	No
UC(1) to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.2555	cooler	0.9947	No
UC(2) to MCIS	July	3pm-8pm	1650	0	0.9327	4.9895	1.7493	warmer	0.0665	No
UC(2) to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.8783	warmer	0.6578	No
MCIS to HHs	July	3pm-8pm	1650	0	0.9327	4.9895	0.871	cooler	0.6648	No

TC(1) to UC(1)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.896	warmer	0.9696	No
TC(1) to UC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.1172	cooler	0.44	No
TC(1) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.2179	warmer	0.3868	No
TC(1) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.5312	warmer	0.902	No
TC(1) HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.4431	cooler	0.9988	No
UC(1) to UC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	3.0132	cooler	0.1011	No
UC(1) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.3219	warmer	0.8563	No
UC(1) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.6352	warmer	0.998	No
UC(1) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.3391	cooler	0.8495	No
UC(2) to MCIS	August	5:30am-11:30am	2119	0	0.9162	18.7051	4.3351	warmer	0.0038	Yes
UC(2) to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	3.684	warmer	0.1411	No
UC(2) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.6741	warmer	0.6883	No
MCIS to TC(2)	August	5:30am-11:30am	2119	0	0.9162	18.7051	0.6867	cooler	0.9971	No
MCIS to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	2.661	cooler	0.196	No
TC(2) to HHs	August	5:30am-11:30am	2119	0	0.9162	18.7051	1.9743	cooler	0.7595	No
TC(1) to UC(1)	August	11pm-4pm	1793	0	0.8948	12.7846	2.5512	warmer	0.0539	No
TC(1) to UC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	1.6008	cooler	0.4655	No
TC(1) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	4.7382	warmer	<0.0001	Yes
TC(1) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	2.7338	warmer	0.1659	No
TC(1) HHs	August	11pm-4pm	1793	0	0.8948	12.7846	0.9592	warmer	0.8866	No
UC(1) to UC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	4.152	cooler	0.0001	Yes
UC(1) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	2.187	warmer	0.1438	No
UC(1) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	0.1825	warmer	1	No
UC(1) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	1.592	cooler	0.4717	No
UC(2) to MCIS	August	11pm-4pm	1793	0	0.8948	12.7846	6.339	warmer	<0.0001	Yes
UC(2) to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	4.3345	warmer	0.0033	Yes
UC(2) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	2.56	warmer	0.0526	No
MCIS to TC(2)	August	11pm-4pm	1793	0	0.8948	12.7846	2.0045	cooler	0.4949	No
MCIS to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	3.779	cooler	0.0007	Yes
TC(2) to HHs	August	11pm-4pm	1793	0	0.8948	12.7846	1.7746	cooler	0.6264	No
TC(1) to UC(1)	August	3pm-8pm	1793	0	0.9535	12.011	0.6822	warmer	0.9916	No
TC(1) to UC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.1466	cooler	1	No
TC(1) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	2.5126	warmer	0.281	No
TC(1) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.007836	warmer	1	No
TC(1) HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.6032	warmer	0.9952	No
UC(1) to UC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.8288	cooler	0.9797	No
UC(1) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	1.8304	warmer	0.6234	No
UC(1) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.6744	cooler	0.9975	No
UC(1) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.079	cooler	1	No
UC(2) to MCIS	August	3pm-8pm	1793	0	0.9535	12.011	2.6592	warmer	0.2253	No
UC(2) to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	0.1544	warmer	1	No
UC(2) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.7498	warmer	0.987	No
MCIS to TC(2)	August	3pm-8pm	1793	0	0.9535	12.011	2.5048	cooler	0.5514	No
MCIS to HHs	August	3pm-8pm	1793	0	0.9535	12.011	1.9094	cooler	0.5803	No
TC(2) to HHs	August	3pm-8pm	1793	0	0.9535	12.011	0.5954	warmer	0.9986	No

TC(1) to UC(1)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.4372	cooler	0.9994	No
