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Pavement albedo assessment: methods, aspects, and implication

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Pavement albedo assessment: Methods, aspects, and implication

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ABSTRACT

Pavement albedo is an important factor when evaluating thermal performance of pavement. Many pavement thermal models have used a constant albedo value in their simulations of pavement temperature profile, but in the real world the albedo value keeps changing diurnally. Information regarding albedo value for different materials is currently limited. Pavement tining is a common practice used in interstate highways in order to control the noise and pavement expansion. There has been, however, no report studying the influence of pavement tining on pavement albedo. This study investigates three topic: diurnal variation of albedo value, influence of albedometer height and its measuring range, and influence of pavement tining on pavement albedo.

All albedo measurements used albedometer test method. Diurnal variations of albedo value were examined for both concrete and asphalt pavement. An analysis of energy collection based on both dynamic and constant albedo values was performed. The influence albedometer height on measuring range was examined for 2 different albedometer heights. The influence of pavement tining on pavement albedo was examined for two experimental parking lot sections.

CHAPTER 1. INTRODUCTION

1.1. Problem Statement

In recent years, global climate change has become a popular topic in government, industry, and research in general, with increasing interests since 1950. The Urban Island Effect (UHI), one of the most studied topic, is generally described as a condition when temperatures in urban areas are higher than those in surrounding suburban or rural areas, resulting in several negative economic and environmental impacts. For example, more energy will be consumed in the summer to cool communities, and high temperatures will negatively influence air quality. With the rapid development of urban and rural areas, more land surface has been paved, and people living in rural areas are more likely to moving into large cities, especially in some Asian countries (Madlener & Sunak, 2011). This enhances the UHI effect in urban areas at the present time.

Several factors are relevant with respect to the UHI. According to a document on the EPA website, reduced vegetation in urban areas, properties of urban materials, urban geometry, and anthropogenic heat are the main factors creating Urban Heat Islands (EPA, 2015). A detailed discussion related to the UHI effect will be discussed in the following chapter. One important factor is how much solar heat absorbed by building and pavement materials. It is critical to estimate the mean and peak solar heat, the main driving force causing cities to heat up, but it is easier to measure the fraction of incident sunlight reflected than to measure the fraction of incident sunlight absorbed by such materials (Levinson, Akbari, & Berdahl, 2010).

Albedo is a technical name to describe the fraction of incident reflected sunlight. Albedo, also known as solar reflectance, is the percentage of the solar radiation reflected by a surface with respect to the total incident solar radiation falling on the surface (ACPA, 2002), and is an important factor in estimating and predicting the near-surface temperature of a pavement structure.

To gain a better understanding of the UHI effect, several pavement heat transfer mathematical models have been established for simulating a pavement's near-surface temperature change; most of these models assume a constant albedo value. The truth is that the albedo value keeps changing during the day because the sun is moving so the angle of the sun is changing as well. There is a lack of research on albedo change throughout a day, and only a few studies on this topic can be found in the literature, so more work is required to support better predictability of near-surface pavement temperature.

1.2. Study Goal and Scope

The goal of this study was to quantify albedo values for different types of pavement at different times throughout a day. Both concrete and asphalt pavements were included in this study. Unlike previous research effort that involved building test pads, this study utilized existing real-world pavement. To achieve the stated goal, several research objectives were established:

(1) Measure the albedo for both concrete-based and asphalt-based pavement at different locations.

(2) Monitor the full-day albedo change for both concrete-based and asphalt-based pavement.

(3) Investigate possible reasons for albedo change during a day.

(4) Investigate the influence of pavement tining on surface albedo

(5) Provide recommendations for future albedo measurement.

1.3. Outline of This Thesis

This thesis has five chapters. Chapter 2 includes a literature review of the Urban Heat Island effect, mitigation strategies for the UHI effect, and introduction of several pavement thermal models. Chapter 3 presents a proposed method for albedo measurement, a study of the diurnal variation of albedo, and an investigation of the albedometer measuring range. Chapter 4 describes the construction of an experimental section on pavement tining and albedo measurement on tining pavement. Chapter 5 is a summary of the study, with recommendations for future study.

CHAPTER 2. LITERATURE REVIEW

2.1. Global warming and the Urban Heat Island Effect

As urbanization processes change landscapes throughout the world, open land with vegetation is replaced by roads, buildings, and other infrastructural elements. With all these concrete or asphalt materials replacing vegetation, more heat is absorbed from the sun, causing cities to become warmer. In the 1810s, a chemist from Britain, Luke Howard, first discovered the Urban Heat Island Effect as he observed a temperature difference between London and its surrounding rural area (Mills, 2008). In another development, global warming at a larger scale around the world has drawn increasing interest. Following rapid economic and social development, people have become more aware of the environmental impact of infrastructure such as roads and buildings. Figure 2.1 is a satellite image of the surface temperature at Des Moines, Iowa, shows that typically the temperatures in urban areas are higher than those of surrounding rural areas.

This picture directly shows that the temperature in downtown Des Moines is higher than that in surrounding areas. There are also two cool zones, Saylorville Lake and Lake Red Rock, at the northern and the eastern sides of downtown Des Moines. This illustrates that a body of water can help cool the city because water has a high heat capacity. The average temperature difference between downtown areas and surrounding rural areas can be as much as 22 °F.

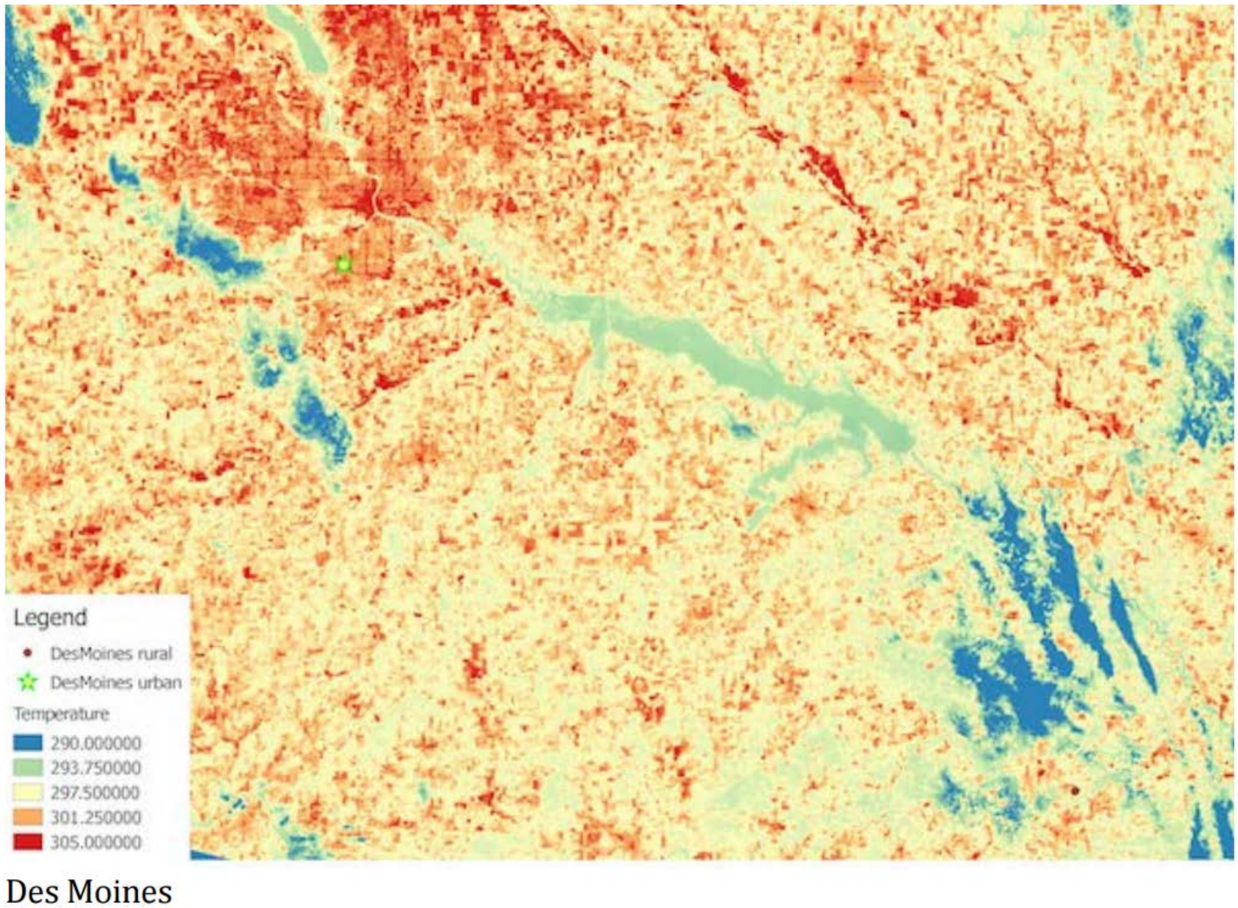


Figure 2.1 Des Moines Satellite Images Depicting Urban Heat Island in Land Surface Temperatures (Kenward, Yawitz, Sanford, & Wang, 2014)

Figure 2.2 is some facts of Urban Heat Island Effect in the city of Des Moines. The temperature difference can be up to 24 °F, and the average difference is 2.9 °F. All these facts prove that the UHI effect could become an intensive problem for our society. There is a critical need for action to cool down the cities.

While the Urban Heat Island is an example of local climate change, global warming is considered to be a worldwide problem. UHI effects can contribute to global warming and both effects will increase energy consumption as cities are cooled in summer. Achieving a better understanding of the UHI effect would be beneficial in help in understanding and solving global warming issue.

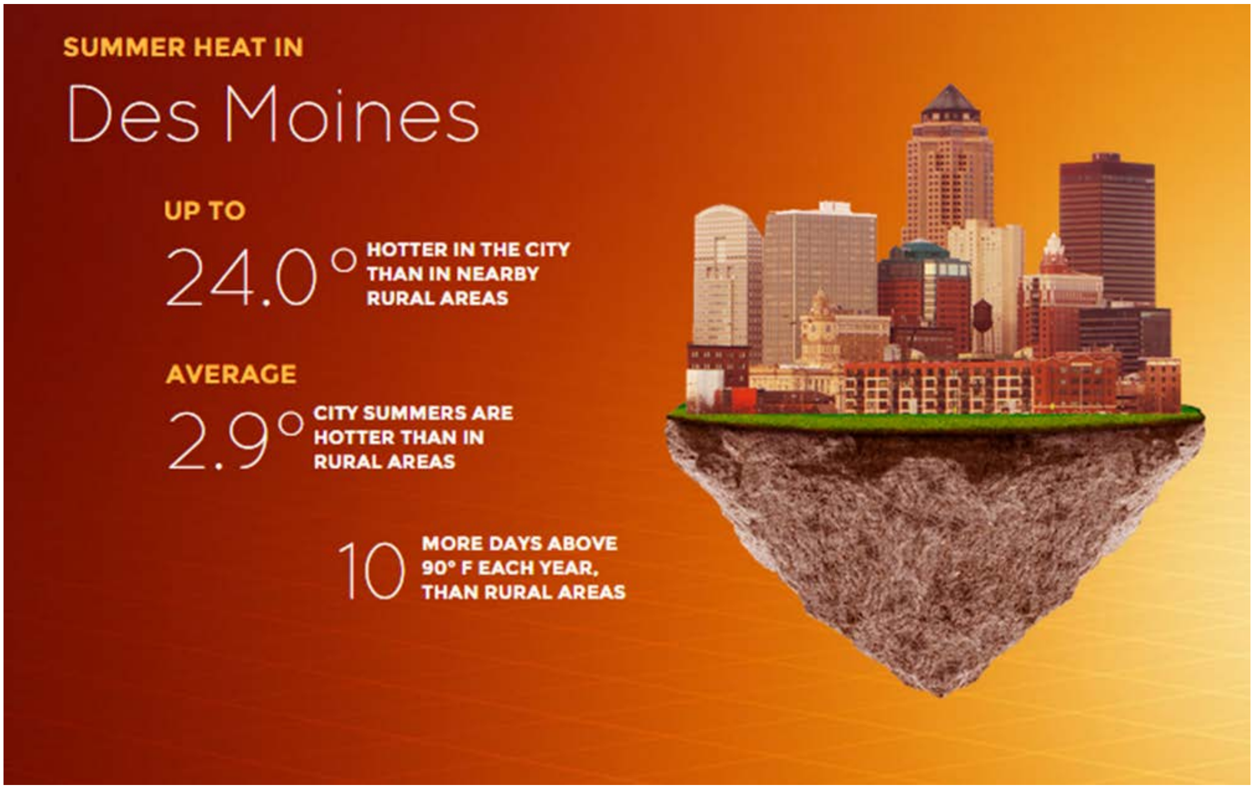


Figure 2.2 Summary of Summer Temperature of city of Des Moines (Kenward, Yawitz, Sanford, & Wang, 2014).

2.2. Impacts of Urban the Heat Island Effect

The UHI effect produces both positive and negative impact. In wintertime or in colder areas, the UHI effect will actually save energy by reducing the need for heat production; the negative impact on communities in summertime is, however, considered to be more critical.

2.2.1. Energy consumption

In summertime, a great deal of energy is used to cool the cities, and electrical demand in summer time keeps increasing as cities become hotter. Researchers from Lawrence Berkeley National Laboratory (LBNL) performed calculations showing that electricity demand increased by 1.5 to 2% for every 1°F increase in air temperature within the range 68 to 77 °F (Akbari H. , 2005). Peak electricity demand always occurs in late afternoon when most city lights are activated, causing a very large electricity shortage, especially in China during summertime. Sometimes electrical power companies must cut off the electricity supply for some communities to protect cities' electrical systems. Figure 2.3 is an example from the city of New Orleans showing the resulting increase in electrical power demand as temperature increases.

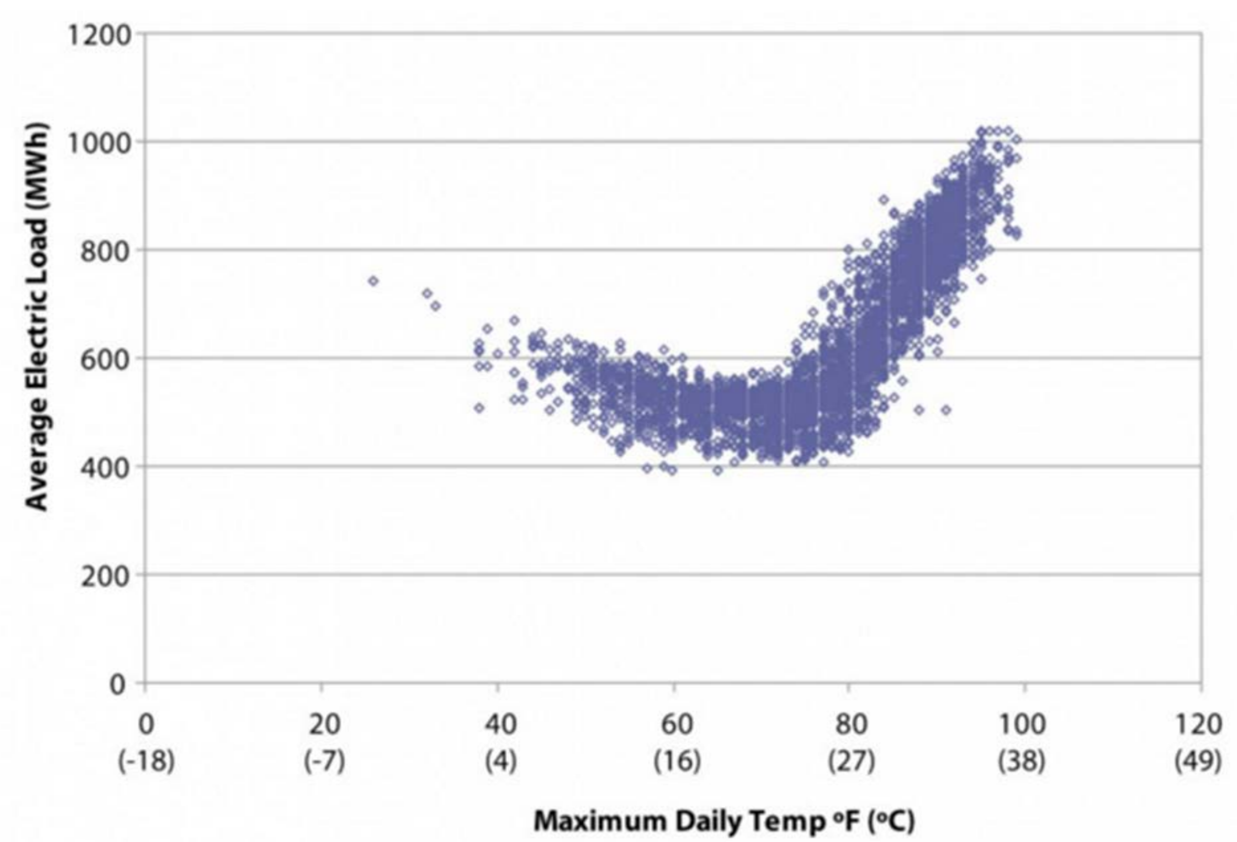


Figure 2.3 Electric Loads increase with Temperature Increase (EPA, Heat Island Compendium, 2015)

So far the discussion has discussed some of the UHI effect's negative impact on energy consumption. However, negative impact can switch to positive impact in some cold areas or during wintertime. The UHI effect may save some energy in the wintertime because cities absorb more energy from the sun. Overall, however, as mentioned above, most studies find the negative effects to be generally more significant.

2.2.2. Air quality

When temperatures increase within a certain range, chemical and biological reactions will become more active, bringing more pollutants into the environment. The major issue here is that higher temperatures in large cities will directly increase the formation of ground-level ozone produced when NO_x contacts volatile organic compounds (VOCs) in the presence of sunlight under warm conditions (Yamashita & et al, 2010). Figure 2.4 is a plot of ground-level ozone concentration with respect to temperature in the city of Des Moines. It is very clear that, as temperatures increase, the ground-level ozone concentration also increases.

The levels of some other air pollutants will also increase due to the extra demand for electrical power needed to cool down the cities. Most presently-generated electrical power is produced by power plants, and the increased power needed in summer results in the power plant burning more fossil fuels, increasing the emission of several primary pollutants such as sulfur dioxide, nitrogen oxides, carbon monoxide, mercury, and particulate matter from the power plant. All those pollutants will affect the local air quality and add to the formation of ground-level ozone.

