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Sources of Heat in Synthetic Turf Systems

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To the Graduate Council:

I am submitting herewith a dissertation written by Adam William Thoms entitled "Sources of Heat in Synthetic Turf Systems." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plants, Soils, and Insects.

John C. Sorochan, Major Professor

We have read this dissertation and recommend its acceptance:

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Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Sources of Heat in Synthetic Turf Systems

A Dissertation Presented for the
Doctor of Philosophy
Degree

The University of Tennessee, Knoxville

Adam William Thoms

August 2015

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ABSTRACT

With options for cooling synthetic turf limited, an outdoor experiment was conducted at the University of Tennessee Center for Athletic Field Safety (Knoxville, TN) to develop a model to predict maximum, minimum, and mean synthetic turf surface temperature using forecasted atmospheric conditions. Synthetic turf surface temperature varied due to both air temperature and solar radiation. Predictive models using these data accounted for 86, 95, and 94% of the variation in daily maximum, minimum, and mean synthetic turf surface temperature. Accuracy of these models for predicting daily mean and minimum synthetic turf surface temperature using 48 and 72-hour forecasted air temperature data was ± 1 °C, while the daily maximum synthetic turf temperature (± 4.7 to 5.3 °C) was less accurate.

Infilled synthetic turf contains several components that may affect surface temperature including the aggregate base layer, crumb rubber and silica sand infill, synthetic turf backing, and polyethylene pile fibers themselves. In a glasshouse study at the University of Tennessee (Knoxville, TN) each component of an infilled synthetic turf system was placed in a controlled rise temperature chamber for 4 hours with surface temperature monitored. Surface temperatures for components containing pile fibers were 15 °C greater than those without fibers. No differences in temperature were observed among fibers with and without crumb rubber infill. These data indicate that fibers affect surface temperature on synthetic turf more than other components.

Research was also conducted at the University of Tennessee investigating methods for reducing surface temperature on infilled synthetic turf again in a controlled temperature rise chamber for 4 hours, including the use of reflective pigments, fans, and water absorbent pads placed below the turf surface. Results from this study indicate the greatest reduction in surface

temperature (32 °C compared to the control) was the fan applying forced air to the surface. In addition, reflective pigments and sub-surface forced air applied through the aggregate base each offered lower surface temperatures than the non-treated control. Applications of forced air to the surface were further tested in a field study. In the field studies, the forced air significantly reduced surface temperature compared to non-treated controls.

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INTRODUCTION

BACKGROUND

Synthetic turf playing surfaces were originally developed for inner-city children to become more physically fit in the 1960's (Morehouse, 1992). Many inner-city areas lacked green spaces for children to play; the result was a difference in physical fitness of rural children compared to inner-city children. The Ford Foundation and Chemstrand worked to create a playing surface that would be able to tolerate heavy foot traffic and would be easy to maintain while being used year-round. One of the earliest and most noteworthy installations of synthetic turf was in the Houston Astrodome (Levy et al., 1990). The popularity of this installation resulted in synthetic turf being known as AstroTurf (Morehouse, 1990).

Early synthetic turf consisted of 12.7 mm tall green nylon fibers knitted through a polyester backing with a foam pad glued over asphalt (Morehouse, 1992). This new, low maintenance playing surface soon was installed in several cities around the United States, and led to two other companies producing a similar synthetic turf product (Morehouse, 1992). Tartan Turf (3M Company, Minneapolis, MN) used lower denier (mass in g of 9000 m of yarn) nylon fibers glued over a polyurethane pad turf; while, Poly-Turf (American Biltrite; Wellesley, MA) used polypropylene fibers which would mat down over a solid virgin vinyl layer over a pad (Levy et al., 1990; Spinney and Warnalis, 1972). In Europe, Poligras (Adolff Co; Germany) developed a synthetic turf for soccer and field hockey (Serensits et al., 2013).

A second-generation of synthetic turf was introduced in the mid-1970's and early-1980's with taller fibers and silica sand infill. Omniturf (Synthetic Turf International; Dalton, GA) is an example of this system; the surface was comprised of 25.5 mm tall slit-film polypropylene fibers filled with silica sand to keep the fibers upright and to provide enough ballast to keep the turf in place (Serensits et al., 2013). These second generation synthetic turf systems had very

high surface hardness levels and were abrasive, which limited installations in the United States (Serensits et al., 2013).