TC(1) to UC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.49	cooler	0.086	No
TC(1) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	0.9515	warmer	0.9766	No
TC(1) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.1051	cooler	1	No
TC(1) HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.5792	cooler	0.3528	No
UC(1) to UC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.0528	cooler	0.1815	No
UC(1) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	1.3888	warmer	0.8895	No
UC(1) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	0.3321	warmer	0.9998	No
UC(1) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.142	cooler	0.5624	No
UC(2) to MCIS	September	5:30am-11:30am	2262	0	0.923	21.5767	4.4415	warmer	0.0116	Yes
UC(2) to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	3.3849	warmer	0.104	No
UC(2) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	0.9108	warmer	0.9807	No
MCIS to TC(2)	September	5:30am-11:30am	2262	0	0.923	21.5767	1.0566	cooler	0.9633	No
MCIS to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	3.5307	cooler	0.0797	No
TC(2) to HHs	September	5:30am-11:30am	2262	0	0.923	21.5767	2.4741	cooler	0.3999	No
TC(1) to UC(1)	September	11pm-4pm	1914	0	0.9329	19.1535	0.836	warmer	0.9869	No
TC(1) to UC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	3.2293	cooler	0.1382	No
TC(1) to MCIS	September	11pm-4pm	1914	0	0.9329	19.1535	3.1688	warmer	0.155	No
TC(1) to TC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	1.166	warmer	0.9446	No
TC(1) HHs	September	11pm-4pm	1914	0	0.9329	19.1535	1.2632	cooler	0.9236	No
UC(1) to UC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	4.0753	cooler	0.0286	Yes
UC(1) to MCIS	September	11pm-4pm	1914	0	0.9329	19.1535	2.3328	warmer	0.4705	No
UC(1) to TC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	0.33	warmer	0.9998	No
UC(1) to HHs	September	11pm-4pm	1914	0	0.9329	19.1535	2.0992	cooler	0.5864	No
UC(2) to MCIS	September	11pm-4pm	1914	0	0.9329	19.1535	6.4081	warmer	<0.0001	Yes
UC(2) to TC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	4.4053	warmer	0.014	Yes
UC(2) to HHs	September	11pm-4pm	1914	0	0.9329	19.1535	1.9761	warmer	0.6475	No
MCIS to TC(2)	September	11pm-4pm	1914	0	0.9329	19.1535	2.0028	cooler	0.6344	No
MCIS to HHs	September	11pm-4pm	1914	0	0.9329	19.1535	4.4319	cooler	0.0132	Yes
TC(2) to HHs	September	11pm-4pm	1914	0	0.9329	19.1535	2.4292	cooler	0.4246	No
TC(1) to UC(1)	September	3pm-8pm	1914	0	0.9687	17.7282	0.03637	cooler	1	No
TC(1) to UC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.9401	cooler	0.9932	No
TC(1) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	2.1698	warmer	0.795	No
TC(1) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.1783	cooler	1	No
TC(1) HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.2525	cooler	1	No
UC(1) to UC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.9038	cooler	0.9943	No
UC(1) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	2.2062	warmer	0.7837	No
UC(1) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.1419	cooler	1	No
UC(1) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.2161	cooler	1	No
UC(2) to MCIS	September	3pm-8pm	1914	0	0.9687	17.7282	3.1099	warmer	0.4658	No
UC(2) to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	0.7619	warmer	0.9975	No
UC(2) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.6877	warmer	0.9984	No
MCIS to TC(2)	September	3pm-8pm	1914	0	0.9687	17.7282	2.3481	cooler	0.7377	No
MCIS to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	2.4223	cooler	0.7124	No
TC(2) to HHs	September	3pm-8pm	1914	0	0.9687	17.7282	0.0742	cooler	1	No

TC(1) to UC(1)	October	5:30am-11:30am	2418	0	0.9371	27.7683	2.0566	cooler	0.7677	No
TC(1) to UC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.8103	cooler	0.1509	No
TC(1) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.5888	cooler	0.9989	No
TC(1) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.2249	cooler	0.968	No
TC(1) HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	5.3953	cooler	0.011	Yes
UC(1) to UC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.7537	cooler	0.8655	No