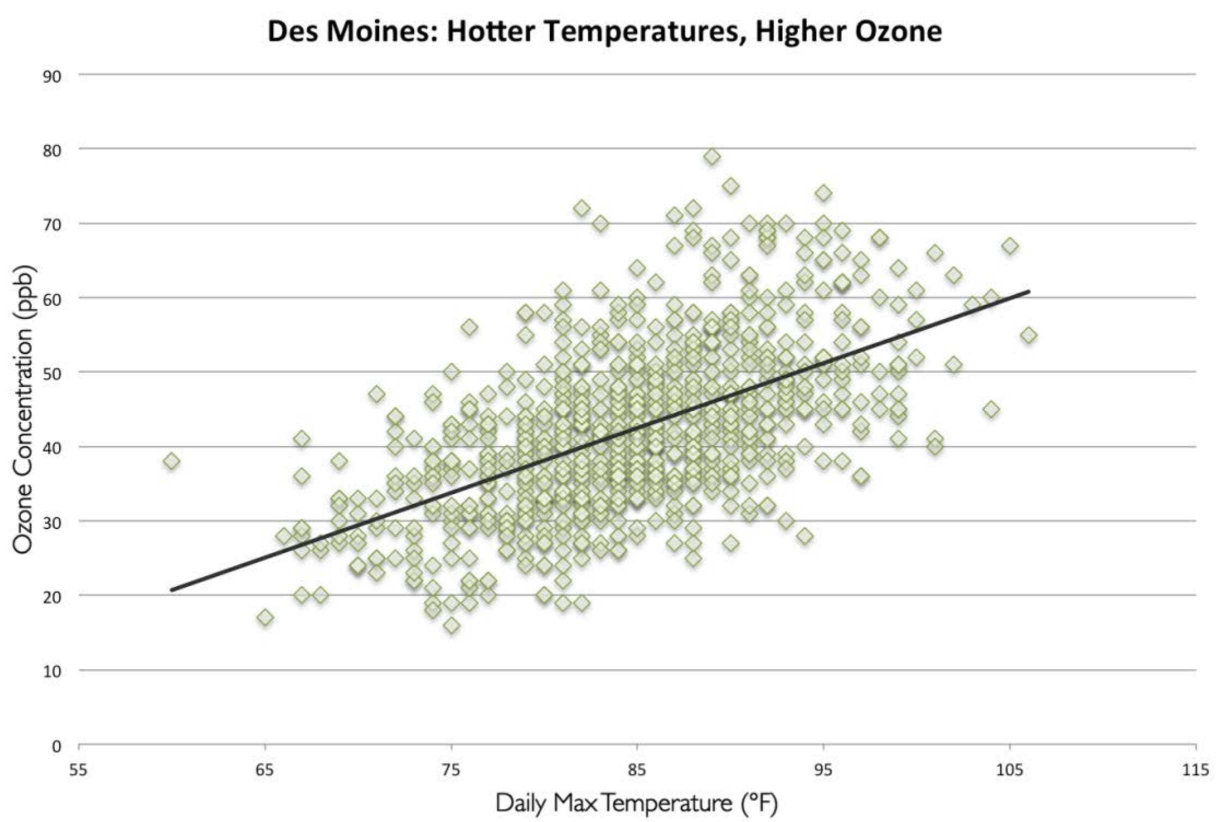


Figure 2.4 The Relationship between Daily Max Temperature and Ozone Concentration of City of Des Moines (Kenward, Yawitz, Sanford, & Wang, 2014).

2.2.3. Water quality

The UHI affects water quality by increasing the temperature of the water body. In summer time, the pavement temperature can be much higher than the air temperature because the pavement materials directly absorb sunlight radiation. It has been reported that the surface temperature of pavement and rooftops can be 50 to 90 °F higher than the surrounding air temperature (EPA, Heat Island Compendium, 2015). When a storm is imminent on a hot summer day, the storm runoff will contact the warm pavement or rooftop and the excess heat will be transferred to the storm runoff, increasing its temperature. Data recorded in

Arlington, Virginia shows that the temperature of surface runoff increased by 8 °F in 40 minutes (EPA, Beating the Heat: Mitigatin Thermal Impacts, 2003).

As surface runoff drains into the rivers, lakes, and other water bodies, it transfers heat into them, so the temperatures of those water bodies will increase as well. Water temperature is an important factor that relates to water quality. As water temperature increases, chemical reactions and biological processes within a water body will be affected; some chemical reactions, e.g., decomposition, will be accelerated as temperature increases. Biological processes like metabolism and reproduction of many aquatic species are sensitive to temperature change.

2.2.4. Health Problems and Human Comfort

High summer temperatures make people feel uncomfortable. In extreme situations of high temperatures and high relative humidity people may experience serious health problems, some even leading to death; each summer, some children and older adults die because of high temperatures and there are many heat-related illnesses such as heat cramps, non-fatal heat stroke, and headaches. The increase in air pollutants and ground-level ozone formation mentioned above will also cause health problems.

Another concern is that a warmer environment is more likely to spread diseases. Some insects carry viruses that tend to be more active in warm environments, increasing the risk of human infection.

2.3. Some mitigation strategies for the Urban Heat Island Effect

EPA has listed on their website 4 major approaches for mitigating the Urban Heat Island Effect. (1) Trees and vegetation in urban area, (2) Green roofs, (3) Cool roofs, and (4) Cool pavements; all these strategies have their own strengths and limitations, and there have been many research studies on each, but this review will not cover all of them, focusing rather on the key factor of albedo. The review will thus focus more on cool pavement, a topic closely related to the albedo.

2.3.1. Cool pavements

City development brings the significant change that more land is paved with concrete or asphalt, and such land cover changes from vegetation into impervious pavement with a low albedo value are major causes for the formation of the UHI effect. Cool pavement is not one specific kind pavement. According to the EPA, cool pavements refer to a range of technologies that tend to make pavements absorb and store less energy so that their surface temperature is lower than that of conventional pavements (EPA, Reducing Urban Heat Island: Compendium of Strategies Cool Pavements, 2015).

One big advantage in developing cool pavement is a decrease in peak summertime temperature. Cool pavements normally have a higher albedo value than traditional pavement. It is recommended to use lighter color concrete rather than dark asphalt because high reflectively pavements will reflect more solar radiation back to space, resulting in less energy absorbed and stored in the cities. There are several benefits of cool pavements, including (1)

Cool pavements can help save energy required for cooling in summer by decreasing peak temperature, (2) A study by Taha simulating smog formation indicated that a change of 0.3 albedo value brought a 12% decrease in population-weighted ozone (Taha, 1997), (3) A highly reflective material resulting in a low temperature will extend the pavement life. There are, however, some concerns regarding cool pavements that have also drawn a great deal of attention. For example, some worry that night glare caused by highly-reflective material might lead to more automobile accidents (Akbari, Pomerantz, & Taha, 2001).

2.3.2. Trees

Shade trees will help block solar radiation from reaching the ground and can help decrease the temperature through evaporation; such factors can directly help mitigate the Urban Heat Island effect. Another benefit of trees could be reducing greenhouse gas by absorbing CO_2. Taha estimated the ambient temperature around a tree-covered area, with simulation results showing an average city temperature decrease of 0.3 to 1 °C (Taha, 1997). In some hot and dry areas, however, water shortage may be a serious problem, and large consumption of water by planting trees may exacerbate a water shortage problem.

2.3.3. Cool roofs and green roofs

Cool roofs refers to the roofs using high reflected materials with a high albedo value. This will help roof surface to reflect sunlight and heat away from a building. Less energy is absorbed by the building, thus it reduces the temperature inside the buildings.

Green roofs refers to grown vegetation on the rooftop. The vegetation will provide shade which reduces the heat absorbed by the building. Besides that, the evaporation process among vegetation will remove heat from rooftops.

2.4. Pavement thermal model

With rapidly increasing interest in the Urban Heat Island mitigation topic, use of pavement heat transfer models has become a hot topic. Based on the overall UHI effect literature review of the previous chapter, this chapter will provide a narrowed-down literature review focusing on several mathematical models for use in pavement temperature studies. An existing limitation of current pavement temperature models is research regarding pavement albedo variation with time. Using different albedo values in a simulation will also make the model more complex, so this review will focus on the albedo value in those models, and how albedo variation influences their accuracy.

2.4.1. Pavement thermal model basic principles

There are three relevant basic components linking pavement-system heat transfer in a pavement thermal model: conduction, convection, and radiation (Giedt, 1967). Conduction refers to heat transfer among different pavement layers, from the top layer down through the thickness of the pavement system. Convection refers to heat transfer between the top pavement layers and surrounding environment above the pavement surface. Radiation refers to short-wave solar energy emitted by the sun and received by the pavement. Heat transfer among air, buildings, trees, or other objects surrounding the pavement is also considered to be through radiation. All current thermal models are based on these basic components. With respect to radiation, not all short-wave solar radiation is absorbed by the pavement materials;

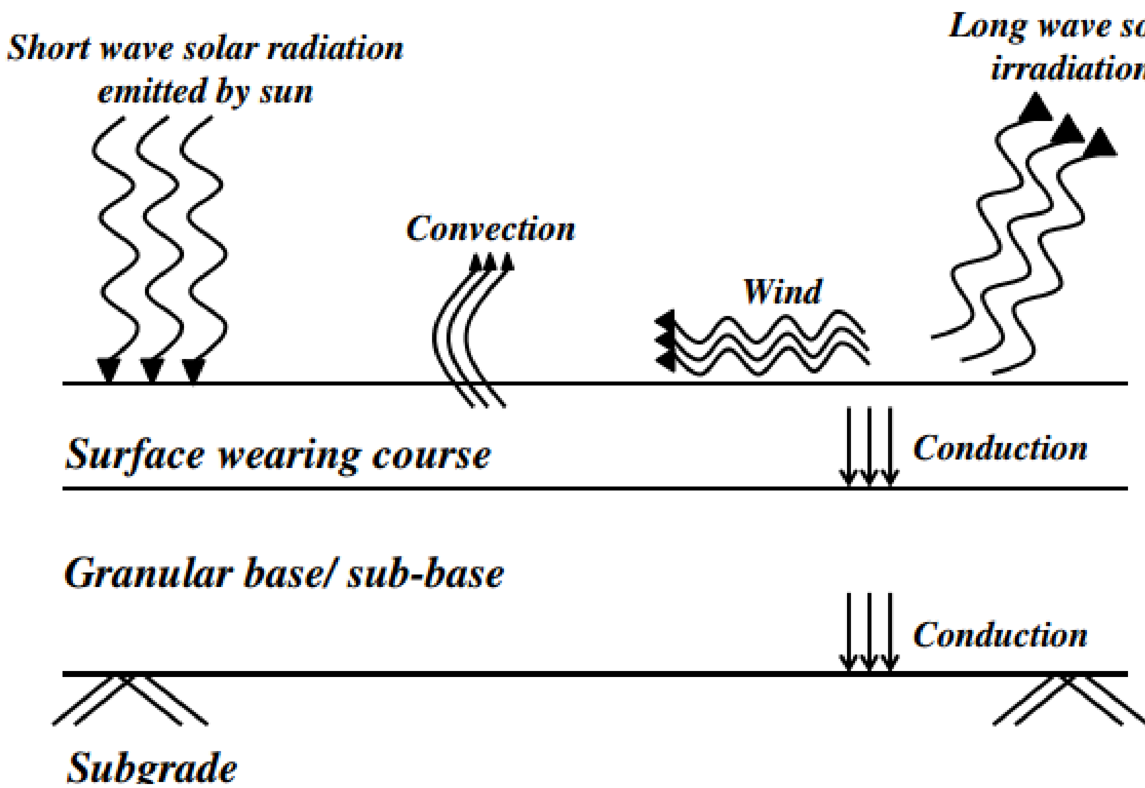


Figure 2.5 Schematic of Thermal Model Basics (Chandrappa & Biligiri, 2015)

some is reflected back into the air, and only a portion of the solar radiation is absorbed. Albedo, called in some papers solar reflectance, is the ratio of reflected solar radiation to the total solar radiation received from the sun (ACPA, 2002). Albedo values range from zero to one. An Albedo value of one means that all solar radiation emitted from sun is reflected back by the materials, while an albedo value of zero means that all solar radiation is absorbed by the materials. Figure 2.5 is a schematic diagram showing these three basic components and their relationships in a pavement system.

The albedo value of a pavement surface is closely related to the pavement temperature and is a key factor affecting the results of pavement thermal modeling. Only the absorbed portion of the total solar radiation should be used as the source of energy in the pavement thermal models, and current modeling has shown that an increasing pavement albedo occurring during the simulation could decrease the peak temperature for a given day. Currently, most models use a fixed albedo value for any day during the simulation, but real-word data shows that the albedo value may keep changing during such a day.

2.4.2. Introduction to existing thermal models

A sufficiently accurate pavement thermal model can contribute a great deal to understanding how much a land cover change contributes to the Urban Heat Island effect. Pavement thermal models will also help with decision-making processes in street design. Pavement thermal modeling is not, however, simple work; heat transfer in a pavement structure is a complex process.

In general, there are two different categories of pavement heat transfer, daytime and nighttime. During daytime the pavement structure receives solar radiation from the sun and, as previously discussed, the pavement surface reflects back some portion of the solar radiation to the sky. The amount of such radiation is related to the pavement material albedo. The heat absorbed at the pavement surface transfers downwards into the base course, the sub-base course, and the soil layer, with the conduction process dominating during daytime. Not all the thermal mass is transferred to the soil; depending on the materials' specific heat, a certain amount of thermal mass is stored in the pavement, base, and sub-base layers. During nighttime there is no incoming solar radiation, so the air temperature drops faster than that of the pavement structure. The heat transfer process is basically inverted. In this case the stored thermal mass is released by the pavement, base, and sub-base courses with the convection process dominating. This is the reason why we observe the night temperature in paved areas to be normally higher than in unpaved areas.

At this time, several pavement thermal models have been published. Most of them use a transient numerical model in a one-dimensional finite-difference scheme; this is the simplest thermal model for predicting a pavement temperature profile. Although some investigators have also developed two-dimensional and three-dimensional models, their accuracy has not significantly improved. This study does not include a thorough investigation of pavement thermal models, so this literature review will not be comprehensive with respect to all the thermal models. The following section will provide a short introduction to some of the previously-developed thermal models and the albedo values used for those simulations.

Gui developed a one-dimensional mathematical model for calculating near-surface temperatures based on a fundamental energy balance; the calculation is based on hourly measured solar radiation, air temperature, dew-point temperature, and wind velocity data (Gui, Phelan, Kaloush, & Golden, 2007). Figure 2.6 is a sketch showing the basic fundamentals underlying this model. Gui used a constant pavement albedo value of 0.17 to calculate the near-surface temperature for asphalt pavement. According to the results, the error in peak temperature compared with real-word data was ±3 °C. Gur also reported that the albedo value had more impact on the maximum temperature than on the minimum temperature because the albedo value was used only during the daytime when the sun was present. During the nighttime pavement cooling process there is no albedo value at all (Gui, Phelan, Kaloush, & Golden, 2007). Although Gui investigated the effects of varying albedo value on maximum and minimum temperature, he used a constant albedo value for each simulation.

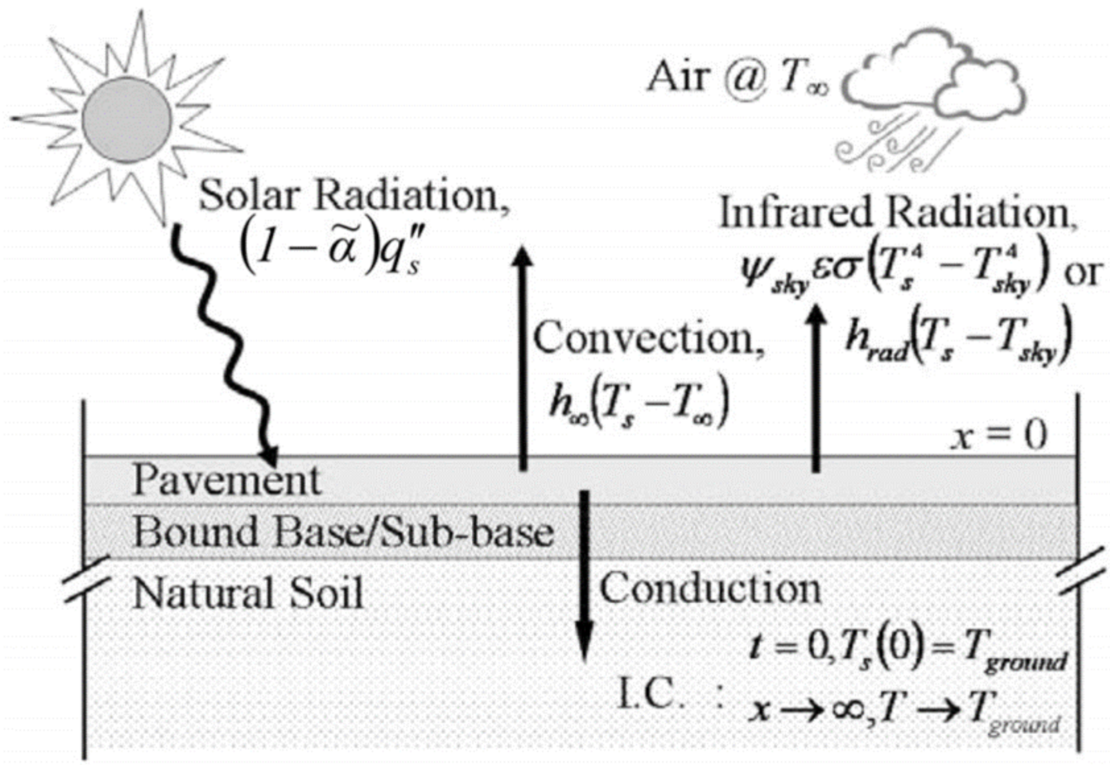


Figure 2.6 Heat transfer modes between pavements for in Gui's model (Gui, Phelan, Kaloush, & Golden, 2007)

Li developed a general local microclimate model that included both the pavement structure and near-surface air and took the processes of radiation, convection, conduction, shading, and evaporation into account. This model used both a finite-element method and a finite-difference method. Li validated this model against field measurements data from his previous work. A temperature plot for a typical hot summer day simulated by the model agreed fairly well with the field measurement data, but there were still some differences in peak temperatures. This model used constant albedo values during the simulation, 0.09 and 0.08 for asphalt, and 0.29 and 0.26 for concrete (Li, 2012).

Table 2.1 summarizes some thermal models and the albedo value they used in the simulation.

Table 2.1 Some thermal models and the albedo value they use

Year	Author(s)	Albedo Value
2001	Hermansson	0.15 (Asphalt) 0.4 (Asphalt with snow cover)
2002	Qin, Berliner, and Karnieli	0.3 (Soil)
2007	Gui	0.17 (Asphalt)
2008	Herb, Janke, Mohseni, and Stefan	0.12 (Asphalt) 0.2 (Concrete)
2012	Li	0.09 (Asphalt) 0.08 (Asphalt) 0.29 (Concrete) 0.26(Concrete)

CHAPTER 3. FIELD MEASUREMENT OF ALBEDO

3.1. Introduction

Albedo, or solar reflectance, is a very important factor when estimating thermal performance of a material. Albedo is defined as the ratio of reflected solar radiation from a surface to the total amount of incident solar radiation received by the surface (ACPA, 2002) and is an important factor that should be taken into account in pavement thermal models. Absorption of incident solar radiation is a source of energy that heats up exterior surfaces of pavements, buildings, and other outdoor materials, but measuring the portion of absorbed incident solar radiation is difficult and complex; it is much easier to measure the portion of incident solar radiation that is reflected (Levinson, Akbari, & Berdahl, 2010). Typically, pavement temperature is higher than the ambient air temperature because of the absorption of solar radiation. This is one of the causes of a surface heat island. A high albedo material will help decrease the heat island effect since in that case a large portion of the solar radiation is reflected back to the sky rather than absorbed and stored by the material. A low albedo material conversely absorbs more solar radiation and may cause a significant increase in surface temperature.

Some investigators and research studies have reported measured albedo values for several pavement materials. Li measured several common pavement materials and other land covers at UC Davis and investigated several factors affecting albedo values. Table 3.1 shows some of the albedo values reported in his dissertation. However, most of the albedo values he reported were for normal pavement surfaces with no tining. There has been no research investigating the relationship between pavement surface albedo and pavement texturing, and detailed information regarding albedo measurement has not been described in the current literature.

Table 3.1 some albedo value for different materials reported by Li (Li, 2012)

MATERIAL TYPE	PERMEABLE TYPE	MEAN ALBEDO VALUE	MAXIMUM ALBEDO VALUE OBSERVED	MINIMUM ALBEDO VALUE OBSERVED
ASPHALT	Impermeable	0.09	0.10	0.07
ASPHALT	Permeable	0.08	0.09	0.07
ASPHALT	Permeable	0.08	0.10	0.07
CONCRETE	Impermeable	0.29	0.31	0.27
CONCRETE	Permeable	0.18	0.19	0.17
CONCRETE	Permeable	0.26	0.28	0.23

3.2. Albedo measurement methodology

3.2.1. Method and equipment

Literature about albedo measurement methods has been very limited; two ASTM standard testing methods for determining solar reflectance of surfaces are the foundations relied on by most researchers. The first is ASTM C1549, Standard Test Method for Determination of Solar Reflectance near Ambient Temperature Using a Portable Solar Reflectometer (ASTM, ASTM C1549-09 Standard test method for determination of solar reflectance near ambient temperature using a portable solar reflecometer, 2009). The second is

ASTM E1918, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field (ASTM, ASTM E1918-06 Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field, 2006). Some additional modifications and improvements are needed for some specific measurement tasks.