Third generation synthetic turf surfaces used since 1997 generally consist of a carpet pile of nylon and polyethylene fibers attached to a polypropylene or polyester woven backing (Lim and Walker, 2009). Holes are punched in the backing to allow for water infiltration. This generation of turf is typically laid over a stone or soil base (Lim and Walker, 2009). To help the fibers stand up, reduce surface hardness, and provide ballast, a combination of crumb rubber and silica sand are used as infill (Lim and Walker, 2009).

When exposed to solar radiation, synthetic turf surface temperature increases significantly (Buskirk et al., 1971; Koon et al., 1971; Kandelin et al., 1976, Williams and Pulley, 2002; Akoi, 2005; Devitt et al., 2007; McNitt et al., 2008; Petrass et al., 2014). Buskirk et al. (1971) reported non-infilled synthetic turf surface temperatures 35 to 60 °C higher than nearby natural grass. On infilled synthetic turf, temperatures ranging from 70 to 93 °C have been reported in Utah, Tennessee, and Pennsylvania (Williams and Pulley, 2002; Thoms et al., 2014; McNitt et al., 2008). However, little is known as to what causes these increased temperatures and how to cool the surfaces.

Elevated surface temperatures on synthetic turf can affect shoe-to-surface interactions involved in lower body injury incidence as well (Torg et al. 1996; Kent et al., 2012). Meyers and Barnhill (2004) reported increased high school football injury incidence rates on infilled synthetic turf in Texas (compared to natural turfgrass) when temperatures ranged from 27 to 37 °C.

Since 1990, there have been 38 high school and college football player fatalities attributed to heat illness (Boden et al., 2013). Cutaneous thermal injury can happen at surface temperatures

above 44 °C, and second degree burns can happen following 35 sec of exposure to surface temperatures above 77.5 °C (Harrington et al., 1995). Numerous researchers have reported synthetic turf surface temperatures greater than this 44 °C threshold (Williams and Pulley 2002; Thoms et al., 2012; McNitt et al., 2008).

The objective of this research was to explore three strategies: develop a temperature model to predict synthetic turf surface temperature, determine what synthetic turf components add to increased surface temperature, and evaluate alternate methods for lowering synthetic turf surface temperature.

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**CHAPTER 1: MODELS FOR PREDICTING SURFACE TEMPERATURES
ON SYNTHETIC TURF PLAYING SURFACES**

This chapter is based on a paper published on July 09, 2014 by Adam W. Thoms, James T. Brosnan, Jeremy M. Zidek, and John C. Sorochan:

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My primary contributions to this paper include (i) Discovering the concept (ii) Design and conducting the experiments, (iii) processing, analyzing and interpreting data, (iv) reading literature, (v) writing the manuscript

ABSTRACT

Despite widespread use on athletic fields, synthetic turf surface temperatures are considerably higher than those measured on natural turfgrass when exposed to solar radiation. Elevated temperatures may pose health risks to athletes competing on synthetic turf. Research was conducted at the University of Tennessee Centre for Athletic Field Safety to create a model for predicting synthetic turf surface temperature using atmospheric data. Synthetic turf surface temperature was measured on ten different synthetic turf plots (42 m²) varying in fibre type and infill characteristics. Plots were arranged in a randomized complete block design with three replications. Two temperature sensors placed in the centre of each plot measured surface temperature on 10-min intervals for three 8-week periods over the course of 2 years.

Atmospheric data including air temperature (°C), relative humidity (%), precipitation (mm), and solar radiation (W m⁻²) were collected on the same interval. Synthetic turf surface temperature varied due to both air temperature and solar radiation. Predictive models using these data accounted for 86, 95, and 94% of the variation in daily maximum, minimum, and mean synthetic

turf surface temperature. Accuracy of these models for predicting daily mean and minimum synthetic turf surface temperature using 48 and 72-h forecasted air temperature data was excellent (± 1 °C). Models using 48 and 72-h forecasted were less accurate in predicting daily maximum synthetic turf surface temperature (± 4.75 to 5.33 °C). Our findings indicate that 72 h forecasted air temperature data can be used to predict daily minimum and mean surface temperature of synthetic turf. Such models could be used to schedule athletic events around periods of potentially hazardous surface temperatures.