UC(1) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.4679	warmer	0.932	No
UC(1) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.8318	warmer	0.9944	No
UC(1) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.3387	cooler	0.2718	No
UC(2) to MCIS	October	5:30am-11:30am	2418	0	0.9371	27.7683	3.2216	warmer	0.3095	No
UC(2) to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	2.5854	warmer	0.5555	No
UC(2) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	1.585	cooler	0.908	No
MCIS to TC(2)	October	5:30am-11:30am	2418	0	0.9371	27.7683	0.6361	cooler	0.9984	No
MCIS to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	4.8065	cooler	0.0322	No
TC(2) to HHs	October	5:30am-11:30am	2418	0	0.9371	27.7683	4.1704	cooler	0.0902	No
TC(1) to UC(1)	October	11pm-4pm	2406	0	0.944	28.8386	2.0518	cooler	0.8191	No
TC(1) to UC(2)	October	11pm-4pm	2406	0	0.944	28.8386	4.087	cooler	0.1557	No
TC(1) to MCIS	October	11pm-4pm	2406	0	0.944	28.8386	0.4157	warmer	0.9999	No
TC(1) to TC(2)	October	11pm-4pm	2406	0	0.944	28.8386	1.2049	cooler	0.9782	No
TC(1) HHs	October	11pm-4pm	2406	0	0.944	28.8386	4.7503	cooler	0.0636	No
UC(1) to UC(2)	October	11pm-4pm	2406	0	0.944	28.8386	2.0352	cooler	0.8241	No
UC(1) to MCIS	October	11pm-4pm	2406	0	0.944	28.8386	2.4676	warmer	0.6768	No
UC(1) to TC(2)	October	11pm-4pm	2406	0	0.944	28.8386	0.8469	warmer	0.9956	No
UC(1) to HHs	October	11pm-4pm	2406	0	0.944	28.8386	2.6984	warmer	0.5886	No
UC(2) to MCIS	October	11pm-4pm	2406	0	0.944	28.8386	4.5027	warmer	0.0904	No
UC(2) to TC(2)	October	11pm-4pm	2406	0	0.944	28.8386	2.8821	warmer	0.5177	No
UC(2) to HHs	October	11pm-4pm	2406	0	0.944	28.8386	0.6633	cooler	0.9986	No
MCIS to TC(2)	October	11pm-4pm	2406	0	0.944	28.8386	1.6207	cooler	0.9244	No
MCIS to HHs	October	11pm-4pm	2406	0	0.944	28.8386	5.166	cooler	0.0339	Yes
TC(2) to HHs	October	11pm-4pm	2406	0	0.944	28.8386	3.5453	cooler	0.2876	No
TC(1) to UC(1)	October	3pm-8pm	2046	0	0.9802	24.1892	1.1898	cooler	0.9956	No
TC(1) to UC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	1.0378	cooler	0.9977	No
TC(1) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	0.3726	warmer	1	No
TC(1) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.9822	cooler	0.9982	No
TC(1) HHs	October	3pm-8pm	2046	0	0.9802	24.1892	3.7826	cooler	0.6137	No
UC(1) to UC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.1521	warmer	1	No
UC(1) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	1.5624	warmer	0.9848	No
UC(1) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.2076	warmer	1	No
UC(1) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.5928	cooler	0.8801	No
UC(2) to MCIS	October	3pm-8pm	2046	0	0.9802	24.1892	1.4104	warmer	0.9904	No
UC(2) to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	0.0556	warmer	1	No
UC(2) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.7449	cooler	0.8532	No
MCIS to TC(2)	October	3pm-8pm	2046	0	0.9802	24.1892	1.3548	cooler	0.992	No
MCIS to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	4.1552	cooler	0.5186	No
TC(2) to HHs	October	3pm-8pm	2046	0	0.9802	24.1892	2.8004	cooler	0.8427	No

	Month	Peak Time Period	N-Value	Building Variation	Observation B/W Correlations	Residual	Temperature	Warmer / Cooler	p-value	Significant
SDWRw to HHw	May	5:30am-11:30am	2346	0	0.9702	12.2144	1.7863	cooler	0.797	No
SDWRw to UCC	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.4166	warmer	0.9996	No
SDWRw to WS	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.5464	warmer	0.9987	No
SDWRw to KCw	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.3435	warmer	0.9999	No
SDWwR to GSIC	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.2808	cooler	0.9999	No
HHw to UCC	May	5:30am-11:30am	2346	0	0.9702	12.2144	2.2028	warmer	0.6262	No
HHw to WS	May	5:30am-11:30am	2346	0	0.9702	12.2144	2.3326	warmer	0.5695	No
HHw to KCw	May	5:30am-11:30am	2346	0	0.9702	12.2144	2.1298	warmer	0.6579	No
HH to GSIC	May	5:30am-11:30am	2346	0	0.9702	12.2144	1.5055	warmer	0.8876	No
UCC to WS	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.1298	warmer	1	No