3.2.1.1. ASTM C1549 test method

The ASTM C1549 test method is used for determining the solar reflectance of flat opaque materials either in the field or in the laboratory. This method relies on using a commercial portable solar reflectometer to measure reflected light with four different detectors, with each detector having color filters that respond to four specific wavelengths of light. The light source is provided by a diffuse tungsten halogen lamp. This test method is suitable for measuring the mean solar reflectance of a flat, opaque, and heterogeneous surface (ASTM, ASTM C1549-09 Standard test method for determination of solar reflectance near ambient temperature using a portable solar reflecometer, 2009), but is not suitable for this specific study that seeks to determine the diurnal variation of albedo and the tining influence on the surface albedo.

3.2.1.2. ASTM E1918 test method

The ASTM E1918 test method is used for determining the solar reflectance of various horizontal and low-sloped\ surfaces and materials in the field. The method relies on using a pyranometer and requires that the sun angle with respect to a surface normal be less than 45°. It also recommends that the test should be performed on a clear sunny and cloudless day. Figure 3.1 shows the recommended configuration of the pyranometer setup. The distance between the pyranometer and the material's surface is 0.5 meters (1.64 feet) and, although it does not specify that how much area is be measured at this height, it states that the test

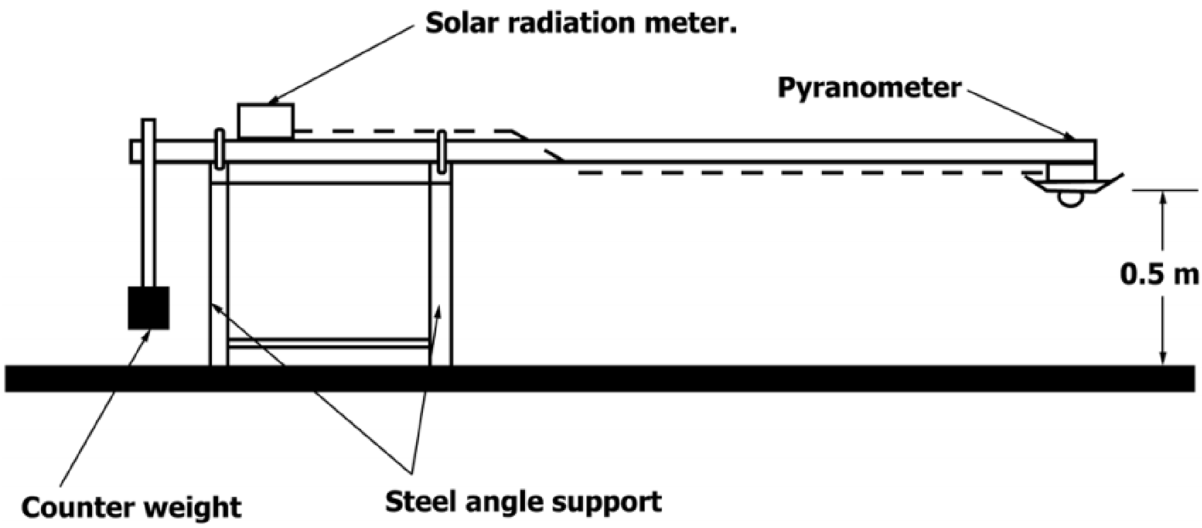


Figure 3.1 Schematic of the recommended pyranometer standing (ASTM, ASTM E1918-06 Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field, 2006)

method should only be applied on a large surface (circles at least four meters in diameter).

The ASTM E1918 test method is also known as the one-pyranometer method. The pyranometer must be flipped over during the test to measure both incoming and reflected solar radiation, a relatively inconvenient technique in practice. This might also increase the test error since the incoming solar radiation and reflected solar radiation are not simultaneously measured. During early morning and late afternoon, the solar radiation may quickly change so this method might not provide an accurate albedo value.

The ASTM E1918 test method is better than the ASTM C1549 test method for this specific study, but is still not good enough. Modification and improvements are needed to produce a suitable test method for this study.

3.2.1.3. Albedometer test method

The albedometer test method is a test method improved over ASTM E1918. Instead of using only one pyranometer, the albedometer test method uses two identical pyranometers to make simultaneous readings for both incoming and reflected solar radiation. This method can continuously monitor the albedo value as it changes with time. The model CMA 6 albedometer from Kipp & Zonen B.V. was used in this study. It is comprised of two CMP 6 pyranometers providing two signal outputs on one signal connector. This albedometer, shown in Figure 3.2, is recognized as a First Class Pyranometer that can measure hemispherical (global or diffuse) solar radiation integrated over a wavelength range from 0.3 to 3 µm (Kipp & Zonen B.V, 2013). The data acquisition system is a data logger from Campbell Scientific with serial number CR1000.

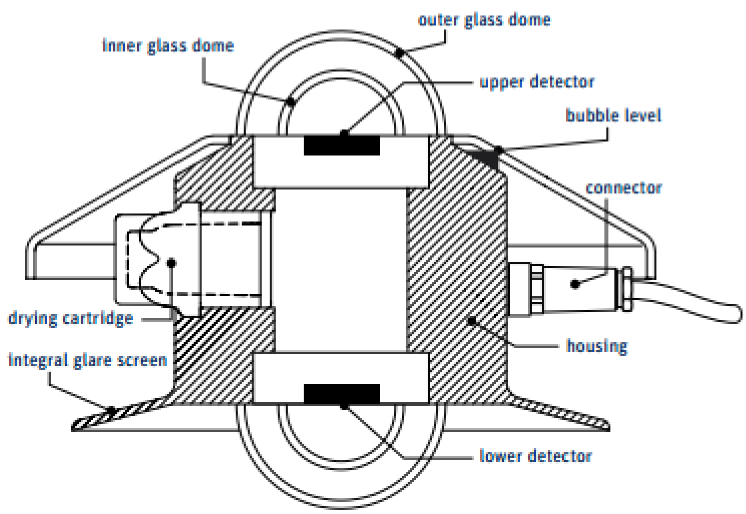


Figure 3.2 Schema of CMA 6 Albedometer from Kipp & Zonen B.V (Kipp & Zonen B.V, 2013).

First class pyranometer is one of the classification of ISO-9060 Standard. ISO-9060 section 4.3.2 states for purpose of solar energy test applications, first class pyranometer is recommend (ISO 9060, 1990). Besides that, there are another two types of pyranometer, secondary standard and second class. Table 3.2 is a detailed summary of ISO 9060 classification of three types of pyranometers.

Table 3.2 ISO 9060 Pyranometer Specifications (ISO 9060, 1990)

ISO 9060 PYRANOMETER SPECIFICATIONS	SECONDARY STANDARD	FIRST CLASS	SECOND CLASS
RESPONSE TIME: TIME TO REACH 95% RESPONSE	< 15 sec.	< 30 sec.	< 60 sec.
ZERO-OFFSET:			
OFFSET-A: RESPONSE TO 200 W/M² NET THERMAL RADIATION, VENTILATED	+ 7 W/m²	+ 7 W/m²	+ 7 W/m²
OFFSET-B: RESPONSE TO 5K/H CHANGE IN AMBIENT TEMPERATURE	± 2 W/m²	± 2 W/m²	± 2 W/m²
NON-STABILITY: % CHANGE IN RESPONSIVITY PER YEAR	± 0.8%	± 1.5%	± 3%
NON-LINEARITY: % DEVIATION FROM RESPONSIVITY AT 500 W/M² DUE TO CHANGE IN IRRADIACNE FROM 100-1000 W/M²	± 0.5%	± 1%	± 3%
DIRECTIONAL RESPONSE: THE RANGE OF ERRORS CAUSED BY ASSUMING THAT THE NORMAL INCIDENCE RESPONSIVITY IS VALID FOR ALL DIRECTIONS WHEN MEASURING FROM ANY DIRECTION, A BEAM RADIATION WHOSE NORMAL INCIDENCE IRRADIACNE IS 1000 W/M³	± 10 W/m²	± 20 W/m²	± 20 W/m²
SPECTRAL SELECIVITY: % DEVIATION OF THE PRODUCT OF SPECTRAL ABSORBANCE AND TRANSMITTANCE FROM THE CORRESPONDING MEAN, FROM 0.35 – 1.5 μM	± 3%	± 5%	± 10%
TEMPERATURE RESPONSE: % DEVIATION DUE TO CHANGE IN AMBIENT WITH AN INTERVAL OF 50K	2%	4%	8%
TILT REPONSE: % DEVIATION IN RESPONSIVITY RELATIVE TO 0° TILT, DUE TO CHANGE IN TILG FROM 0° TO 90° TILT AT 1000 W/M² BEAM IRRADIANCE	± 0.5%	± 2%	± 5%

3.3. Diurnal variation of albedo

The location of the diurnal variation of albedo study was the Ames Municipal Airport. This location has a large open area that will perfectly pick up early morning and late afternoon data. Also, no one will enter the airport facility, making it safe to leave all the equipment outside during the entire day. The Ames Municipal Airport facility has both concrete and asphalt pavement. The concrete section is newly constructed, while the asphalt section is pretty old. The experimental plan is described in Table 3.3.

Table 3.3 Experimental plan for full day albedo measurement

PAVEMENT TYPE	EXPERIMENTAL DATE	DURATION	WEATHER	TEST METHOD
ASPHALT	09/11/2015	3 days	Sunny	Albedometer
CONCRETE	09/19/2015	3 days	Sunny	Albedometer
ASPHALT	10/3/2015	2 days	Mostly Sunny	Albedometer

The albedometer was supported by a tripod and positioned at a height of 2 feet above the ground. Three weight stacks were placed on the tripod to make it more weather proof. Information about the setup can be found in the reference section in the end of this thesis.

Figure 3.3 Albedo measurement system with an albedometer

The results plotted for each measurement are shown in Figure 3.4 through Figure 3.12. The results show that the albedo value changes continually during the day. In the early morning, the albedo value changed rapidly from high to low as the sun rose over the horizon, from 1 to 0.28 for asphalt pavement over a 10-minute interval. Then the change of albedo slowed down, with the albedo value changed only from 0.22 to 0.28. In the late afternoon just before sunset the albedo value again changed rapidly from 0.28 to 1. The same basic pattern of diurnal variation of albedo value was observed for the concrete pavement, the only difference being that average albedo value for the concrete pavement was higher than that for the asphalt. The reason is that the color of asphalt pavement is normally darker than concrete pavement.

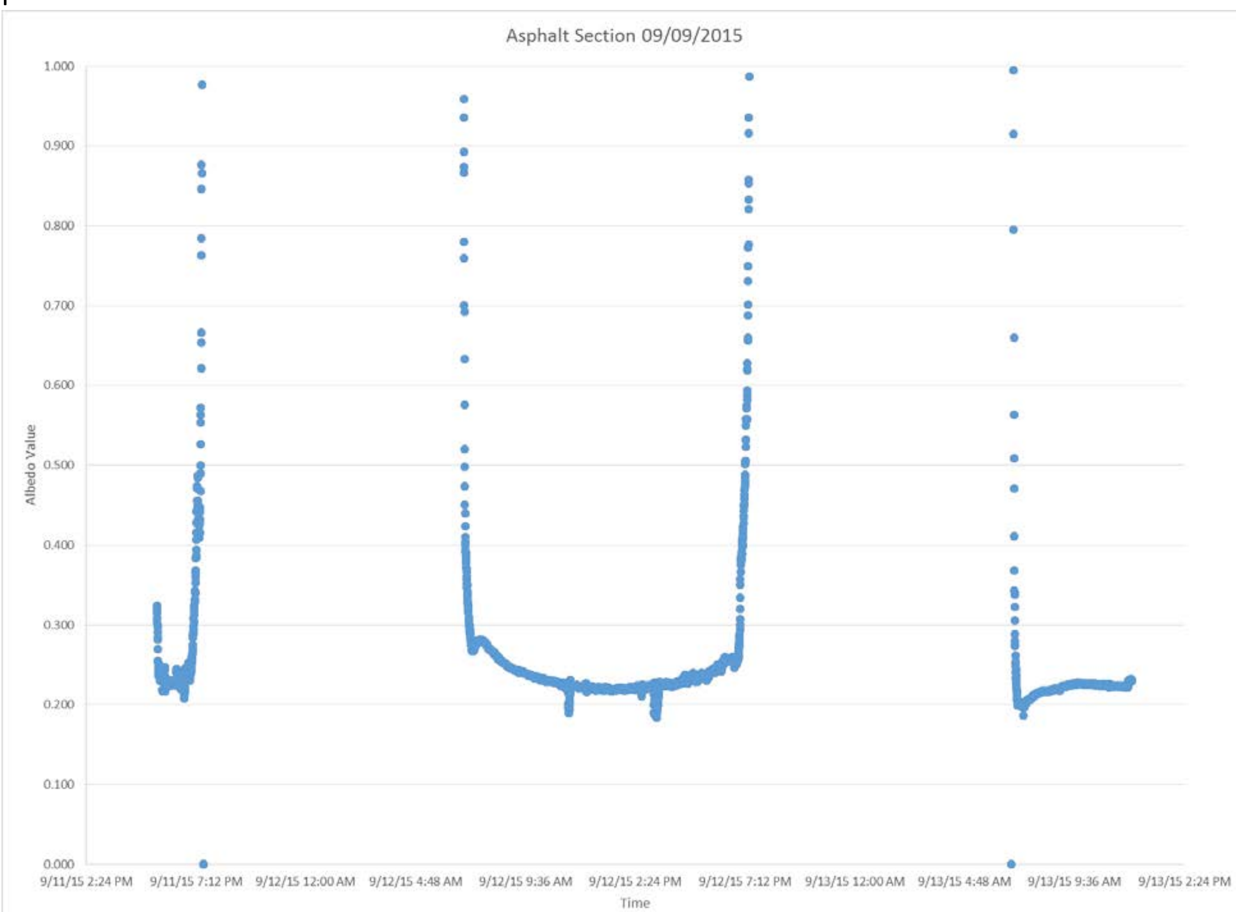


Figure 3.4 Diurnal variation of albedo on asphalt pavement in 3 days measured on 09/11/2015

The results for asphalt pavement measured during the time interval from 09/11/2015 to 09/13/2015 are presented in Figure 3.4, Figure 3.5, and Figure 3.6. Figure 3.4 presents overall meaurement results for the asphalt pavement on 09/11/2015. Figure 3.5 presents the results of albedo variation on 09/12/2015 over a narrow range to better show the pattern of diurnal albedo variation. The albedo value changed quite a lot during short time intervals in early morning and late afternoon, from 6:43 am to 9 am and 5:50 pm to 7:40 pm. The albedo value changed only within a small range (from 0.24 to 0.22) between 9 am and 5:50 pm. Figure 3.6 provides further analysis of the energy collection from the asphalt pavement on 09/12/2015. Figure 3.6 (b) represents energy collection based on the actual data, while Figure 3.6 (c) is energy collection based on an assumed albedo value of 0.22. Figure 3.6 (d) is the net energy difference found between using a dynamic albedo value and a constant albedo value. The results indicate that the energy collection patterns for the dynamic albedo value and constent albedo value are essentially the same, reflecting an energy of only up to 12,000 w/m^2, which is insignificant comparing to the total energy that the surface can absorb that can range up to 1.1 million w/ m^2.

The same analyses for concrete pavement are presented in Figure 3.7,Figure 3.8, and Figure 3.9 with the same results as for the asphalt pavement. The albedo value only changed a lot in the early morning and late afternoon. Between 9:00 am to 6 pm, the albedo value only changed within a range from 0.325 to 0.335. The net difference of energy collection between using a dynamic albedo value (actual data) and a constant albedo value (assumed to be 0.33) was only about 3400 w/m2. This is also insignificant compared to the total energy the surface can capture in one day.

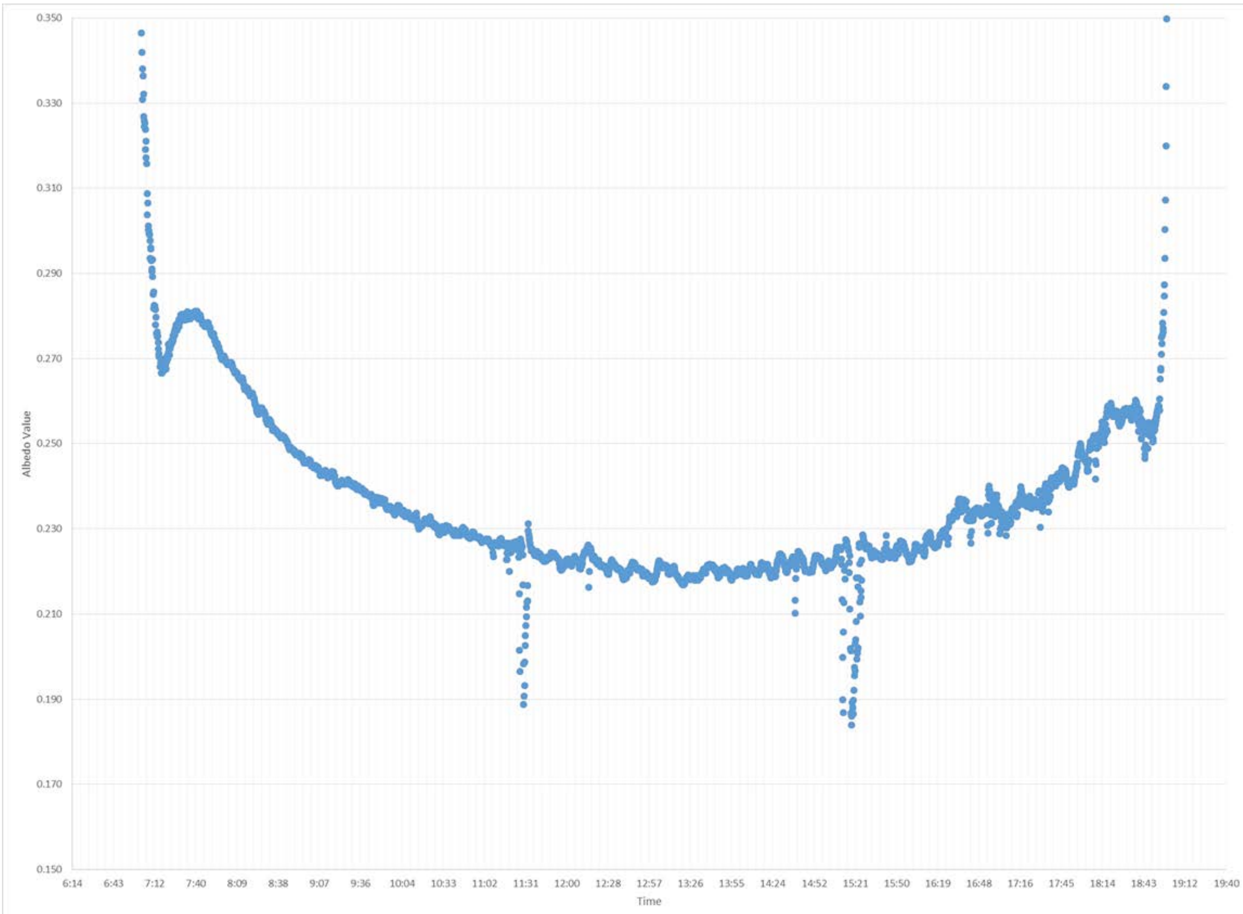


Figure 3.5 Zoom-in plot for one day albedo variation for asphalt pavement measured on 09/12/2015