INTRODUCTION

The first major synthetic turf playing surface was used in the Houston Astrodome in 1966 (Whitehurst, 1968). This surface was comprised of 12.7 mm long nylon fibres, stitched to a denier of 500 into a polyester nylon backing (Levy et al., 1990). A rubber pad underneath the backing consisted of a 15.9 mm thick layer of closed cell nitrile rubber with polyvinyl chloride. Since then synthetic turf playing surfaces have been modified to improve aesthetics, shock attenuation, and ball roll characteristics (Levy et al., 1990; Lim and Walker, 2009). Modern synthetic turf systems are comprised of longer fibres (5.7 cm) infilled with mixtures of crumb rubber and sand (Thoms et al., 2012). Improvements in synthetic turf technology have been accompanied by increased use on athletic fields. Over 1,000 synthetic playing surfaces are installed each year in the United States alone (Miller, 2009).

One major drawback to use of synthetic turf on athletic fields is elevated surface temperatures compared to natural turfgrass (Lim and Walker, 2009). Urban temperature modelling of areas where natural turfgrass cover has been removed and replaced with synthetic turf has demonstrated an increase in atmospheric temperature up to 4 °C (Yaghoobin et al., 2010). Lim and Walker (2009) reported surface temperatures above 65.6 °C on infilled synthetic turf athletic fields during August. Williams and Pulley (2006) suggested that electromagnetic radiation affects infilled synthetic turf surface temperature more than ambient air temperature after measuring surface temperatures > 90 °C at ambient air temperatures of 36.7 °C. White lines and shaded areas on football field's measure lower in surface temperature than areas colored with green pigment due to variability in light reflectance and solar radiation intensity (Williams and Pulley, 2006). Even non-infilled synthetic turf temperatures have been found to exceed those measured on natural turfgrass by 35 to 60 °C (Buskirk et al., 1971).

Elevated surface temperatures on synthetic turf can affect shoe-to-surface interactions involved in lower body injury incidence (Torg et al., 1996; Kent et al., 2012). Meyers and Barnhill (2004) reported increased high school football injury incidence rates on infilled synthetic turf in Texas (compared to natural turfgrass) when temperatures ranged from 27 to 37 °C. Later research by Meyers (2010) reported that collegiate football injury incidence rates were lower on infilled synthetic turf than natural turfgrass when temperatures exceeded 21 °C; however, different natural and infilled synthetic turf surfaces were used in the work of Meyers (2010) and Meyers and Barnhill (2004). Buskirk et al. (1971) placed thermocouples on the soles of cleats to determine that heat transfer from surface-to-athlete was significant enough to cause heat-related health concerns independent of the air temperature one meter above the playing surface. DeVitt et al. (2007) recorded hazardous surface temperatures (> 75 °C) on infilled synthetic turf. Since 1990 there have been 38 high school and college football player fatalities attributed to heat illness (Boden et al., 2013). Cutaneous thermal injury can happen at surface temperatures above 44 °C, and second degree burns can happen following 35 sec of exposure to surface temperatures above 77.5 °C (Harrington et al., 1995). Numerous researchers have reported synthetic turf surface temperatures greater than this 44 °C threshold (Williams and Pulley, 2006; Thoms et al., 2012; McNitt et al., 2008).

Efforts have been made to cool synthetic turf playing surfaces using overhead irrigation. Williams and Pulley (2002) reported 30 min of irrigation reduced infilled synthetic turf surface temperature to that of natural turfgrass located near the trial site; however, this reduction lasted only 5 min after irrigation ceased. McNitt et al. (2008) observed that irrigation reduced infilled synthetic turf surface temperature by 30 °C for up to 20 min. However, McNitt et al. (2008) did note that surface temperatures on irrigated infilled synthetic turf were lower than non-irrigated

synthetic turf for approximately 3 h. The researchers suggested that the duration of synthetic turf surface cooling from irrigation is dependent on environmental conditions such as wind speed, ambient temperature, and solar radiation (McNitt et al., 2008). Besides limited efficacy, increased surface wetness from irrigation can reduce shoe traction on synthetic turf leading to injury (Niebel et al., 1973; Heidt et al., 1996; McNitt, 2005).