UCC to KCw	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.07306	cooler	1	No
UCC to GSIC	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.4461	cooler	1	No
WS to KCw	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.4119	cooler	1	No
WS to GSIC	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.885	cooler	0.9987	No
KCw to GSIC	May	5:30am-11:30am	2346	0	0.9702	12.2144	0.4731	cooler	0.9999	No
SDWRw to HHw	May	11pm-4pm	1980	0	0.9588	16.4244	1.7799	cooler	0.8154	No
SDWRw to UCC	May	11pm-4pm	1980	0	0.9588	16.4244	0.5951	warmer	0.9983	No
SDWRw to WS	May	11pm-4pm	1980	0	0.9588	16.4244	0.129	warmer	1	No
SDWRw to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.4109	warmer	0.9997	No
SDWwR to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.1114	cooler	1	No
HHw to UCC	May	11pm-4pm	1980	0	0.9588	16.4244	2.375	warmer	0.5698	No
HHw to WS	May	11pm-4pm	1980	0	0.9588	16.4244	1.9089	warmer	0.7678	No
HHw to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	2.1909	warmer	0.651	No
HH to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	1.6686	warmer	0.8524	No
UCC to WS	May	11pm-4pm	1980	0	0.9588	16.4244	0.4661	cooler	0.9995	No
UCC to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.1842	cooler	1	No
UCC to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.7065	cooler	0.9962	No
WS to KCw	May	11pm-4pm	1980	0	0.9588	16.4244	0.2819	warmer	1	No
WS to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.2404	cooler	1	No
KCw to GSIC	May	11pm-4pm	1980	0	0.9588	16.4244	0.5233	cooler	0.9991	No
SDWRw to HHw	May	3pm-8pm	1980	0	0.9248	21.2085	2.0237	cooler	0.6153	No
SDWRw to UCC	May	3pm-8pm	1980	0	0.9248	21.2085	0.947	warmer	0.9764	No
SDWRw to WS	May	3pm-8pm	1980	0	0.9248	21.2085	0.2783	warmer	0.9999	No
SDWRw to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.861	warmer	0.9845	No
SDWwR to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	0.4633	cooler	0.9992	No
HHw to UCC	May	3pm-8pm	1980	0	0.9248	21.2085	2.9707	warmer	0.2004	No
HHw to WS	May	3pm-8pm	1980	0	0.9248	21.2085	2.302	warmer	0.4751	No
HHw to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	2.8847	warmer	0.2281	No
HH to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.5604	warmer	0.8273	No
UCC to WS	May	3pm-8pm	1980	0	0.9248	21.2085	0.6687	cooler	0.9952	No
UCC to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.08599	cooler	1	No
UCC to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.4103	cooler	0.88	No
WS to KCw	May	3pm-8pm	1980	0	0.9248	21.2085	0.5827	warmer	0.9975	No

WS to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	0.7416	cooler	0.9922	No
KCw to GSIC	May	3pm-8pm	1980	0	0.9248	21.2085	1.3243	cooler	0.905	No
SDWRw to HHw	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.4995	cooler	0.9997	No
SDWRw to UCC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.4223	warmer	0.9999	No
SDWRw to WS	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.6005	warmer	0.9992	No
SDWRw to KCw	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.158	warmer	1	No
SDWwR to GSIC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.09638	cooler	1	No
HHw to UCC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.9217	warmer	0.994	No
HHw to WS	June	5:30am-11:30am	2256	0	0.9801	12.4681	1.1	warmer	0.9865	No
HHw to KCw	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.6575	warmer	0.9988	No
HH to GSIC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.4031	warmer	0.9999	No
UCC to WS	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.1783	warmer	1	No
UCC to KCw	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.2643	cooler	1	No
UCC to GSIC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.5186	cooler	0.9996	No
WS to KCw	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.4425	cooler	0.9998	No
WS to GSIC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.6969	cooler	0.9984	No
KCw to GSIC	June	5:30am-11:30am	2256	0	0.9801	12.4681	0.2544	cooler	1	No
SDWRw to HHw	June	11pm-4pm	1914	0	0.9704	17.9236	0.2906	warmer	1	No
SDWRw to UCC	June	11pm-4pm	1914	0	0.9704	17.9236	0.7471	warmer	0.998	No