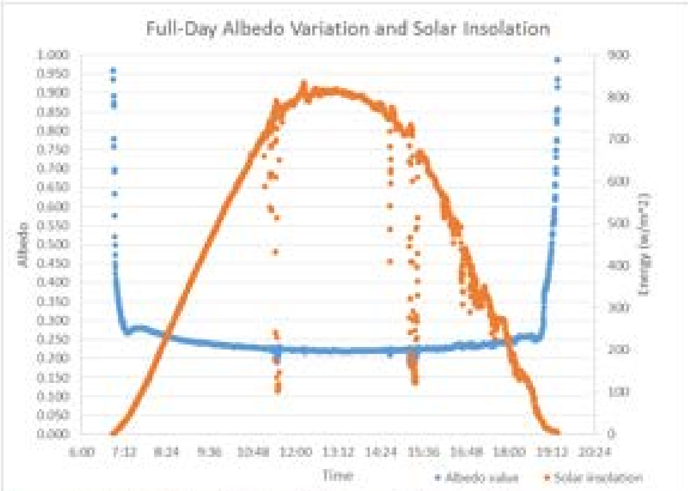


Figure 3.6 (a) Full day albedo variation and solar insolation

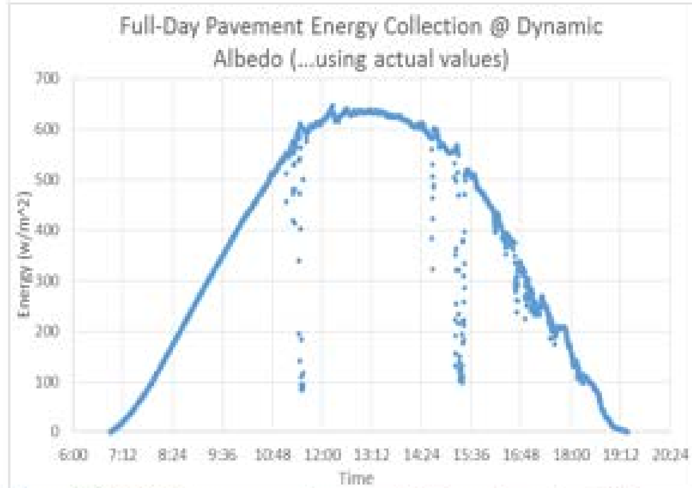
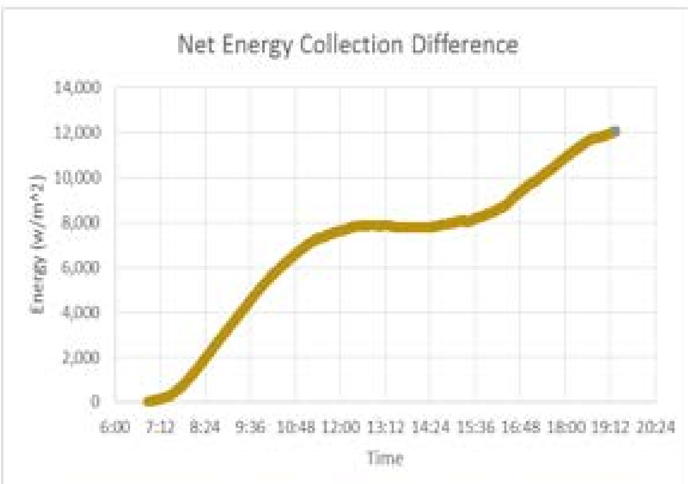


Figure 3.6 (b) Full day pavement energy collection under real condition



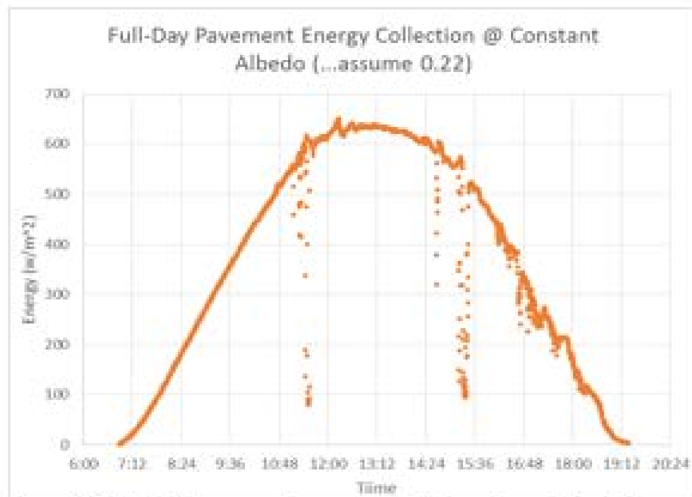


Figure 3.6 Further analysis for albedo variation on asphalt pavement measured on 09/12/2015

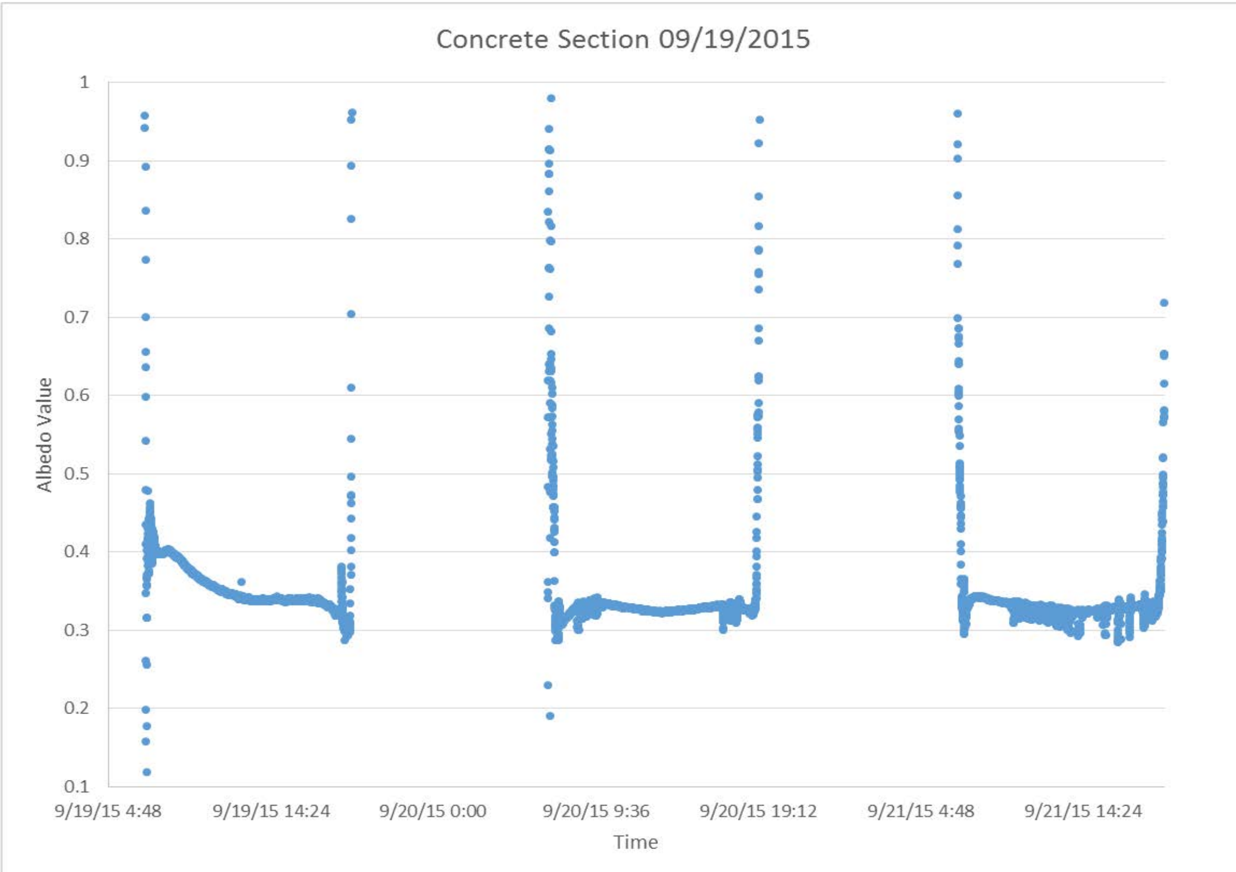


Figure 3.7 Diurnal variation of albedo on concrete pavement in 3 days measured on 09/19/2015

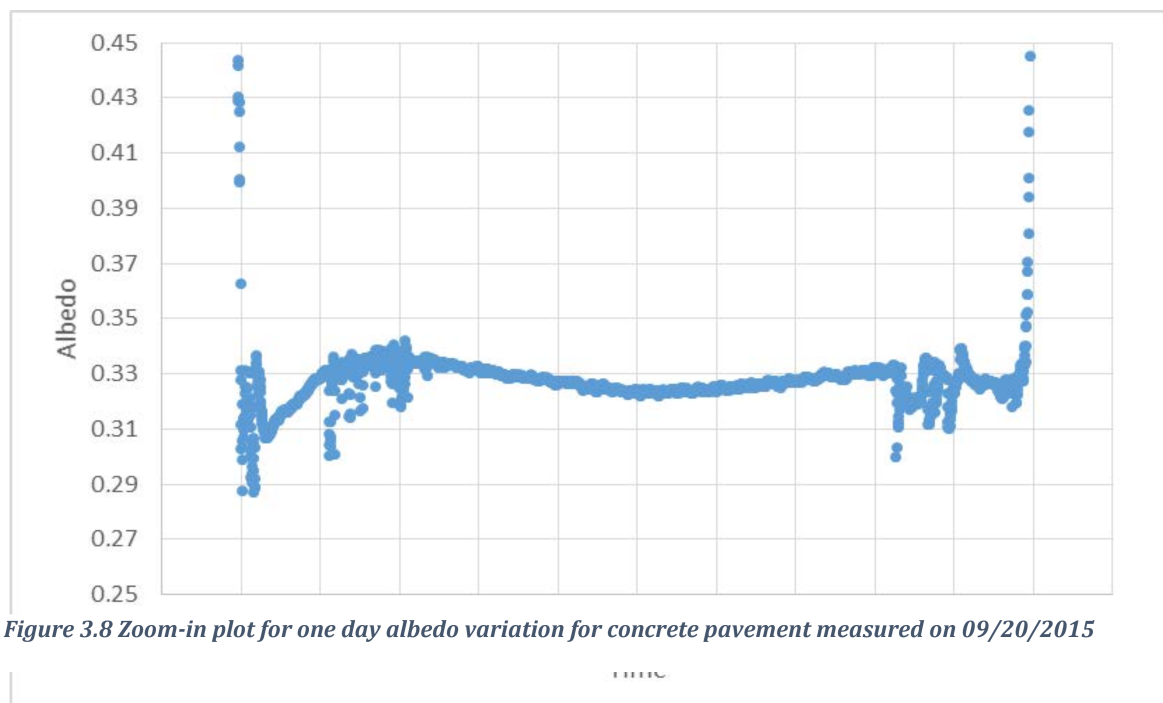


Figure 3.8 Zoom-in plot for one day albedo variation for concrete pavement measured on 09/20/2015

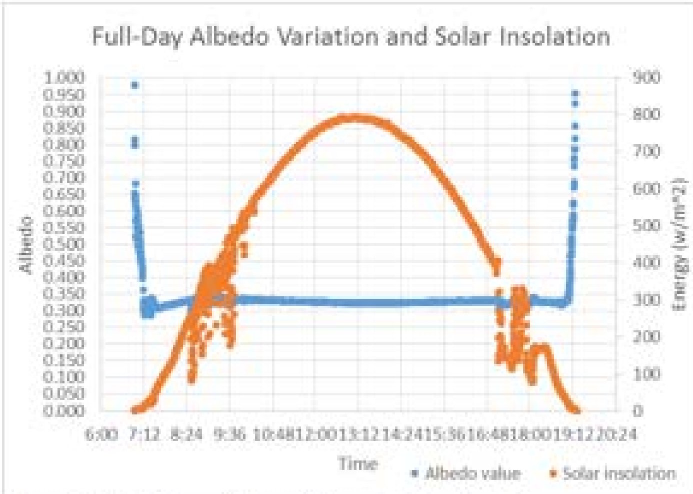


Figure 3.9 (a) Full day albedo variation and solar insolation

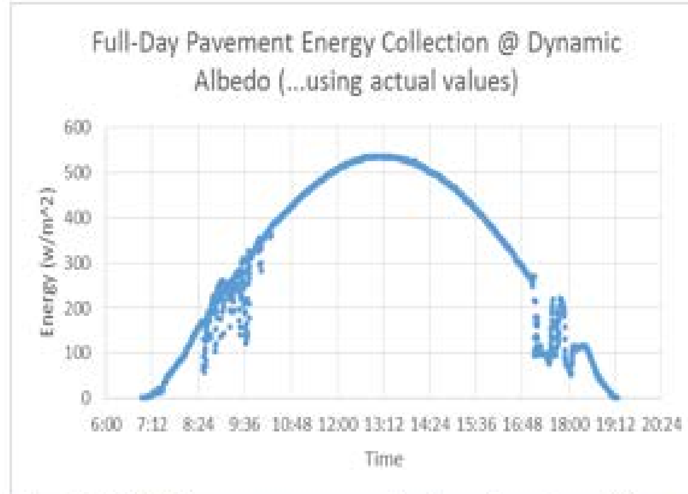
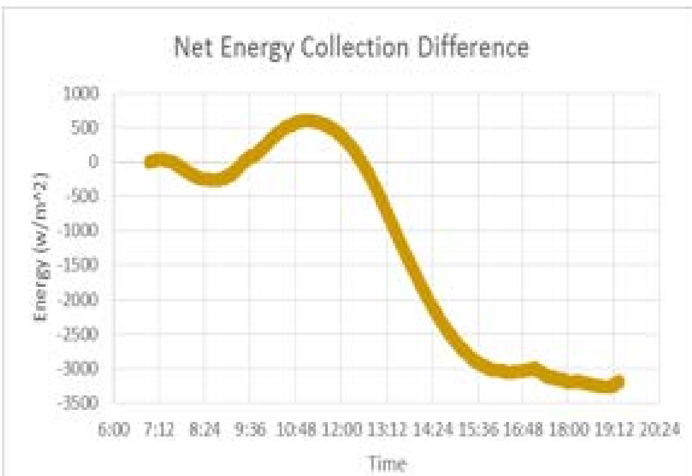


Figure 3.9 (b) Full day pavement energy collection under real condition



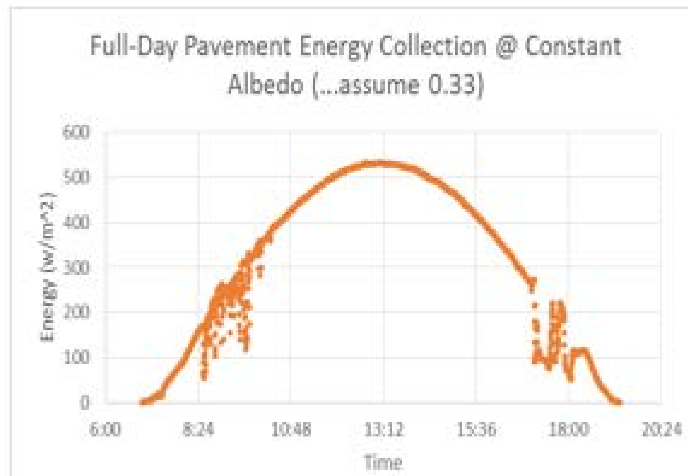


Figure 3.9 Further analysis for albedo variation on concrete pavement measured on 09/20/2015

value and actual value

(constant albedo value)

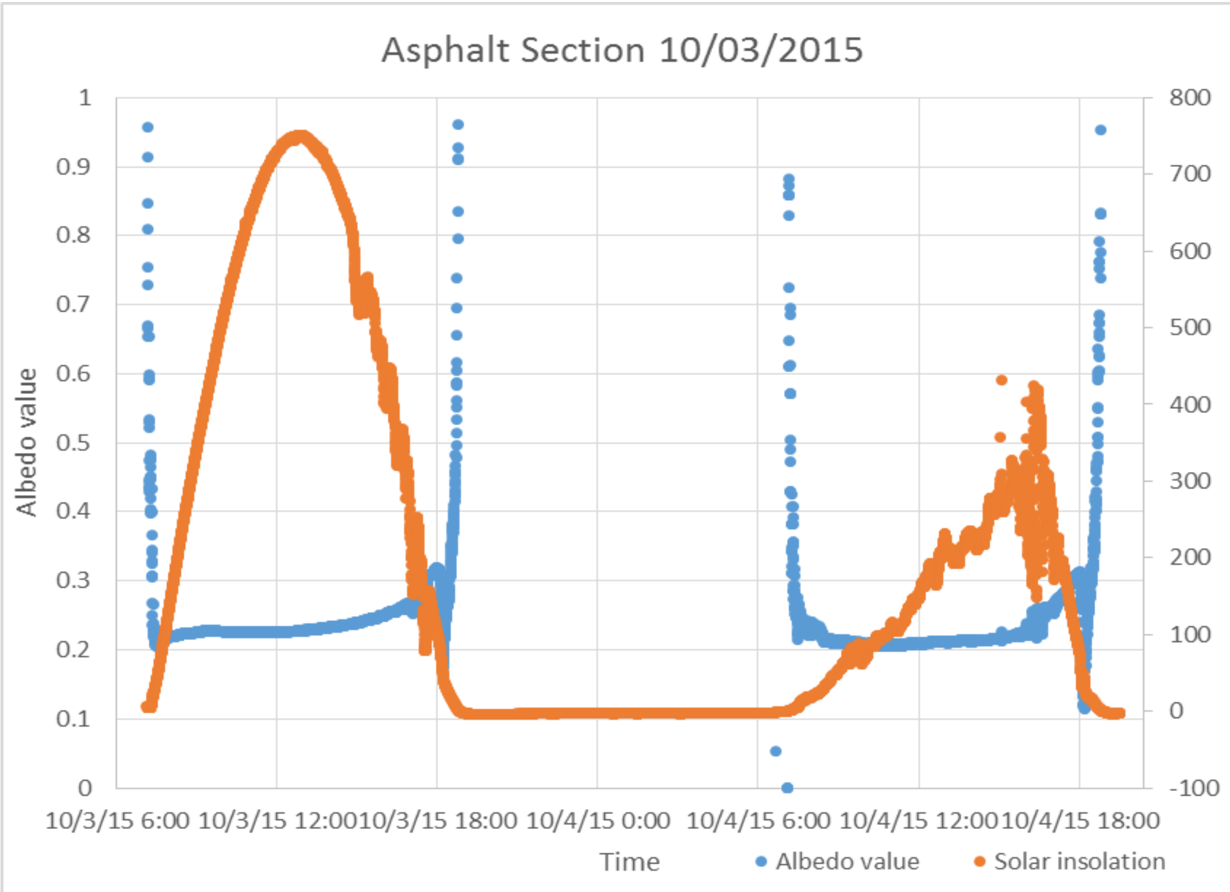


Figure 3.10 Diurnal variation of albedo on asphalt pavement in 3 days measured on 10/03/2015

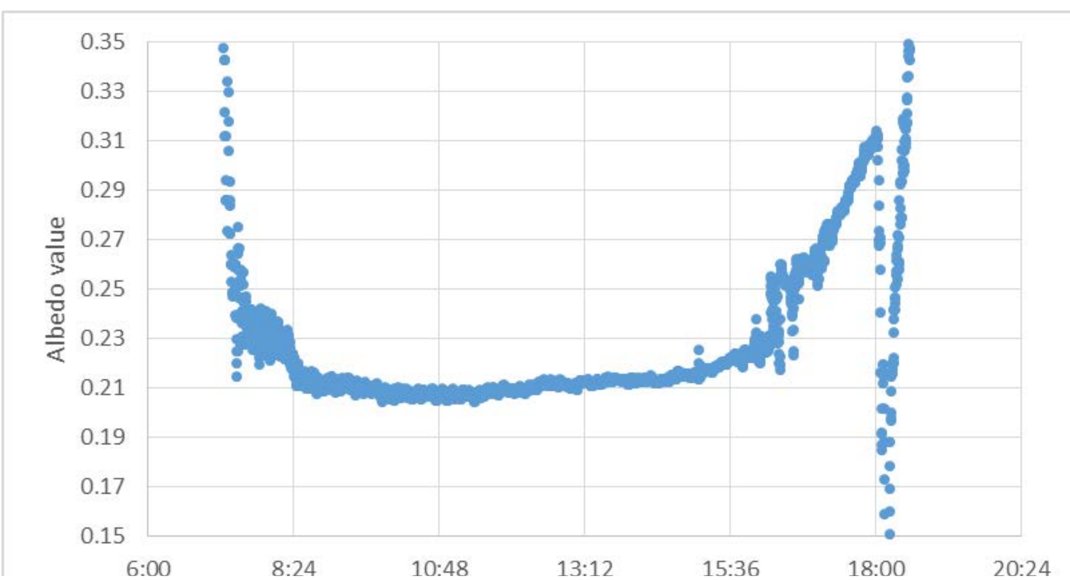


Figure 3.11 Zoom-in plot for one day albedo variation for asphalt pavement measured on 10/04/2015