Certain municipalities are restricting play on synthetic turf athletic fields during periods of potentially hazardous surface temperatures. For example, infilled synthetic turf athletic fields at Brigham Young University (Provo, UT) cannot be used when surface temperatures exceed 49 °C (Lim and Walker, 2009). A tool to accurately predict synthetic turf surface temperature would aid turf managers in scheduling field use around time periods where surface temperatures are potentially hazardous to athletes. Considering that atmospheric conditions (i.e., solar radiation, air temperature, etc.) can affect synthetic turf surface temperature (Lim and Walker, 2009), our objective was to build a model to predict synthetic turf surface temperature using these atmospheric data.

MATERIALS AND METHODS

Research was conducted on ten synthetic turf surfaces at the University of Tennessee Centre for Athletic Field Safety (Knoxville, TN). Plots (4.6 by 9.1 m) were constructed on a 15.2 cm deep base of washed aggregate (25 to 2.4 mm diameter) capped with 5.1 cm of fine aggregate (9.5 to 0.3 mm diameter) on 12 April 2011. Ten different synthetic turf playing surfaces (**Table 1.1**) were installed on 12 April 2011. These synthetic surfaces were infilled with sand (2 mm to 0.05 mm diameter) and crumb rubber particles (2 mm to 0.15 mm diameter) on 21 April 2011. Sand-to-rubber infill ratios are presented in Table 1.1.

Synthetic turf surface temperatures were measured during three time periods: 22 August to 20 October 2011; 14 February to 12 April 2012; and 25 May to 27 July 2012. During each time period, surface temperature data were collected using two sensors (TidbiT v2 Temp Logger; Onset Computer Corp., Bourne, MA) placed in the centre of each plot to prevent an edge effect. Data were collected on 10-min intervals from midnight to midnight local time. Atmospheric data including air temperature ($^{\circ}\text{C}$), relative humidity (%), precipitation (mm), and solar radiation (W m^{-2}) were collected on the same interval using a weather station and solar pyranometer (HOBO U30; Onset Computer Corp., Bourne, MA) located 457 m from the field site located over mowed grass away from buildings. Air temperature readings were shaded from direct solar radiation, and the pyrometer was installed to manufacturer specifications.

Forecast data were collected from the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) using the National Centres for Environmental Prediction (NCEP) Global Forecast Systems (GFS) Model Output Statistics (MOS) short range model, known as GFS-MOS. This model is valid for 6 to 72 h from time of release in the United States, Puerto Rico, and the US Virgin Islands. MOS is a technique used to objectively interpret numerical model output and produce site-specific guidance (Anonymous, 2013). The forecast data used in this project were valid for the Knoxville, TN NOAA-NWS weather station located at 35.82° N and 83.98° W . Daily forecast data were collected for each of the time periods that surface temperature data were collected (22 August to 20 October 2011; 14 February to 12 April 2012; and 25 May to 27 July 2012).

Maximum, minimum, and mean surface temperature data were collected and subjected to ANOVA in SAS (SAS Institute, Cary, NC) at $\alpha = 0.05$. Multivariate linear regression was conducted in Minitab (Minitab Inc. State College, PA) at the $\alpha = 0.05$ significance level in order

to determine atmospheric parameters (i.e., air temperature, relative humidity, precipitation, and solar radiation) that could be used to predict daily maximum, minimum, and mean synthetic turf surface temperature. Models offering the highest R^2 values were selected for further evaluation using GFS-MOS forecast data.