SDWRw to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.6087	warmer	0.9993	No
SDWRw to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.102	warmer	1	No
SDWwR to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.04669	warmer	1	No
HHw to UCC	June	11pm-4pm	1914	0	0.9704	17.9236	0.4565	warmer	0.9998	No
HHw to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.3181	warmer	1	No
HHw to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.1886	cooler	1	No
HH to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.2439	cooler	1	No
UCC to WS	June	11pm-4pm	1914	0	0.9704	17.9236	0.1384	cooler	1	No
UCC to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.6451	cooler	0.999	No
UCC to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.7004	cooler	0.9985	No
WS to KCw	June	11pm-4pm	1914	0	0.9704	17.9236	0.5067	cooler	0.9997	No
WS to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.562	cooler	0.9995	No
KCw to GSIC	June	11pm-4pm	1914	0	0.9704	17.9236	0.05534	cooler	1	No
SDWRw to HHw	June	3pm-8pm	1914	0	0.9436	20.742	0.5069	warmer	0.9993	No
SDWRw to UCC	June	3pm-8pm	1914	0	0.9436	20.742	1.6095	warmer	0.8723	No
SDWRw to WS	June	3pm-8pm	1914	0	0.9436	20.742	1.1385	warmer	0.9681	No
SDWRw to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.9805	warmer	0.9834	No
SDWwR to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.1792	warmer	1	No
HHw to UCC	June	3pm-8pm	1914	0	0.9436	20.742	1.1026	warmer	0.9722	No
HHw to WS	June	3pm-8pm	1914	0	0.9436	20.742	0.6317	warmer	0.9978	No
HHw to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.4736	warmer	0.9995	No
HH to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.3277	cooler	0.9999	No
UCC to WS	June	3pm-8pm	1914	0	0.9436	20.742	0.471	cooler	0.9995	No
UCC to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.629	cooler	0.9979	No
UCC to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	1.4303	cooler	0.9184	No
WS to KCw	June	3pm-8pm	1914	0	0.9436	20.742	0.158	cooler	1	No
WS to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.9594	cooler	0.9849	No

KCw to GSIC	June	3pm-8pm	1914	0	0.9436	20.742	0.8013	cooler	0.9934	No
SDWRw to HHw	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.2439	cooler	0.9998	No
SDWRw to UCC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.4195	warmer	0.9966	No
SDWRw to WS	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.6421	warmer	0.9764	No
SDWRw to KCw	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.1733	warmer	1	No
SDWwR to GSIC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.2125	warmer	0.9999	No
HHw to UCC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.6634	warmer	0.9729	No
HHw to WS	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.886	warmer	0.9113	No
HHw to KCw	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.4172	warmer	0.9967	No
HH to GSIC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.4564	warmer	0.995	No
UCC to WS	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.2226	warmer	0.9998	No
UCC to KCw	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.2462	cooler	0.9997	No
UCC to GSIC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.207	cooler	0.9999	No
WS to KCw	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.4688	cooler	0.9943	No
WS to GSIC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.4296	cooler	0.9962	No
KCw to GSIC	July	5:30am-11:30am	2340	0	0.9652	5.3364	0.0392	warmer	1	No
SDWRw to HHw	July	11pm-4pm	1980	0	0.9236	6.32	0.4447	warmer	0.9876	No
SDWRw to UCC	July	11pm-4pm	1980	0	0.9236	6.32	0.7753	warmer	0.8737	No
SDWRw to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.4808	warmer	0.9824	No
SDWRw to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.1722	warmer	0.9999	No
SDWwR to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.5185	warmer	0.9754	No
HHw to UCC	July	11pm-4pm	1980	0	0.9236	6.32	0.3306	warmer	0.9969	No
HHw to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.03616	warmer	1	No
HHw to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.2719	cooler	0.9988	No
HH to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.07386	warmer	1	No