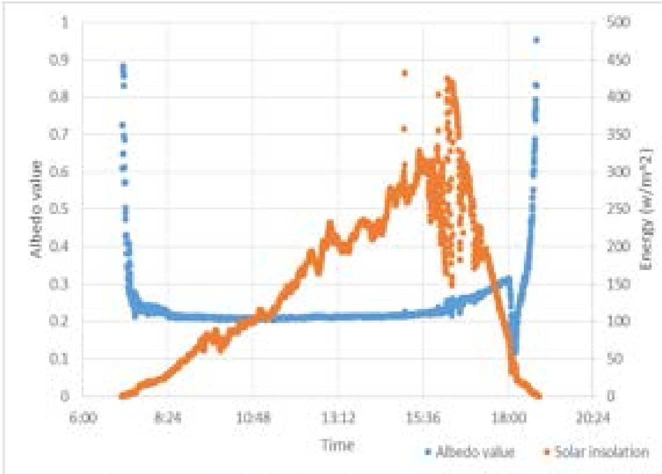


Figure 3.12 (a) Full day albedo variation and solar insolation

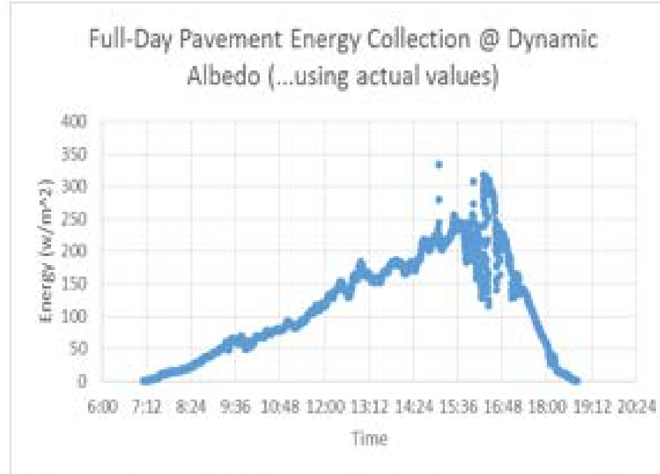


Figure 3.12 (b) Full day pavement energy collection under real condition

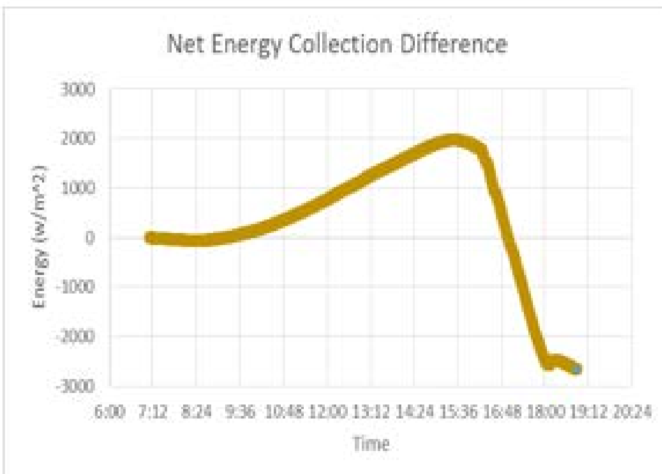


Figure 3.12 (d) Net energy collection difference between constant albedo value and actual value

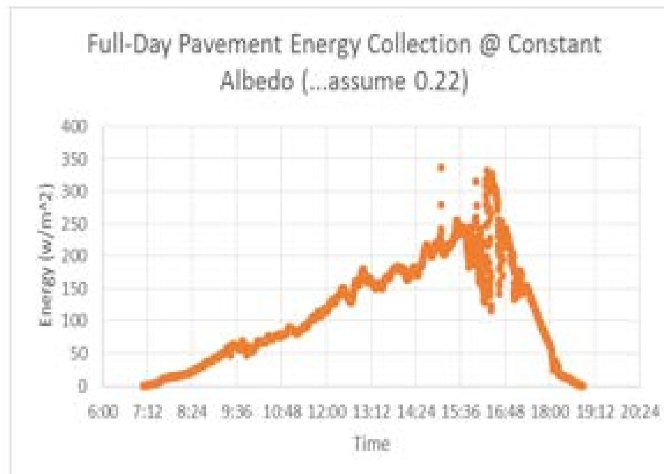


Figure 3.12 (c) Full day pavement energy collection under model condition (constant albedo value)

Figure 3.12 Further analysis for albedo variation on asphalt pavement measured on 10/04/2015

The result for the third measurement on asphalt pavement on 10/03/2015 was a little bit different from the previous two measurements. The weather on 10/04/2015 was cloudy, not a good condition for measuring albedo as recommended by ASTM E1918. From the solar insolation plot on Figure 3.10, while a significant difference can be noticed for a sunny day with a clear sky, the pattern of albedo variation is essentially the same. This indicates that weather conditions should not significantly impact the albedo measurement.

Li at UC Davis also investigated the diurnal variation of albedo on asphalt pavement. Figure 3.13 is the comparison of our results with his results. Our results is on the right side, while his results is on the left side. His results shows that the albedo value was constant at the middle of the day, while we never observed the albedo became constant during the day. Besides that, Li did not report any albedo value above 0.26 for asphalt section for a full day (Li, 2012). However, we observed that the albedo value for asphalt section can up to 1 in the early morning and late afternoon.

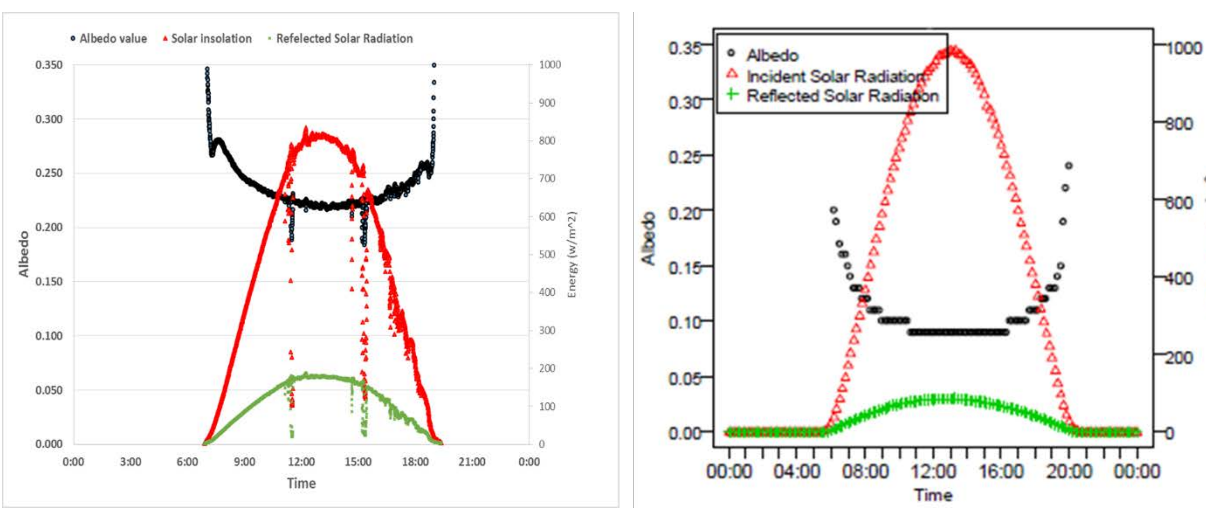


Figure 3.13 Comparison of diurnal variation of albedo for asphalt pavement with Li's results (Li, 2012).

In summary, we can draw several following conclusions from this experiment:

1) The albedo for pavements changes during a day.
2) The albedo changes rapidly only in early morning and later afternoon for a short period of time (less than 30 minutes).
3) The albedo remains fairly stable within a narrow range throughout much of the day.
4) It is acceptable to use a constant albedo value for the simulation in thermal model.
5) It is acceptable to measure albedo in a mostly sunny.

3.4. Measuring range of albedometer at different heights

The main purpose of this section is to investigate the relationship between the height of the albedometer and the measuring range to help minimize the construction area as described in a later chapter.

The height of the albedometer will directly affect the bottom-facing albedometer area. The ASTM E1918 test method is the approved method for measuring solar reflectance of a horizontal surface, and it recommends that the height of pyranometer be 0.5 meters above the ground. It does not, however, clarify how big an area the pyranometer is measuring at this height, mentioning only that circles at least four meters in diameter are needed (ASTM, ASTM E1918-06 Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field, 2006). Information is limited as to why the ASTM test method specifies such information.

Due to the tripod limitations, only two heights, 17 inches and 24 inches, were used in this study, The location chosen was the parking lot on the east side of Haber Road in Ames. The surface of this parking lot surface is concrete with a high albedo value. Two black foam boards with a low albedo value (can be close to zero) were moved from outside the measurement range toward the albedometer to determine at what distance the albedo value changed; this distance would be taken as the range of the effective area the albedometer is measuring. In theory, if the solar radiation is perpendicular to the ground surface, the effective area the

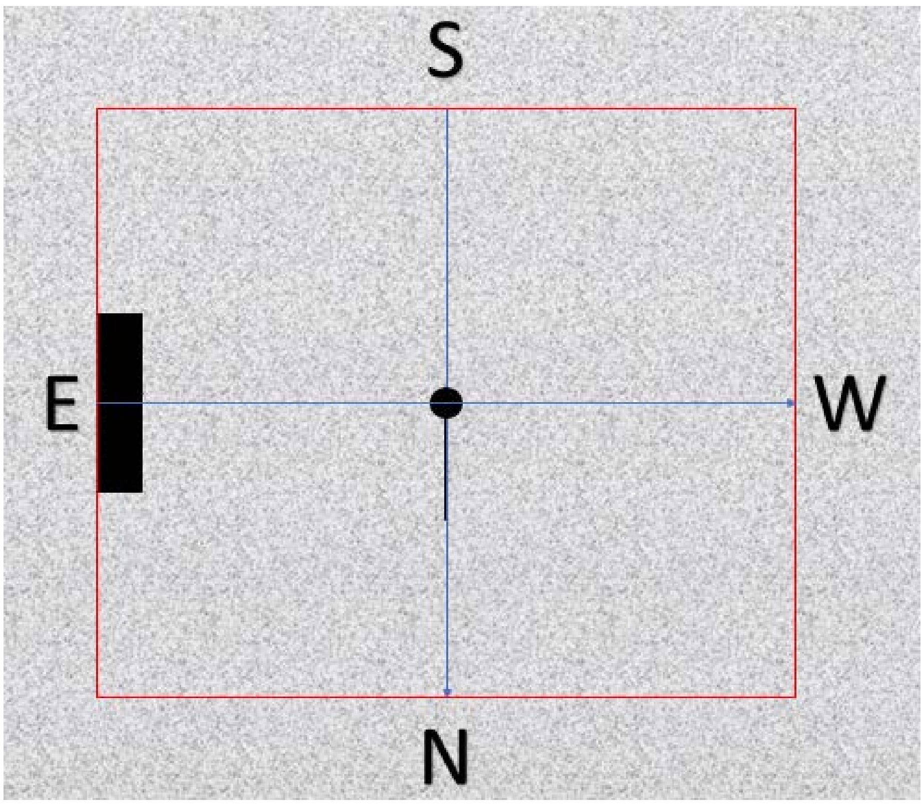


Figure 3.14 Plan View of the Set-up of Black Foam Board

albedometer is measuring should be a circle. However, over the course of a day the solar radiation reaches the ground at different angles, so most of the time the effective albedometer area forms an ellipse. Two black foam boards were moved in two different directions, one from north to south, and the other from west to east. Each time the foam boards moved 1 foot and a corresponding albedo value was recorded. Figure 3.14 is additional explanation on the experimental plan. The black rectangle are represented the foam board, and the circle and the center stands for the albedometer.

The data from this measurement is plotted in the Figure 3.15 and Figure 3.16. The corresponding measuring range for the albedometer setting at different heights is shown below each of the plots. In the morning and the afternoon, when the sun creates big shadows, the range of albedometer measurement is roughly elliptical, but for an albedometer height of t 17 inches, the measuring range is closer to being circular. Decreasing the height of the albedometer will in this way decrease the influence of the solar angle.

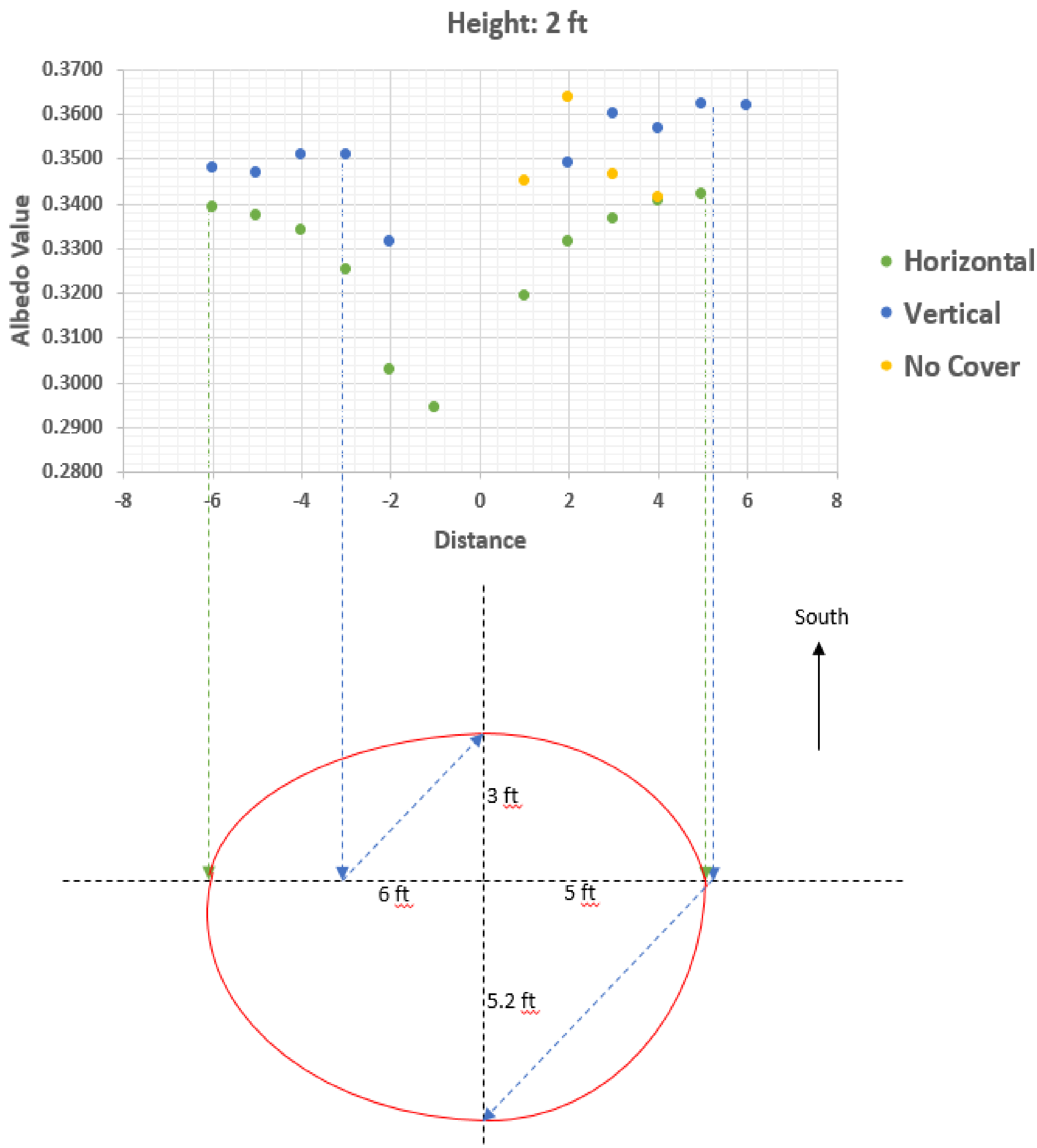


Figure 3.15 Albedo values for difference distance for the albedometer at height of 2 feet and its corresponding measuring range

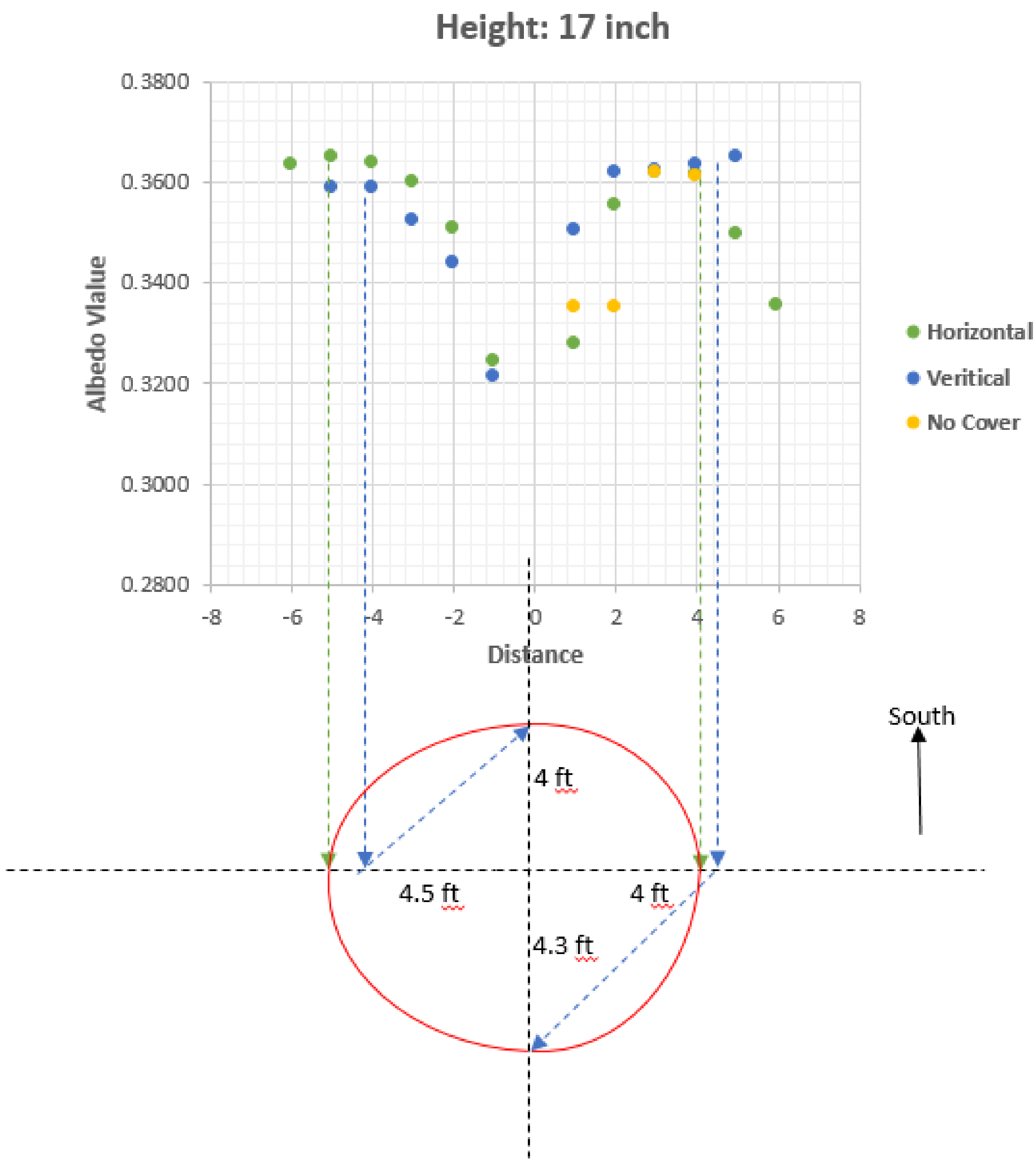


Figure 3.16 Albedo values for difference distance for the albedometer at height of 2 17 inches and its corresponding measuring range

CHAPTER 4. PAVEMENT TINING AND ALBEDO

4.1. Introduction

Pavement tining, either longitudinal or transverse, is common on interstate highways with high traffic volume and high vehicle speeds. The main purpose of such tining is to control noise and the expansion of the pavement. There are two simple effects causing tire noise. One is the sound of the tread contacting the road surface, while the other is compression of air inside the tread grooves (Phillips, 2015), and pavement tining will help decrease these effects. In general, designers often describe nominal tining by specification of dimensions such as spacing, depth, and width, although it is actually not that simple (Rasmussen, Garber, Fick, R., & Wiegand, 2008).

Currently, while there has been no study of the relationship between pavement tining and surface albedo, there is a possibility that pavement tining will affect surface albedo, one of the surface properties of a material. Tining changes the pavement surface from relatively smooth to rough and may produce a large effect on how radiation is reflected. The tining of the

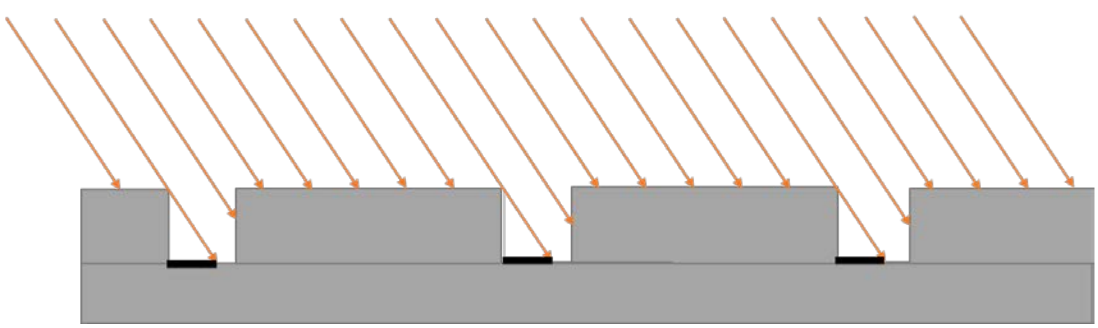


Figure 4.1 Pavement tining makes small shadow areas in the gap

pavement will create small shadows in the tiny grooves in the pavement surface. Figure 4.1 is a simplified illustration showing how such shadows can be created by pavement tining. This effect will be greater in the early morning or late afternoon when the incident angle of solar radiation is larger and the shadow area is larger. As the sun moves, the shadow area will decrease and reach a minimum at about noon.

4.2. Construction of experimental sections

Tining is normally applied to roads with design speeds of 45 mph or greater. However, measuring the albedo on a high speed road with heavy traffic creates many safety concerns. Two experimental sections were constructed in a parking lot on campus To simulate tining influence on the pavement surface albedo in a safe environment, measurements were performed on a newly constructed concrete parking lot at the east side of Haber Road. Because the parking lot was already built, a cut-off saw with diamond blade was used to produce the tining grooves. In real-world construction, the tining spacing is normally 1 inch, but to decrease the workload the experimental sections used 2 inch spacing and a depth of 3 mm. From the results in Chapter 4, the effective measuring range with an 18 inch high albedometer setting is a 4-foot circle. Two square sections with dimensions 4 feet by 4 feet were constructed with different tining directions, one north-south, and the other east-west. Figure 4.2 shows pictures of the two experimental sections and the construction process.

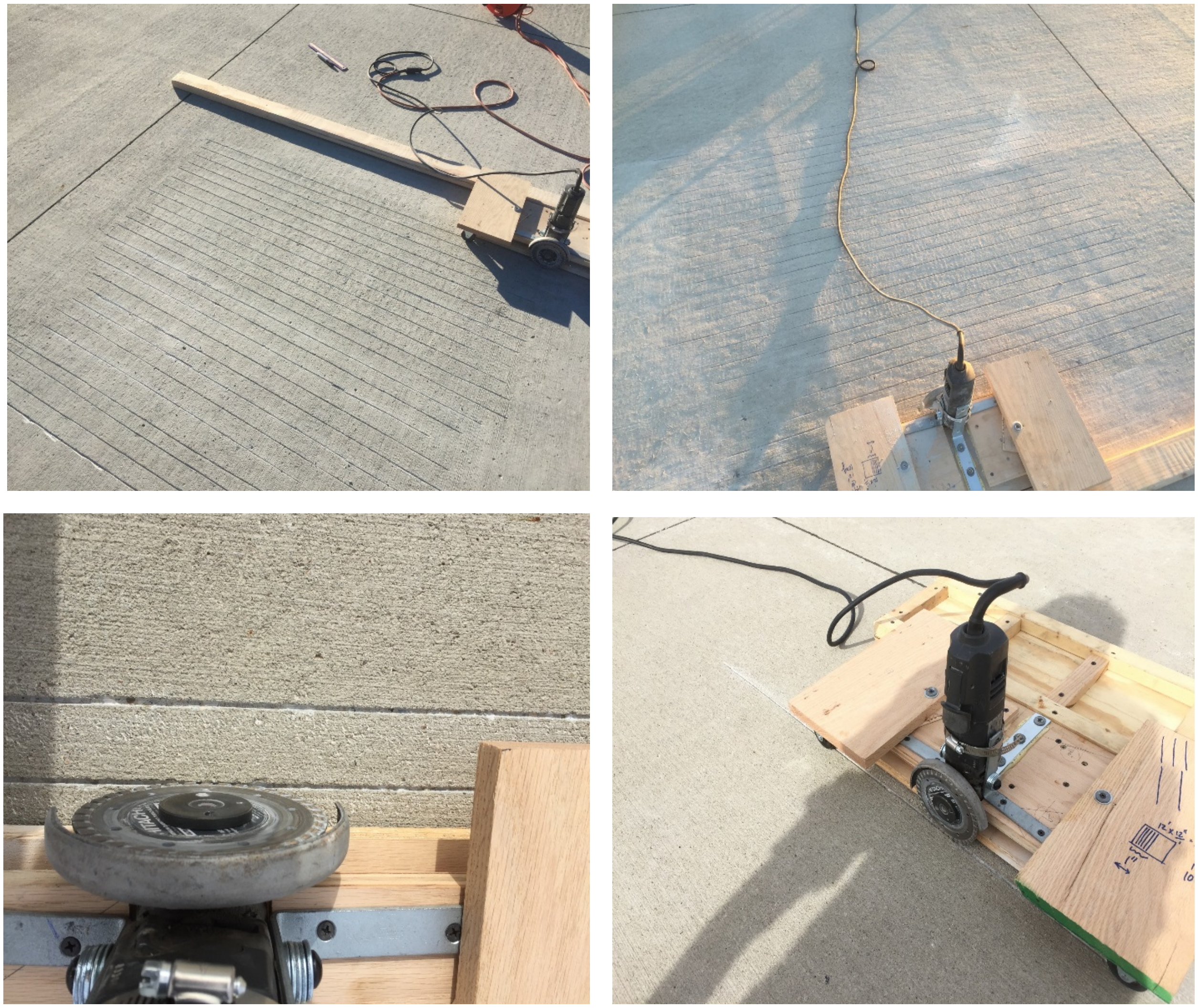


Figure 4.2 Construction Process of Pavement Surface Tining

4.3. Results and discussion

The albedo values for both tined sections and a section with no tining were measured at three different times: morning, noon, and afternoon. During daytime, the sun angle keeps changing and will produce create different shadowing at different times. The three time segments were taken as sufficiently representative. All data were collected on November 6, 2015, a sunny day with no clouds at all.

Table 4.1 below is a summary of average albedo value for three section in three time segments.

Table 4.1 Summary of albedo value observed for tining concrete

TINING TYPE	TIME	MEAN ALBEDO VALUE	MAXIMUM ALBEDO VALUE OBSERVED	MINIMUM ALBEDO VALUE OBSERVED
NO TINING	Morning	0.3479	0.3569	0.3320
NO TINING	Noon	0.3583	0.3613	0.3549
NO TINING	Afternoon	0.3557	0.3749	0.3330
N-S TINING	Morning	0.3799	0.3833	0.3775
N-S TINING	Noon	0.3817	0.3825	0.3808
N-S TINING	Afternoon	0.3874	0.3971	0.3820
W-E TINING	Morning	0.3758	0.3780	0.3734
W-E TINING	Noon	0.3783	0.3810	0.3756
W-E TINING	Afternoon	0.3682	0.3891	0.3361

Figure 4.3 below is the plot of the mean albedo values for different tining versus time. From the plot, the albedo value for two tining sections can be seen to be higher than concrete pavement with no tining. Larger changes were observed for the north-south direction in the tining section. As the sun moved from east to west during the day, the results met the expectation that north-south direction tining shadows would create larger changes. The albedo values for both tining sections were higher than those for normal pavement section with no

tining. A possible reason for this might be that the construction process exposed fresh, perhaps whiter, concrete below the surface, resulting in a higher albedo value.

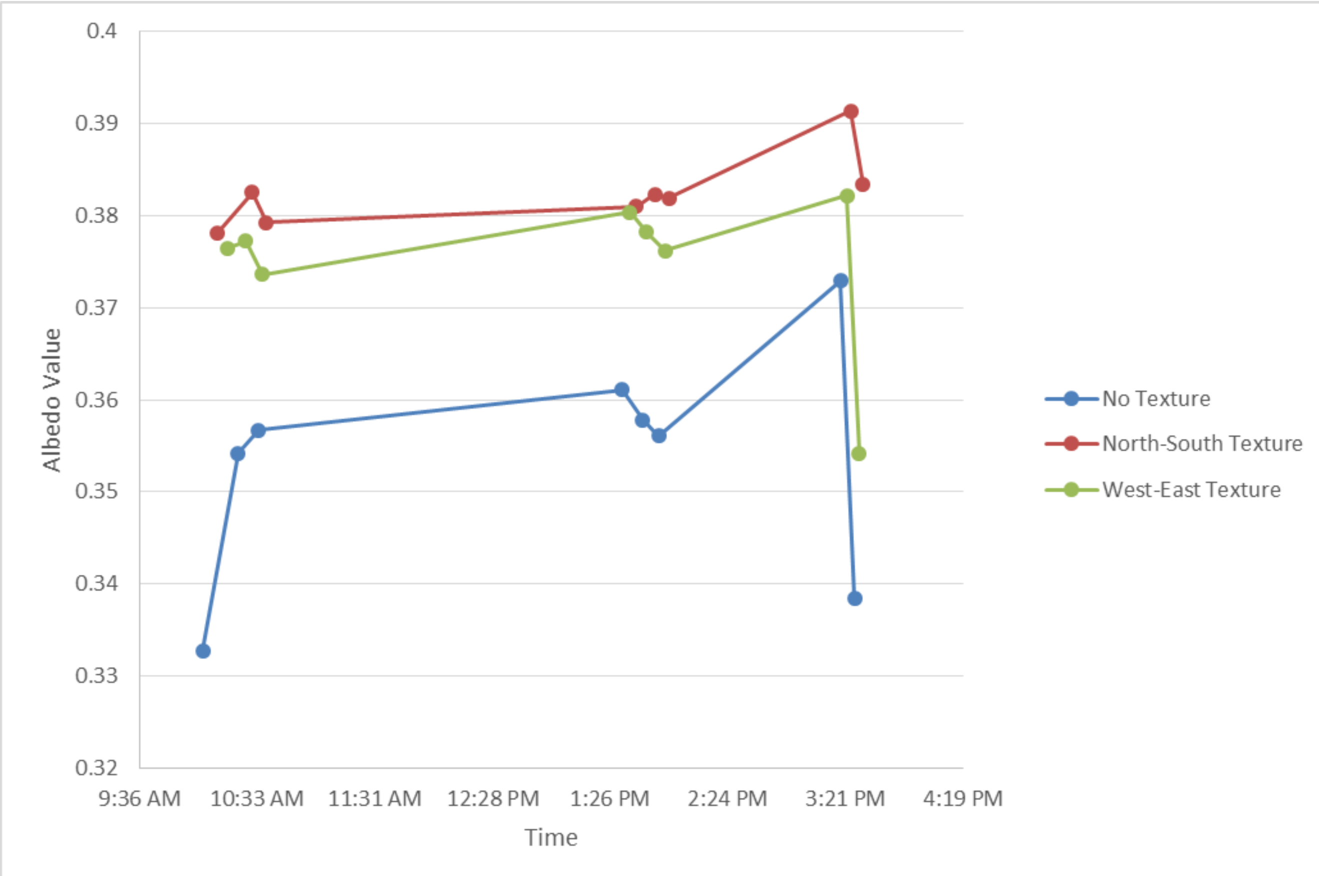


Figure 4.3 Albedo value for 3 experimental sections with time

CHAPTER 5. CONCLUSION

5.1. Summary

Albedo is an important topic of the study of the Urban Heat Island effect. Different albedo values for different materials significantly influence the daily maximum temperature and are therefore an important factor in pavement thermal modeling. The investigation of diurnal variation of albedo in this study indicates that the albedo value is not constant over the course of a day. In early morning and late afternoon albedo values reach their maxima but over a long period time (9:00 am to 6 pm), the albedo values change only within a very narrow range. The energy collection difference between dynamic albedo and constant albedo values is negligible, so the results indicate that thermal models using a constant albedo value should be total acceptable. This study also investigated the measurement range different albedometer height settings. This will improve future albedo measuring methods.

Pavement tining will affect the pavement surface albedo value because tining creates small shadow areas that affect radiation. However, results showed a higher albedo value in tining sections for this study, not matching our expectations. A possible reason for this discrepancy might be the whiter color of the fresh cuts on the experimental sections.

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5.2. Recommendations

Although this study investigated the albedometer measuring range at different heights, more tests at different heights should be made to demonstrate a comprehensive relationship between the height and the measuring range. The study also did not consider measurement accuracy of the albedometer setting at different heights. Comparison of average albedo values measured at different heights will help improve albedo measurements in the future.

It is still recommended to measure the albedo on a sunny day with clear sky, but if weather conditions are not perfect, the data may still be acceptable as long as there was no rain. The measurement results of albedo value will not change much on a partly cloudy day.

More future tests should be performed with respect to the influence of tining on pavement albedo. As the tining collects dirt and dust with time, different results might be observed.

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APPENDIX A: WEATHER INFORMATION FOR ALBEDO VARIATION MEASUREMENT

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	59.0°F	52.0°F	78%	30.04 in	10.0 miles	North	10.4 mph	-	N/A		Clear
1:53 AM	57.0°F	51.1°F	81%	30.06 in	10.0 miles	North	8.1 mph	-	N/A		Clear
2:53 AM	55.9°F	51.1°F	84%	30.06 in	10.0 miles	North	9.2 mph	-	N/A		Clear
3:53 AM	54.0°F	50.0°F	86%	30.07 in	10.0 miles	North	10.4 mph	-	N/A		Clear
4:53 AM	53.1°F	48.9°F	86%	30.08 in	10.0 miles	NNW	8.1 mph	-	N/A		Clear
5:53 AM	51.1°F	48.9°F	92%	30.09 in	10.0 miles	North	12.7 mph	-	N/A		Clear
6:53 AM	51.1°F	48.0°F	89%	30.12 in	10.0 miles	North	12.7 mph	-	N/A		Clear
7:53 AM	51.1°F	48.0°F	89%	30.15 in	10.0 miles	North	11.5 mph	-	N/A		Clear
8:53 AM	53.1°F	48.0°F	83%	30.16 in	10.0 miles	North	11.5 mph	-	N/A		Clear
9:53 AM	57.0°F	50.0°F	77%	30.17 in	10.0 miles	North	10.4 mph	-	N/A		Clear
10:53 AM	61.0°F	51.1°F	70%	30.18 in	10.0 miles	NNW	12.7 mph	-	N/A		Clear
11:53 AM	62.1°F	48.0°F	60%	30.18 in	10.0 miles	North	13.8 mph	-	N/A		Mostly Cloudy
12:53 PM	64.9°F	48.0°F	54%	30.17 in	10.0 miles	NNW	13.8 mph	-	N/A		Mostly Cloudy
1:53 PM	63.0°F	45.0°F	52%	30.17 in	10.0 miles	NNW	16.1 mph	21.9 mph	N/A		Mostly Cloudy
2:53 PM	64.9°F	44.1°F	47%	30.16 in	10.0 miles	NNW	12.7 mph	-	N/A		Scattered Clouds
3:53 PM	64.0°F	44.1°F	48%	30.14 in	10.0 miles	North	13.8 mph	25.3 mph	N/A		Mostly Cloudy
4:53 PM	64.9°F	42.1°F	43%	30.13 in	10.0 miles	NNW	15.0 mph	-	N/A		Partly Cloudy
5:53 PM	63.0°F	42.1°F	46%	30.13 in	10.0 miles	North	11.5 mph	-	N/A		Partly Cloudy
6:53 PM	62.1°F	43.0°F	50%	30.13 in	10.0 miles	NNW	15.0 mph	-	N/A		Overcast
7:53 PM	57.9°F	44.1°F	60%	30.14 in	10.0 miles	North	5.8 mph	-	N/A		Mostly Cloudy
8:53 PM	55.9°F	46.9°F	72%	30.15 in	10.0 miles	NNW	4.6 mph	-	N/A		Overcast
9:53 PM	55.9°F	48.0°F	75%	30.16 in	10.0 miles	North	4.6 mph	-	N/A		Overcast
10:53 PM	54.0°F	48.0°F	80%	30.15 in	10.0 miles	NW	4.6 mph	-	N/A		Overcast
11:53 PM	53.1°F	48.0°F	83%	30.15 in	10.0 miles	NW	6.9 mph	-	N/A		Mostly Cloudy

September 11, 2015

September 12, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	51.1°F	46.9°F	86%	30.16 in	10.0 miles	NW	5.8 mph	-	N/A		Partly Cloudy
1:53 AM	48.9°F	46.9°F	93%	30.16 in	10.0 miles	NW	3.5 mph	-	N/A		Clear
2:53 AM	48.9°F	46.0°F	90%	30.16 in	10.0 miles	WNW	3.5 mph	-	N/A		Clear
3:53 AM	48.0°F	45.0°F	89%	30.16 in	10.0 miles	NNW	4.6 mph	-	N/A		Clear
4:53 AM	46.9°F	45.0°F	93%	30.17 in	10.0 miles	North	4.6 mph	-	N/A		Clear
5:53 AM	46.0°F	44.1°F	93%	30.17 in	10.0 miles	North	4.6 mph	-	N/A		Clear
6:53 AM	46.0°F	44.1°F	93%	30.18 in	10.0 miles	NNW	3.5 mph	-	N/A		Clear
7:53 AM	48.0°F	45.0°F	89%	30.18 in	10.0 miles	North	5.8 mph	-	N/A		Clear
8:53 AM	53.1°F	46.9°F	80%	30.19 in	10.0 miles	North	4.6 mph	-	N/A		Clear
9:53 AM	57.9°F	46.9°F	67%	30.19 in	10.0 miles	NE	6.9 mph	-	N/A		Clear
10:53 AM	62.1°F	46.0°F	56%	30.19 in	10.0 miles	ENE	8.1 mph	-	N/A		Clear
11:53 AM	64.0°F	44.1°F	48%	30.18 in	10.0 miles	NNE	10.4 mph	-	N/A		Partly Cloudy
12:53 PM	66.0°F	43.0°F	43%	30.16 in	10.0 miles	NNE	9.2 mph	-	N/A		Clear
1:53 PM	66.0°F	39.0°F	37%	30.14 in	10.0 miles	Variable	6.9 mph	-	N/A		Clear
2:53 PM	66.9°F	43.0°F	42%	30.11 in	10.0 miles	NNW	4.6 mph	-	N/A		Clear
3:53 PM	68.0°F	42.1°F	39%	30.09 in	10.0 miles	Variable	5.8 mph	-	N/A		Clear
4:53 PM	69.1°F	42.1°F	38%	30.06 in	10.0 miles	Calm	Calm	-	N/A		Clear
5:53 PM	66.9°F	39.9°F	37%	30.06 in	10.0 miles	Calm	Calm	-	N/A		Clear
6:53 PM	64.9°F	42.1°F	43%	30.05 in	10.0 miles	Calm	Calm	-	N/A		Clear
7:53 PM	53.1°F	48.9°F	86%	30.06 in	10.0 miles	Calm	Calm	-	N/A		Clear
8:53 PM	50.0°F	48.0°F	93%	30.08 in	5.0 miles	Calm	Calm	-	N/A		Clear
9:53 PM	48.9°F	46.9°F	93%	30.09 in	3.0 miles	WSW	3.5 mph	-	N/A		Clear
10:53 PM	48.0°F	46.0°F	93%	30.08 in	3.0 miles	Calm	Calm	-	N/A		Clear
11:53 PM	48.0°F	46.0°F	93%	30.07 in	4.0 miles	Calm	Calm	-	N/A		Clear