UCC to WS	July	11pm-4pm	1980	0	0.9236	6.32	0.2944	cooler	0.9982	No
UCC to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.6025	cooler	0.9532	No
UCC to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.2567	cooler	0.9991	No
WS to KCw	July	11pm-4pm	1980	0	0.9236	6.32	0.3081	cooler	0.9978	No
WS to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.03771	warmer	1	No
KCw to GSIC	July	11pm-4pm	1980	0	0.9236	6.32	0.3458	warmer	0.9961	No
SDWRw to HHw	July	3pm-8pm	1980	0	0.7568	6.13116	0.6878	warmer	0.7276	No
SDWRw to UCC	July	3pm-8pm	1980	0	0.7568	6.13116	1.8133	warmer	0.0039	Yes
SDWRw to WS	July	3pm-8pm	1980	0	0.7568	6.13116	1.1035	warmer	0.222	No
SDWRw to KCw	July	3pm-8pm	1980	0	0.7568	6.13116	1.1137	warmer	0.2131	No
SDWwR to GSIC	July	3pm-8pm	1980	0	0.7568	6.13116	0.6772	warmer	0.7405	No
HHw to UCC	July	3pm-8pm	1980	0	0.7568	6.13116	1.1256	warmer	0.203	No
HHw to WS	July	3pm-8pm	1980	0	0.7568	6.13116	0.4157	warmer	0.9585	No
HHw to KCw	July	3pm-8pm	1980	0	0.7568	6.13116	0.4259	warmer	0.9541	No
HH to GSIC	July	3pm-8pm	1980	0	0.7568	6.13116	0.01057	cooler	1	No
UCC to WS	July	3pm-8pm	1980	0	0.7568	6.13116	0.7098	cooler	0.7001	No
UCC to KCw	July	3pm-8pm	1980	0	0.7568	6.13116	0.6997	cooler	0.7129	No
UCC to GSIC	July	3pm-8pm	1980	0	0.7568	6.13116	1.1361	cooler	0.1943	No
WS to KCw	July	3pm-8pm	1980	0	0.7568	6.13116	0.01016	warmer	1	No
WS to GSIC	July	3pm-8pm	1980	0	0.7568	6.13116	0.4263	cooler	0.9539	No
KCw to GSIC	July	3pm-8pm	1980	0	0.7568	6.13116	0.4365	cooler	0.9491	No

SDWRw to HHw	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.4118	cooler	0.9989	No
SDWRw to UCC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.2629	warmer	0.9998	No
SDWRw to WS	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.4501	warmer	0.9977	No
SDWRw to KCw	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.03204	warmer	1	No
SDWwR to GSIC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.1493	warmer	1	No
HHw to UCC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.6747	warmer	0.9889	No
HHw to WS	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.8619	warmer	0.9674	No
HHw to KCw	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.4438	warmer	0.9984	No
HH to GSIC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.5611	warmer	0.9953	No
UCC to WS	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.1873	warmer	1	No
UCC to KCw	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.2308	cooler	0.9999	No
UCC to GSIC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.1136	cooler	1	No
WS to KCw	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.4181	cooler	0.9984	No
WS to GSIC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.3008	cooler	0.9997	No
KCw to GSIC	August	5:30am-11:30am	2236	0	0.9644	7.3228	0.1173	warmer	1	No
SDWRw to HHw	August	11pm-4pm	1892	0	0.9385	9.8459	0.00656	cooler	1	No
SDWRw to UCC	August	11pm-4pm	1892	0	0.9385	9.8459	0.8297	warmer	0.9499	No
SDWRw to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.5307	warmer	0.993	No
SDWRw to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.1381	warmer	1	No
SDWwR to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.7268	warmer	0.9714	No
HHw to UCC	August	11pm-4pm	1892	0	0.9385	9.8459	0.8363	warmer	0.9627	No
HHw to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.5372	warmer	0.9949	No
HHw to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.1447	warmer	1	No
HH to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.7334	warmer	0.9789	No
UCC to WS	August	11pm-4pm	1892	0	0.9385	9.8459	0.2991	cooler	0.9996	No
UCC to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.6916	cooler	0.977	No
UCC to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.1029	cooler	1	No
WS to KCw	August	11pm-4pm	1892	0	0.9385	9.8459	0.3926	cooler	0.9983	No
WS to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.1961	warmer	0.9999	No
KCw to GSIC	August	11pm-4pm	1892	0	0.9385	9.8459	0.5887	warmer	0.9888	No
SDWRw to HHw	August	3pm-8pm	1892	0	0.8928	11.6683	0.07961	warmer	1	No
SDWRw to UCC	August	3pm-8pm	1892	0	0.8928	11.6683	1.3115	warmer	0.6268	No