September 13, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	46.0°F	45.0°F	96%	30.06 in	7.0 miles	Calm	Calm	-	N/A		Clear
1:53 AM	45.0°F	44.1°F	97%	30.06 in	10.0 miles	Calm	Calm	-	N/A		Clear
2:53 AM	45.0°F	44.1°F	97%	30.05 in	6.0 miles	Calm	Calm	-	N/A		Clear
3:53 AM	44.1°F	43.0°F	96%	30.05 in	10.0 miles	Calm	Calm	-	N/A		Clear
4:53 AM	43.0°F	43.0°F	100%	30.04 in	3.0 miles	Calm	Calm	-	N/A		Clear
5:05 AM	43.0°F	43.0°F	100%	30.05 in	1.8 miles	Calm	Calm	-	N/A		Clear
5:15 AM	43.0°F	42.1°F	97%	30.05 in	0.5 miles	Calm	Calm	-	N/A	Fog	Fog
5:30 AM	43.0°F	43.0°F	100%	30.05 in	1.0 miles	Calm	Calm	-	N/A		Clear
5:37 AM	43.0°F	42.1°F	97%	30.05 in	4.0 miles	Calm	Calm	-	N/A		Clear
5:53 AM	43.0°F	42.1°F	97%	30.04 in	10.0 miles	Calm	Calm	-	N/A		Clear
6:05 AM	43.0°F	43.0°F	100%	30.05 in	1.8 miles	Calm	Calm	-	N/A		Clear
6:21 AM	43.0°F	42.1°F	97%	30.05 in	2.5 miles	Calm	Calm	-	N/A		Clear
6:29 AM	43.0°F	42.1°F	97%	30.05 in	5.0 miles	Calm	Calm	-	N/A		Clear
6:35 AM	43.0°F	42.1°F	97%	30.05 in	1.8 miles	Calm	Calm	-	N/A		Clear
6:53 AM	42.1°F	42.1°F	100%	30.05 in	1.0 miles	Calm	Calm	-	N/A		Clear
6:58 AM	43.0°F	42.1°F	97%	30.05 in	3.0 miles	Calm	Calm	-	N/A		Clear
7:53 AM	48.0°F	46.9°F	96%	30.06 in	10.0 miles	Calm	Calm	-	N/A		Clear
8:53 AM	55.9°F	51.1°F	84%	30.05 in	10.0 miles	South	6.9 mph	-	N/A		Clear
9:53 AM	62.1°F	48.9°F	62%	30.03 in	10.0 miles	SSW	10.4 mph	-	N/A		Clear
10:53 AM	66.0°F	48.9°F	54%	30.02 in	10.0 miles	SSW	15.0 mph	-	N/A		Clear
11:53 AM	69.1°F	50.0°F	51%	30.01 in	10.0 miles	South	11.5 mph	21.9 mph	N/A		Partly Cloudy
12:53 PM	70.0°F	48.9°F	47%	29.98 in	10.0 miles	SSW	11.5 mph	-	N/A		Clear
1:53 PM	72.0°F	51.1°F	48%	29.95 in	10.0 miles	South	12.7 mph	19.6 mph	N/A		Clear
2:53 PM	73.0°F	51.1°F	46%	29.91 in	10.0 miles	SSE	16.1 mph	-	N/A		Clear
3:53 PM	73.0°F	53.1°F	49%	29.89 in	10.0 miles	South	11.5 mph	21.9 mph	N/A		Clear
4:53 PM	73.0°F	53.1°F	49%	29.87 in	10.0 miles	South	12.7 mph	-	N/A		Clear
5:53 PM	72.0°F	54.0°F	53%	29.86 in	10.0 miles	South	15.0 mph	-	N/A		Clear
6:53 PM	68.0°F	54.0°F	61%	29.86 in	10.0 miles	South	8.1 mph	-	N/A		Clear
7:53 PM	61.0°F	54.0°F	78%	29.86 in	10.0 miles	SSE	6.9 mph	-	N/A		Clear
8:53 PM	60.1°F	54.0°F	80%	29.86 in	10.0 miles	SSE	8.1 mph	-	N/A		Clear
9:53 PM	59.0°F	54.0°F	83%	29.87 in	10.0 miles	SSE	8.1 mph	-	N/A		Clear
10:53 PM	57.9°F	54.0°F	87%	29.87 in	10.0 miles	SSE	6.9 mph	-	N/A		Clear
11:53 PM	57.0°F	54.0°F	89%	29.86 in	10.0 miles	SSE	5.8 mph	-	N/A		Clear

September 19, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	52.0°F	50.0°F	93%	29.99 in	10.0 miles	NW	12.7 mph	-	N/A		Clear
1:53 AM	52.0°F	48.9°F	89%	29.99 in	10.0 miles	NNW	13.8 mph	-	N/A		Clear
2:53 AM	51.1°F	48.9°F	92%	30.01 in	10.0 miles	NNW	12.7 mph	-	N/A		Clear
3:53 AM	51.1°F	48.9°F	92%	30.02 in	10.0 miles	NNW	9.2 mph	-	N/A		Clear
4:53 AM	50.0°F	48.9°F	96%	30.05 in	10.0 miles	NW	9.2 mph	-	N/A		Clear
5:53 AM	50.0°F	48.0°F	93%	30.07 in	10.0 miles	NNW	9.2 mph	-	N/A		Clear
6:53 AM	48.9°F	48.0°F	97%	30.10 in	10.0 miles	NNW	8.1 mph	-	N/A		Clear
7:53 AM	50.0°F	48.0°F	93%	30.12 in	10.0 miles	NNW	6.9 mph	-	N/A		Clear
8:53 AM	54.0°F	48.0°F	80%	30.14 in	10.0 miles	North	9.2 mph	-	N/A		Clear
9:53 AM	57.9°F	48.9°F	72%	30.15 in	10.0 miles	North	6.9 mph	-	N/A		Clear
10:53 AM	60.1°F	48.9°F	67%	30.17 in	10.0 miles	North	6.9 mph	-	N/A		Clear
11:53 AM	64.0°F	48.9°F	58%	30.17 in	10.0 miles	NNW	8.1 mph	-	N/A		Clear
12:53 PM	64.9°F	46.0°F	50%	30.16 in	10.0 miles	Variable	5.8 mph	-	N/A		Clear
1:53 PM	66.0°F	45.0°F	47%	30.14 in	10.0 miles	WNW	8.1 mph	-	N/A		Clear
2:53 PM	69.1°F	45.0°F	42%	30.12 in	10.0 miles	Variable	4.6 mph	-	N/A		Clear
3:53 PM	69.1°F	43.0°F	39%	30.11 in	10.0 miles	West	4.6 mph	-	N/A		Clear
4:53 PM	70.0°F	44.1°F	39%	30.10 in	10.0 miles	NNE	3.5 mph	-	N/A		Clear
5:53 PM	69.1°F	41.0°F	36%	30.10 in	10.0 miles	Calm	Calm	-	N/A		Clear
6:53 PM	64.9°F	46.0°F	50%	30.09 in	10.0 miles	ESE	3.5 mph	-	N/A		Clear
7:53 PM	55.0°F	48.0°F	77%	30.09 in	10.0 miles	South	3.5 mph	-	N/A		Clear
8:53 PM	54.0°F	46.9°F	77%	30.11 in	10.0 miles	SW	3.5 mph	-	N/A		Clear
9:53 PM	50.0°F	46.9°F	89%	30.13 in	10.0 miles	SW	4.6 mph	-	N/A		Clear
10:53 PM	48.9°F	46.9°F	93%	30.13 in	10.0 miles	Calm	Calm	-	N/A		Clear
11:53 PM	48.0°F	46.9°F	96%	30.13 in	10.0 miles	Calm	Calm	-	N/A		Clear

September 20, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	46.9°F	46.0°F	97%	30.12 in	10.0 miles	Calm	Calm	-	N/A		Clear
1:53 AM	46.0°F	46.0°F	100%	30.12 in	4.0 miles	Calm	Calm	-	N/A		Clear
2:53 AM	46.0°F	45.0°F	96%	30.12 in	9.0 miles	Calm	Calm	-	N/A		Clear
3:53 AM	44.1°F	43.0°F	96%	30.12 in	3.0 miles	Calm	Calm	-	N/A		Clear
4:00 AM	44.1°F	43.0°F	96%	30.13 in	2.0 miles	SE	3.5 mph	-	N/A		Clear
4:10 AM	45.0°F	44.1°F	97%	30.13 in	4.0 miles	Calm	Calm	-	N/A		Clear
4:48 AM	44.6°F	44.6°F	100%	30.13 in	2.5 miles	Calm	Calm	-	N/A		Clear
4:53 AM	45.0°F	45.0°F	100%	30.13 in	6.0 miles	Calm	Calm	-	N/A		Clear
5:53 AM	44.1°F	44.1°F	100%	30.12 in	7.0 miles	SE	4.6 mph	-	N/A		Clear
6:53 AM	45.0°F	44.1°F	97%	30.15 in	8.0 miles	Calm	Calm	-	N/A		Clear
7:03 AM	43.0°F	43.0°F	100%	30.15 in	0.8 miles	SSE	3.5 mph	-	N/A		Clear
7:13 AM	44.1°F	44.1°F	100%	30.15 in	0.2 miles	Calm	Calm	-	N/A	Fog	Fog
7:22 AM	45.0°F	44.1°F	97%	30.15 in	1.0 miles	Calm	Calm	-	N/A		Clear
7:31 AM	45.0°F	45.0°F	100%	30.15 in	3.0 miles	Calm	Calm	-	N/A		Clear
7:53 AM	48.0°F	46.9°F	96%	30.15 in	7.0 miles	SE	4.6 mph	-	N/A		Clear
8:53 AM	55.9°F	52.0°F	87%	30.17 in	10.0 miles	SSE	5.8 mph	-	N/A		Clear
9:53 AM	62.1°F	52.0°F	70%	30.16 in	10.0 miles	South	9.2 mph	-	N/A		Clear
10:53 AM	66.0°F	50.0°F	56%	30.15 in	10.0 miles	South	15.0 mph	-	N/A		Clear
11:53 AM	69.1°F	50.0°F	51%	30.13 in	10.0 miles	South	12.7 mph	19.6 mph	N/A		Clear
12:53 PM	71.1°F	48.9°F	45%	30.11 in	10.0 miles	SSW	12.7 mph	25.3 mph	N/A		Clear
1:53 PM	71.1°F	50.0°F	47%	30.08 in	10.0 miles	SSW	13.8 mph	20.7 mph	N/A		Clear
2:53 PM	72.0°F	50.0°F	46%	30.06 in	10.0 miles	South	13.8 mph	-	N/A		Clear
3:53 PM	73.0°F	51.1°F	46%	30.04 in	10.0 miles	South	10.4 mph	19.6 mph	N/A		Clear
4:53 PM	72.0°F	50.0°F	46%	30.03 in	10.0 miles	South	9.2 mph	-	N/A		Clear
5:53 PM	71.1°F	53.1°F	53%	30.04 in	10.0 miles	SSE	8.1 mph	-	N/A		Partly Cloudy
6:53 PM	68.0°F	51.1°F	55%	30.04 in	10.0 miles	South	9.2 mph	-	N/A		Clear
7:53 PM	57.9°F	51.1°F	78%	30.04 in	10.0 miles	SSE	4.6 mph	-	N/A		Clear
8:53 PM	57.0°F	51.1°F	81%	30.04 in	10.0 miles	SE	4.6 mph	-	N/A		Clear
9:53 PM	55.9°F	51.1°F	84%	30.05 in	10.0 miles	South	4.6 mph	-	N/A		Clear
10:53 PM	55.0°F	51.1°F	86%	30.05 in	10.0 miles	SSE	6.9 mph	-	N/A		Clear
11:53 PM	55.0°F	52.0°F	89%	30.04 in	10.0 miles	SSE	6.9 mph	-	N/A		Clear

September 21, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	53.1°F	51.1°F	93%	30.03 in	10.0 miles	SSE	8.1 mph	-	N/A		Clear
1:53 AM	52.0°F	51.1°F	97%	30.02 in	10.0 miles	SSE	4.6 mph	-	N/A		Clear
2:53 AM	52.0°F	50.0°F	93%	30.01 in	10.0 miles	SE	4.6 mph	-	N/A		Clear
3:53 AM	51.1°F	50.0°F	96%	30.01 in	10.0 miles	SE	4.6 mph	-	N/A		Clear
4:53 AM	51.1°F	50.0°F	96%	30.01 in	10.0 miles	SE	4.6 mph	-	N/A		Clear
5:53 AM	51.1°F	50.0°F	96%	30.02 in	10.0 miles	SE	5.8 mph	-	N/A		Clear
6:53 AM	50.0°F	48.9°F	96%	30.04 in	10.0 miles	SSE	4.6 mph	-	N/A		Clear
7:53 AM	53.1°F	51.1°F	93%	30.05 in	10.0 miles	SSE	6.9 mph	-	N/A		Clear
8:53 AM	60.1°F	55.0°F	83%	30.05 in	10.0 miles	SSE	5.8 mph	-	N/A		Clear
9:53 AM	66.0°F	57.0°F	73%	30.05 in	10.0 miles	South	10.4 mph	-	N/A		Clear
10:41 AM	69.1°F	60.1°F	73%	30.06 in	10.0 miles	South	12.7 mph	-	N/A		Mostly Cloudy
10:53 AM	69.1°F	60.1°F	73%	30.04 in	10.0 miles	South	12.7 mph	-	N/A		Mostly Cloudy
11:53 AM	70.0°F	60.1°F	71%	30.04 in	10.0 miles	South	16.1 mph	23.0 mph	N/A		Overcast
12:53 PM	72.0°F	60.1°F	66%	30.01 in	10.0 miles	SSW	15.0 mph	20.7 mph	N/A		Mostly Cloudy
1:40 PM	73.9°F	61.0°F	64%	30.01 in	10.0 miles	South	15.0 mph	21.9 mph	N/A		Scattered Clouds
1:53 PM	73.9°F	61.0°F	64%	29.99 in	10.0 miles	South	16.1 mph	-	N/A		Partly Cloudy
2:53 PM	75.0°F	61.0°F	62%	29.97 in	10.0 miles	South	13.8 mph	-	N/A		Clear
3:53 PM	75.9°F	61.0°F	60%	29.96 in	10.0 miles	SSW	11.5 mph	-	N/A		Partly Cloudy
4:53 PM	75.0°F	60.1°F	60%	29.96 in	10.0 miles	South	12.7 mph	-	N/A		Partly Cloudy
5:53 PM	73.9°F	60.1°F	62%	29.96 in	10.0 miles	South	11.5 mph	-	N/A		Partly Cloudy
6:53 PM	71.1°F	60.1°F	68%	29.96 in	10.0 miles	South	9.2 mph	-	N/A		Overcast
7:53 PM	69.1°F	61.0°F	75%	29.97 in	10.0 miles	South	5.8 mph	-	N/A		Overcast
8:53 PM	69.1°F	61.0°F	75%	29.98 in	10.0 miles	SSE	8.1 mph	-	N/A		Overcast
9:53 PM	68.0°F	61.0°F	78%	29.99 in	10.0 miles	SSE	6.9 mph	-	N/A		Overcast
10:53 PM	66.9°F	61.0°F	81%	29.99 in	10.0 miles	SE	6.9 mph	-	N/A		Overcast
11:53 PM	66.0°F	61.0°F	84%	30.00 in	10.0 miles	SSE	6.9 mph	-	N/A		Overcast

October 3, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
2:53 AM	45.0°F	39.9°F	82%	30.24 in	10.0 miles	ENE	6.9 mph	-	N/A		Clear
3:53 AM	44.1°F	39.0°F	82%	30.24 in	10.0 miles	East	4.6 mph	-	N/A		Clear
4:53 AM	42.1°F	39.0°F	89%	30.25 in	10.0 miles	NE	3.5 mph	-	N/A		Clear
5:53 AM	42.1°F	39.0°F	89%	30.26 in	10.0 miles	NE	6.9 mph	-	N/A		Clear
6:53 AM	41.0°F	39.0°F	93%	30.26 in	10.0 miles	ENE	6.9 mph	-	N/A		Clear
7:53 AM	42.1°F	39.0°F	89%	30.26 in	10.0 miles	NE	6.9 mph	-	N/A		Clear
8:53 AM	46.0°F	41.0°F	83%	30.27 in	10.0 miles	ENE	4.6 mph	-	N/A		Clear
9:53 AM	50.0°F	42.1°F	74%	30.26 in	10.0 miles	ENE	9.2 mph	-	N/A		Clear
10:53 AM	53.1°F	42.1°F	66%	30.25 in	10.0 miles	ENE	8.1 mph	-	N/A		Clear
11:53 AM	55.9°F	41.0°F	57%	30.21 in	10.0 miles	East	9.2 mph	-	N/A		Clear
12:53 PM	57.9°F	39.9°F	51%	30.20 in	10.0 miles	East	10.4 mph	19.6 mph	N/A		Clear
1:53 PM	60.1°F	37.9°F	44%	30.18 in	10.0 miles	NE	10.4 mph	-	N/A		Clear
2:53 PM	62.1°F	36.0°F	38%	30.16 in	10.0 miles	ENE	13.8 mph	-	N/A		Clear
3:53 PM	63.0°F	37.0°F	38%	30.14 in	10.0 miles	NE	13.8 mph	17.3 mph	N/A		Clear
4:53 PM	62.1°F	37.0°F	39%	30.14 in	10.0 miles	ENE	12.7 mph	-	N/A		Clear
5:53 PM	61.0°F	36.0°F	39%	30.15 in	10.0 miles	ENE	9.2 mph	-	N/A		Clear
6:53 PM	57.0°F	37.0°F	47%	30.16 in	10.0 miles	East	6.9 mph	-	N/A		Clear
7:53 PM	53.1°F	39.0°F	59%	30.17 in	10.0 miles	East	5.8 mph	-	N/A		Clear
8:53 PM	51.1°F	39.0°F	63%	30.19 in	10.0 miles	ENE	5.8 mph	-	N/A		Clear
9:53 PM	50.0°F	39.0°F	66%	30.21 in	10.0 miles	ENE	5.8 mph	-	N/A		Clear
10:53 PM	48.9°F	39.0°F	69%	30.21 in	10.0 miles	East	5.8 mph	-	N/A		Clear
11:53 PM	46.9°F	39.0°F	74%	30.20 in	10.0 miles	East	5.8 mph	-	N/A		Clear

October 4, 2015

Time(CDT)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	46.0°F	39.0°F	76%	30.20 in	10.0 miles	East	5.8 mph	-	N/A		Clear
1:53 AM	45.0°F	39.0°F	80%	30.22 in	10.0 miles	Calm	Calm	-	N/A		Clear
2:53 AM	43.0°F	39.0°F	86%	30.21 in	10.0 miles	NE	4.6 mph	-	N/A		Clear
3:53 AM	42.1°F	37.9°F	85%	30.20 in	10.0 miles	ENE	3.5 mph	-	N/A		Clear
4:53 AM	42.1°F	37.9°F	85%	30.21 in	10.0 miles	ENE	5.8 mph	-	N/A		Clear
5:53 AM	41.0°F	37.9°F	89%	30.24 in	10.0 miles	Calm	Calm	-	N/A		Clear
6:43 AM	42.1°F	39.0°F	89%	30.24 in	10.0 miles	ENE	4.6 mph	-	N/A		Mostly Cloudy
6:53 AM	42.1°F	39.0°F	89%	30.25 in	10.0 miles	ENE	3.5 mph	-	N/A		Overcast
7:53 AM	44.1°F	41.0°F	89%	30.25 in	10.0 miles	ENE	3.5 mph	-	N/A		Overcast
8:10 AM	45.0°F	41.0°F	86%	30.25 in	10.0 miles	NE	4.6 mph	-	N/A		Overcast
8:53 AM	46.0°F	42.1°F	86%	30.26 in	10.0 miles	NE	4.6 mph	-	N/A		Overcast
9:53 AM	48.0°F	43.0°F	83%	30.27 in	10.0 miles	NE	6.9 mph	-	N/A		Overcast
10:53 AM	48.9°F	44.1°F	83%	30.28 in	10.0 miles	NNE	5.8 mph	-	N/A		Overcast
11:53 AM	48.9°F	44.1°F	83%	30.27 in	10.0 miles	NNE	8.1 mph	-	N/A		Overcast
12:53 PM	50.0°F	44.1°F	80%	30.26 in	10.0 miles	NNE	6.9 mph	-	N/A		Overcast
1:05 PM	51.1°F	44.1°F	77%	30.25 in	10.0 miles	NNE	9.2 mph	-	N/A		Overcast
1:53 PM	51.1°F	45.0°F	80%	30.25 in	10.0 miles	North	10.4 mph	-	N/A		Overcast
2:53 PM	53.1°F	45.0°F	74%	30.22 in	10.0 miles	ENE	9.2 mph	-	N/A		Overcast
3:53 PM	54.0°F	45.0°F	72%	30.20 in	10.0 miles	NE	8.1 mph	-	N/A		Overcast
4:39 PM	55.9°F	45.0°F	67%	30.19 in	10.0 miles	NE	8.1 mph	-	N/A		Scattered Clouds
4:53 PM	55.0°F	45.0°F	69%	30.20 in	10.0 miles	NE	4.6 mph	-	N/A		Clear
5:53 PM	55.0°F	45.0°F	69%	30.20 in	10.0 miles	ENE	6.9 mph	-	N/A		Clear
6:53 PM	51.1°F	44.1°F	77%	30.20 in	10.0 miles	ENE	4.6 mph	-	N/A		Clear
7:53 PM	50.0°F	44.1°F	80%	30.20 in	10.0 miles	ENE	4.6 mph	-	N/A		Clear
8:53 PM	46.9°F	43.0°F	86%	30.21 in	10.0 miles	NNE	4.6 mph	-	N/A		Clear
9:53 PM	46.9°F	43.0°F	86%	30.22 in	10.0 miles	North	4.6 mph	-	N/A		Clear
10:53 PM	46.0°F	43.0°F	89%	30.22 in	10.0 miles	North	4.6 mph	-	N/A		Clear
11:12 PM	48.0°F	44.1°F	86%	30.22 in	10.0 miles	North	6.9 mph	-	N/A		Mostly Cloudy
11:53 PM	46.9°F	43.0°F	86%	30.22 in	10.0 miles	NE	4.6 mph	-	N/A		Scattered Clouds

APPENDIX B: DATA OF INVESTIGATION ALBEDOMETER MEASURING RANGE WITH HEIGHT

Height: 17 inches

Vertical							
	up	568.8	568.8	568.5	568.3	568	
	down	190.9	190.9	190.7	190.3	190	
	Albedo	0.3356	0.3356	0.3354	0.3349	0.3345	0.3352
+ 5 ft	up	551.7	551.7	552.1	551.9	552	
	down	201.2	201.2	201.7	201.7	201.6	
5	Albedo	0.3647	0.3647	0.3653	0.3655	0.3652	0.3651
+ 4 ft	up	548.5	548.7	548.5	548.5	548.5	
	down	199.6	199.6	199.2	199.4	199.3	
4	Albedo	0.3639	0.3638	0.3632	0.3635	0.3634	0.3635
+ 3 ft	up	546.2	545.8	545.6	545.2	545.9	
	down	198.1	197.6	197.4	197.6	197.5	
3	Albedo	0.3627	0.3620	0.3618	0.3624	0.3618	0.3622
+ 2 ft	up	543.8	543.8	543.8	543.8	543.8	
	down	196.2	196.2	197.1	197.1	197.4	
2	Albedo	0.3608	0.3608	0.3624	0.3624	0.3630	0.3619
+ 1 ft	up	543.8	544	544	543.8	544	
	down	189.9	190.6	190.6	190.8	190.5	
1	Albedo	0.3492	0.3504	0.3504	0.3509	0.3502	0.3502
- 1 ft	up	538.7	540	539.3	539.1	537.5	
	down	173.3	173.5	173.2	173	172.8	
-1	Albedo	0.3217	0.3213	0.3212	0.3209	0.3215	0.3213
- 2 ft	up	546.4	545.8	545.8	545.8	545.8	

	down	188.4	187.9	187.9	187.2	187.7	
-2	Albedo	0.3448	0.3443	0.3443	0.3430	0.3439	0.3440
- 3 ft	up	539.1	539.1	539.1	539.5	539.9	
	down	190	189.7	189.7	190.4	190.6	
-3	Albedo	0.3524	0.3519	0.3519	0.3529	0.3530	0.3524
- 4 ft	up	539.6	539.6	539.5	539.3	539	
	down	193.8	193.8	193.8	193.3	192.8	
-4	Albedo	0.3592	0.3592	0.3592	0.3584	0.3577	0.3587
- 5 ft	up	536.7	536.7	536.3	536.1	536.2	
	down	192.2	192.4	192.6	192.4	192.5	
-5	Albedo	0.3581	0.3585	0.3591	0.3589	0.3590	0.3587
None	up	535.5	535.1	534.9	535.1	535	
	down	193.5	193.1	193.1	193.5	193	
	Albedo	0.3613	0.3609	0.3610	0.3616	0.3607	0.3611

Horizontal							
	up	568.8	568.8	568.5	568.3	568	
	down	190.9	190.9	190.7	190.3	190	
	Albedo	0.3356	0.3356	0.3354	0.3349	0.3345	0.3352
+ 6 ft	up	565.5	565.5	565.3	565.3	565.3	
	down	189.3	189.3	189.5	190	189.9	
6	Albedo	0.3347	0.3347	0.3352	0.3361	0.3359	0.3353
+ 5 ft	up	569.4	569.8	570.4	570.6	570.4	
	down	197.9	198.8	199.7	200.1	199.7	
5	Albedo	0.3476	0.3489	0.3501	0.3507	0.3501	0.3495
+ 4 ft	up	573.9	574.1	573.9	574.1	574.1	
	down	206.9	207.1	207.4	208	207.7	
4	Albedo	0.3605	0.3607	0.3614	0.3623	0.3618	0.3613
+ 3 ft	up	573.9	573.7	573.7	573.9	573.8	
	down	207.4	207.3	208	208	207.8	
3	Albedo	0.3614	0.3613	0.3626	0.3624	0.3621	0.3620
+ 2 ft	up	573.1	572.7	572.9	573.1	573	

	down	203.5	203.5	203.7	203.5	203.6	
2	Albedo	0.3551	0.3553	0.3556	0.3551	0.3553	0.3553
+ 1 ft	up	570.7	570.3	570.3	570.3	570.3	
	down	186.6	186.6	187.3	187.5	187.2	
1	Albedo	0.3270	0.3272	0.3284	0.3288	0.3282	0.3279
- 1 ft	up	569	568.8	568.8	568.8	568.7	
	down	184.3	184.8	184.3	184.8	184.5	
-1	Albedo	0.3239	0.3249	0.3240	0.3249	0.3244	0.3244
- 2 ft	up	567.4	567.4	567.4	567.4	567.3	
	down	198.8	198.8	199.2	199.2	199.4	
-2	Albedo	0.3504	0.3504	0.3511	0.3511	0.3515	0.3509
- 3 ft	up	564.4	564.4	564.4	564.4	564.4	
	down	202.8	203	203	203.3	203.4	
-3	Albedo	0.3593	0.3597	0.3597	0.3602	0.3604	0.3599
- 4 ft	up	562	562	562.8	562.8	562.8	
	down	203.7	204.4	204.8	204.8	204.9	
-4	Albedo	0.3625	0.3637	0.3639	0.3639	0.3641	0.3636
- 5 ft	up	561.2	561.2	561.2	561.2	561.2	
	down	204.8	204.4	204.8	204.8	204.7	
-5	Albedo	0.3649	0.3642	0.3649	0.3649	0.3648	0.3648
- 6 ft	up	559.6	559	558.4	558	557.6	
	down	204.4	203.9	203	202.4	201.5	
-6	Albedo	0.3653	0.3648	0.3635	0.3627	0.3614	0.3635
None	up	555.7	555.5	555.5	555.3	555.5	
	down	200.8	201.2	201	201	201.1	
	Albedo	0.3613	0.3622	0.3618	0.3620	0.3620	0.3619

Height: 24 inches

Vertical							
	up	513.8	514.2	514.4	514.4	514.1	
	down	186.6	187.2	187.2	187	187.1	
	Albedo	0.3632	0.3641	0.3639	0.3635	0.3639	0.3637
+ 6 ft	up	520.8	521.2	521.6	521.2	521	
	down	188.1	188.6	189	189.2	188.3	
6	Albedo	0.3612	0.3619	0.3623	0.3630	0.3614	0.3620
+ 5 ft	up	523.2	523.6	523.2	522.8	522.9	
	down	190	190.6	189.5	188.8	188.9	
5	Albedo	0.3631	0.3640	0.3622	0.3611	0.3613	0.3623
+ 4 ft	up	519.3	518.9	518.5	518.5	518.6	
	down	184.5	184.9	184.9	185.4	185.2	
4	Albedo	0.3553	0.3563	0.3566	0.3576	0.3571	0.3566
+ 3 ft	up	519.8	520	519.6	519.6	519.9	
	down	187	187	187.2	187.2	187.2	
3	Albedo	0.3598	0.3596	0.3603	0.3603	0.3601	0.3600
+ 2 ft	up	513.3	512.9	512.1	511.7	512.3	
	down	178.8	179.1	178.6	178.8	178.8	
2	Albedo	0.3483	0.3492	0.3488	0.3494	0.3490	0.3489
- 2 ft	up	521.6	521.4	521.2	520.8	521.1	
	down	172.5	172.5	173	173	172.8	
-2	Albedo	0.3307	0.3308	0.3319	0.3322	0.3316	0.3315
- 3 ft	up	504.2	503.4	503.4	502.9	501.9	
	down	176.8	176.6	175.9	176.8	176.8	
-3	Albedo	0.3507	0.3508	0.3494	0.3516	0.3523	0.3509
- 4 ft	up	494.8	494.4	493.6	493.2	494.2	
	down	174.1	173.7	173	172.3	173.7	
-4	Albedo	0.3519	0.3513	0.3505	0.3494	0.3515	0.3509
- 5 ft	up	478.6	478.2	478.2	478.2	478.2	
	down	165.5	165.5	166	166	165.9	
-5	Albedo	0.3458	0.3461	0.3471	0.3471	0.3469	0.3466

- 6 ft	up	476.6	475.8	475.4	475	475.5	
	down	165.8	165.3	165.9	164.9	165.1	
-6	Albedo	0.3479	0.3474	0.3490	0.3472	0.3472	0.3477
None	up	473.9	473.5	473.3	473.1	473	
	down	164.6	164.2	163.7	163.7	163.8	
	Albedo	0.3473	0.3468	0.3459	0.3460	0.3463	0.3465

Horizontal

	up	563.8	563.7	564.2	564.4	564.1	
	down	194.6	194.4	194.3	194.6	194.5	
	Albedo	0.3452	0.3449	0.3444	0.3448	0.3448	0.3448
+ 6 ft	up	565.2	565	564.8	564.8	564.8	
	down	193.4	193.4	193	193.1	193	
6	Albedo	0.3422	0.3423	0.3417	0.3419	0.3417	0.3420
+ 5 ft	up	565.2	565.4	565.2	565.2	565.2	
	down	192.5	192.5	192.5	192.5	192.3	
5	Albedo	0.3406	0.3405	0.3406	0.3406	0.3402	0.3405
+ 4 ft	up	564	564	563.8	563.9	564	
	down	189.8	189.8	189.8	189.8	190.2	
4	Albedo	0.3365	0.3365	0.3366	0.3366	0.3372	0.3367
+ 3 ft	up	564.8	564.4	564.6	564.4	564.4	
	down	186.9	187.1	187.1	187.1	187.1	
3	Albedo	0.3309	0.3315	0.3314	0.3315	0.3315	0.3314
+ 2 ft	up	564	564	563.6	563.8	563.2	
	down	179.9	180	179.9	179.9	179.9	
2	Albedo	0.3190	0.3191	0.3192	0.3191	0.3194	0.3192
+ 1 ft	up	565.1	565.1	565.1	564.9	565	
	down	165.4	166.3	166.5	166.8	166.5	
1	Albedo	0.2927	0.2943	0.2946	0.2953	0.2947	0.2943
- 1 ft	up	566.7	566.9	567.1	566.9	566.8	
	down	171.3	171.7	171.7	171.7	172	
-1	Albedo	0.3023	0.3029	0.3028	0.3029	0.3035	0.3029

- 2 ft	up	566.9	566.9	566.7	566.9	566.8	
	down	184.4	184.4	184.4	184.4	184.4	
-2	Albedo	0.3253	0.3253	0.3254	0.3253	0.3253	0.3253
- 3 ft	up	566.3	566.1	565.7	565.5	565.5	
	down	189.3	189.1	188.9	188.9	188.9	
-3	Albedo	0.3343	0.3340	0.3339	0.3340	0.3340	0.3341
- 4 ft	up	564.3	563.9	563.9	563.9	563.9	
	down	190.2	190.2	190.2	190.2	190.2	
-4	Albedo	0.3371	0.3373	0.3373	0.3373	0.3373	0.3372
- 5 ft	up	563.3	563.3	563.3	562.7	562.6	
	down	191.1	191.1	191.1	190.7	190.5	
-5	Albedo	0.3393	0.3393	0.3393	0.3389	0.3386	0.3391
- 6 ft	up	561.5	561.5	561.5	561.4	561.6	
	down	190.5	190.7	190.7	190.7	190.7	
-6	Albedo	0.3393	0.3396	0.3396	0.3397	0.3396	0.3396
None	up	561.9	561.7	561.5	561.6	561.5	
	down	191.8	191.6	191.6	191.6	191.8	
	Albedo	0.3413	0.3411	0.3412	0.3412	0.3416	0.3413

APPENDIX C: DATA OF INVESTIGATION INFLUENCE ON TINING ON PAVEMENT ALBEDO

Morning

No tining						
up	486.4	486.8	487.2	487	487.7	10:07 AM
down	161.7	162.2	162.2	162.2	161.9	
Albedo	0.332442	0.333196	0.332923	0.33306	0.331966	0.332718
North-South						
up	475.1	475.5	476.5	478.2	477.1	10:14 AM
down	179.7	179.9	180.4	180.8	180.1	
Albedo	0.378236	0.378339	0.378594	0.378084	0.377489	0.378148
West-East						
up	487.4	487.4	487.6	487.9	488.5	10:19 AM
down	183.8	183.4	183.4	183.6	183.9	
Albedo	0.377103	0.376282	0.376128	0.376307	0.376459	0.376456

No tining						
up	496.2	496.4	496.9	496.7	499.3	10:24 AM
down	176.4	176.2	175.7	175.6	176.4	
Albedo	0.355502	0.354956	0.353592	0.353533	0.353295	0.354176
North-South						
up	500.2	500.3	500.7	501	500.9	10:31 AM
down	191.7	191.8	191.6	191.2	191.3	
Albedo	0.383247	0.38337	0.382664	0.381637	0.381913	0.382566
West-East						
up	497.4	498.7	499.9	501	501.8	10:28 AM
down	187.3	187.9	188.6	189.2	189.7	
Albedo	0.376558	0.37678	0.377275	0.377645	0.378039	0.377259

No tining						
up	503.3	502.6	503	503	503.4	10:34 AM
down	179.6	179.4	179.3	179.4	179.5	
Albedo	0.356845	0.356944	0.356461	0.35666	0.356575	0.356697
North-South						
up	511.7	511.9	512.2	512.2	511.9	10:38 AM
down	194.2	194.2	194.2	194.2	194	
Albedo	0.379519	0.379371	0.379149	0.379149	0.37898	0.379234
West-East						
up	509	510.1	510.8	510.5	510.7	10:36 AM
down	190.2	190.6	190.9	190.6	190.8	
Albedo	0.373674	0.373652	0.373727	0.373359	0.373605	0.373604

Noon

No tining						
up	464	463.9	463.1	463.2	462.7	1:32 PM
down	167.6	167.3	167.3	167.3	167.1	
Albedo	0.361207	0.360638	0.361261	0.361183	0.361141	0.361086
North-South						
up	462.4	462.2	462.4	461.8	461.5	1:39 PM
down	176.2	176.1	176.1	175.9	175.9	
Albedo	0.381055	0.381004	0.380839	0.380901	0.381148	0.38099
West-East						
up	461.8	461.8	461.5	461.7	461.8	1:36 PM
down	175	175.9	175.5	175.9	175.9	
Albedo	0.378952	0.380901	0.380282	0.380983	0.380901	0.380404

No tining						
up	454.9	455	455.1	455.2	455.6	1:42 PM
down	163	162.9	162.8	162.8	162.8	
Albedo	0.358321	0.358022	0.357724	0.357645	0.357331	0.357808
North-South						
up	456.6	456.2	455	454.1	454.3	1:48 PM
down	174.6	174.5	173.9	173.6	173.6	
Albedo	0.382392	0.382508	0.382198	0.382295	0.382126	0.382304
West-East						
up	453.7	453.5	452.9	450.8	450.5	1:44 PM
down	171.4	171.4	171.4	170.6	170.5	
Albedo	0.377783	0.377949	0.37845	0.378438	0.378468	0.378218

No tining						
up	452.5	448.9	447.3	446.2	445	1:50 PM
down	160.6	159.9	159.3	159	158.7	
Albedo	0.354917	0.356204	0.356137	0.356342	0.356629	0.356046
North-South						
up	439.3	439.6	441	441.9	441.2	1:55 PM
down	167.9	167.9	168.2	168.7	168.7	
Albedo	0.382199	0.381938	0.381406	0.381761	0.382366	0.381934
West-East						
up	439.5	438	437.5	436.8	435.5	1:53 PM
down	165.3	164.5	164.5	164.5	164	
Albedo	0.376109	0.375571	0.376	0.376603	0.376579	0.376172

Afternoon

No tining						
up	267.2	266.2	265.6	263.8	262.7	3:19 PM
down	100	99.8	99.5	97.9	97.1	
Albedo	0.374251	0.374906	0.374623	0.371114	0.369623	0.372904
North-South						
up	244.8	245.1	244.6	243.9	242.9	3:24 PM
down	97.2	95.9	95.5	95.1	94.3	
Albedo	0.397059	0.391269	0.390433	0.389914	0.388226	0.39138
West-East						
up	250.6	249.5	248.7	248	247.3	3:22 PM
down	97.5	95.9	93.5	94.8	93.8	
Albedo	0.389066	0.384369	0.375955	0.382258	0.379296	0.382189

No tining						
up	240.6	239.8	238.6	237.2	237.3	3:26 PM
down	83.5	81.8	80.5	79	79.2	
Albedo	0.347049	0.341118	0.337385	0.333052	0.333755	0.338472
North-South						
up	227.4	225.3	224.3	223.8	223.4	3:30 PM
down	87.5	86.5	86	85.5	85.5	
Albedo	0.384785	0.383933	0.383415	0.382038	0.382722	0.383378
West-East						
up	196.7	194.7	200	199	203.8	3:28 PM
down	72.3	71.1	70	70.1	68.5	
Albedo	0.367565	0.365177	0.35	0.352261	0.336114	0.354223