SDWRw to WS	August	3pm-8pm	1892	0	0.8928	11.6683	1.0855	warmer	0.7894	No
SDWRw to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.5978	warmer	0.9802	No
SDWwR to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.7291	warmer	0.9534	No
HHw to UCC	August	3pm-8pm	1892	0	0.8928	11.6683	1.2319	warmer	0.7567	No
HHw to WS	August	3pm-8pm	1892	0	0.8928	11.6683	1.0059	warmer	0.8796	No
HHw to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.5182	warmer	0.9929	No
HH to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.6496	warmer	0.9802	No
UCC to WS	August	3pm-8pm	1892	0	0.8928	11.6683	0.226	cooler	0.9998	No
UCC to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.7137	cooler	0.9574	No
UCC to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.5823	cooler	0.9824	No
WS to KCw	August	3pm-8pm	1892	0	0.8928	11.6683	0.4876	cooler	0.9921	No
WS to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.3563	cooler	0.9982	No
KCw to GSIC	August	3pm-8pm	1892	0	0.8928	11.6683	0.1313	warmer	1	No

SDWRw to HHw	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.599	warmer	0.9991	No
SDWRw to UCC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.4457	warmer	0.9997	No
SDWRw to WS	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.623	warmer	0.9983	No
SDWRw to KCw	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.2722	warmer	1	No
SDWwR to GSIC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.2416	warmer	1	No
HHw to UCC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.1533	cooler	1	No
HHw to WS	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.02391	cooler	1	No
HHw to KCw	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.3268	cooler	1	No
HH to GSIC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.3574	cooler	0.9999	No
UCC to WS	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.1722	warmer	1	No
UCC to KCw	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.1735	cooler	1	No
UCC to GSIC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.2041	cooler	1	No
WS to KCw	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.3508	cooler	0.9999	No
WS to GSIC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.3813	cooler	0.9998	No
KCw to GSIC	September	5:30am-11:30am	2093	0	0.9779	10.5131	0.03056	cooler	1	No
SDWRw to HHw	September	11pm-4pm	1771	0	0.9461	14.0606	0.6189	warmer	0.9977	No
SDWRw to UCC	September	11pm-4pm	1771	0	0.9461	14.0606	0.9591	warmer	0.9673	No
SDWRw to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.6471	warmer	0.9944	No
SDWRw to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.1252	warmer	1	No
SDWwR to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.6195	warmer	0.9954	No
HHw to UCC	September	11pm-4pm	1771	0	0.9461	14.0606	0.3403	warmer	0.9999	No
HHw to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.02828	warmer	1	No
HHw to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.4936	cooler	0.9992	No
HH to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.000638	warmer	1	No
UCC to WS	September	11pm-4pm	1771	0	0.9461	14.0606	0.312	cooler	0.9998	No
UCC to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.8339	cooler	0.9822	No
UCC to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.3397	cooler	0.9997	No
WS to KCw	September	11pm-4pm	1771	0	0.9461	14.0606	0.5219	cooler	0.998	No
WS to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.02764	cooler	1	No
KCw to GSIC	September	11pm-4pm	1771	0	0.9461	14.0606	0.4943	warmer	0.9984	No
SDWRw to HHw	September	3pm-8pm	1771	0	0.9289	14.596	0.4929	warmer	0.9989	No
SDWRw to UCC	September	3pm-8pm	1771	0	0.9289	14.596	1.6211	warmer	0.6847	No
SDWRw to WS	September	3pm-8pm	1771	0	0.9289	14.596	1.3563	warmer	0.8207	No
SDWRw to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.4153	warmer	0.999	No
SDWwR to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.3006	warmer	0.9998	No
HHw to UCC	September	3pm-8pm	1771	0	0.9289	14.596	1.1282	warmer	0.9508	No
HHw to WS	September	3pm-8pm	1771	0	0.9289	14.596	0.8634	warmer	0.9845	No
HHw to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.07759	cooler	1	No
HH to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.1923	cooler	1	No
UCC to WS	September	3pm-8pm	1771	0	0.9289	14.596	0.2648	cooler	0.9999	No
UCC to KCw	September	3pm-8pm	1771	0	0.9289	14.596	1.2058	cooler	0.8823	No
UCC to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	1.3205	cooler	0.8366	No
WS to KCw	September	3pm-8pm	1771	0	0.9289	14.596	0.941	cooler	0.956	No
WS to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	1.0557	cooler	0.9295	No
KCw to GSIC	September	3pm-8pm	1771	0	0.9289	14.596	0.1147	cooler	1	No

SDWRw to HHw	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.8327	warmer	0.999	No
SDWRw to UCC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4591	warmer	0.9999	No
SDWRw to WS	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.898	warmer	0.9986	No
SDWRw to KCw	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4861	warmer	0.9999	No
SDWwR to GSIC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.01301	warmer	1	No
HHw to UCC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.3736	cooler	1	No
HHw to WS	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.06526	warmer	1	No
HHw to KCw	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.3466	cooler	1	No
HH to GSIC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.8197	cooler	0.9991	No
UCC to WS	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4289	warmer	1	No
UCC to KCw	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.02697	warmer	1	No
UCC to GSIC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4461	cooler	1	No
WS to KCw	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4119	cooler	1	No
WS to GSIC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.885	cooler	0.9987	No
KCw to GSIC	October	5:30am-11:30am	2418	0	0.9842	18.8744	0.4731	cooler	0.9999	No
SDWRw to HHw	October	11pm-4pm	2046	0	0.9438	26.1191	0.9782	warmer	0.9892	No
SDWRw to UCC	October	11pm-4pm	2046	0	0.9438	26.1191	0.9739	warmer	0.9894	No
SDWRw to WS	October	11pm-4pm	2046	0	0.9438	26.1191	1.1938	warmer	0.9738	No
SDWRw to KCw	October	11pm-4pm	2046	0	0.9438	26.1191	0.8913	warmer	0.993	No
SDWwR to GSIC	October	11pm-4pm	2046	0	0.9438	26.1191	0.446	warmer	0.9997	No
HHw to UCC	October	11pm-4pm	2046	0	0.9438	26.1191	0.00431	cooler	1	No
HHw to WS	October	11pm-4pm	2046	0	0.9438	26.1191	0.2156	warmer	1	No
HHw to KCw	October	11pm-4pm	2046	0	0.9438	26.1191	0.08691	cooler	1	No
HH to GSIC	October	11pm-4pm	2046	0	0.9438	26.1191	0.5322	cooler	0.9994	No
UCC to WS	October	11pm-4pm	2046	0	0.9438	26.1191	0.2199	warmer	1	No
UCC to KCw	October	11pm-4pm	2046	0	0.9438	26.1191	0.08261	cooler	1	No
UCC to GSIC	October	11pm-4pm	2046	0	0.9438	26.1191	0.5279	cooler	0.9994	No
WS to KCw	October	11pm-4pm	2046	0	0.9438	26.1191	0.3025	cooler	1	No
WS to GSIC	October	11pm-4pm	2046	0	0.9438	26.1191	0.7478	cooler	0.9969	No
KCw to GSIC	October	11pm-4pm	2046	0	0.9438	26.1191	0.4453	cooler	0.9997	No
SDWRw to HHw	October	3pm-8pm	2046	0	0.9673	24.9757	1.1966	warmer	0.9893	No
SDWRw to UCC	October	3pm-8pm	2046	0	0.9673	24.9757	1.9147	warmer	0.9208	No
SDWRw to WS	October	3pm-8pm	2046	0	0.9673	24.9757	1.9383	warmer	0.9169	No
SDWRw to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	0.2374	warmer	1	No
SDWwR to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.7567	warmer	0.9988	No
HHw to UCC	October	3pm-8pm	2046	0	0.9673	24.9757	0.7181	warmer	0.999	No
HHw to WS	October	3pm-8pm	2046	0	0.9673	24.9757	0.7417	warmer	0.9989	No
HHw to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	0.9591	cooler	0.9962	No
HH to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.4399	cooler	0.9999	No
UCC to WS	October	3pm-8pm	2046	0	0.9673	24.9757	0.02359	warmer	1	No
UCC to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	1.6772	cooler	0.9535	No
UCC to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	1.158	cooler	0.9908	No
WS to KCw	October	3pm-8pm	2046	0	0.9673	24.9757	1.7008	cooler	0.9507	No
WS to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	1.1816	cooler	0.9899	No
KCw to GSIC	October	3pm-8pm	2046	0	0.9673	24.9757	0.5192	warmer	0.9998	No