GFS-MOS forecast data were incorporated into these multivariate linear regression models to predict maximum, minimum, and mean synthetic turf surface temperature. Forecasted cloud cover data were converted into an aggregated daily radiation maximum using three and six hourly time-steps. GFS-MOS provides forecasts for cloud cover as: clear, few clouds, scattered clouds, broken clouds, and overcast clouds. NWS defines these classifications in units of octa, with an octa defined as the fraction of the sky that is covered by clouds; thus, 1 octa is equivalent to 1/8 of the sky covered by clouds. Using this system, cloud cover classifications were defined as follows: 1) Clear: 0 octas; 2) Few: > 0 to 2 octas; 3) Scattered: > 2 to 4 octas; 4) Broken: >4 to 8 octas; and 5) Overcast: 8 octas. The following percentage sky cover conventions were used for this research: Clear: 0 %, Few: 10%, Scattered: 40%, Broken: 80%, Overcast: 100%. Cloud cover data were then correlated to solar radiation values from which a maximum forecasted radiation was estimated according to the methods of (Davies and McKay, 1989). Our model to predict maximum synthetic turf temperature was run using 24, 48, and 72 h forecasted maximum air temperature and solar radiation data. For minimum synthetic turf temperature, only minimum forecasted 48, and 72 h air temperature data were used as predictor variables considering that solar radiation is not present when minimum temperatures are observed on synthetic turf. Additionally, use of 24-h forecast data was not possible for our minimum synthetic turf surface temperature model due to the fact that minimum temperature occurred prior to the forecast initialization point for the first day (J. Zidek, personal observation). Similarly, our mean

synthetic turf temperature model was evaluated using only 48 and 72 h forecasted mean air temperature and solar radiation values. Model accuracy was quantified using R (version 2.15.1; Institute for Statistics and Computing, Vienna, Austria).

RESULTS AND DISCUSSION

Synthetic turf surface temperatures observed in this study ranged from -9.8 to 86.4 °C at ambient air temperatures ranging from -0.4 to 37.1 °C. Despite differences in infill ratios of crumb rubber to sand (0 kg m⁻² to up to 34.2 kg m⁻² of crumb rubber and sand), synthetic turf surface temperatures varied less than 6 °C between the systems suggesting that synthetic turf infill does not affect surface temperature as much as fibres. These findings are similar to what McNitt (2005) reported. Peak surface temperature in this study was higher than those measured by other researchers (Lim and Walker, 2009; Meyers and Barnhill, 2004). This difference may be due to variability in the synthetic turf surfaces evaluated among researchers, differences in ambient air temperature during data collection, or a combination thereof. Peak surface temperature in our study was similar to the 93 °C measured by Williams and Pulley (2006) at an ambient air temperature of 37 °C.

Absorption of solar radiation may explain increased temperatures on synthetic turf surfaces compared to ambient air. Nearly 98% of solar radiation falls within the middle ultraviolet (200 to 315 nm) to near infrared spectrum (720 nm to 0.00015 cm) (Robinson, 1966). Under conditions of maximal absorption, exposure to high intensity short wavelength radiation of this nature will increase temperature more than exposure to longer wavelengths at low intensity (Robinson, 1966). Considering that synthetic turf fibres are extruded polyethylene, dyed green to mimic

natural turfgrass, high rates of solar radiation are likely absorbed on synthetic turf with minimal light reflectance (Williams and Pulley, 2006). This could explain why surface temperatures on synthetic turf exceed those measured in ambient air.

Models to predict maximum and minimum surface temperature

Models using air temperature and solar radiation accounted for a significant percentage of the variability in synthetic turf surface temperature data in this study, with R^2 -values ranging from 0.87 to 0.95 (**Table 1.2**). Our findings support those of other researchers that solar radiation affects maximum synthetic turf surface temperature (Williams and Pulley, 2006; McNitt et al., 2008; Lim and Walker, 2009).

Interestingly, models to predict daily minimum synthetic turf surface temperature were most accurate when only the minimum forecasted temperature data were used as a predictor (**Table 1.2**). Additionally, R^2 -values were higher for models predicting minimum rather than maximum synthetic turf surface temperature (**Table 1.2**). Minimum synthetic turf surface temperatures occurred during hours without solar radiation (i.e. darkness) and consequently less evaporation, humidity, and air movement (Burman and Pochop, 1994). This lack of environmental variation could explain the increased fit of our minimum surface temperature model compared to that used to predict maximum surface temperature.

Accuracy of Surface Temperature Models

Using 24, 48, and 72 h forecasted air temperature and solar radiation data, our model was able to predict daily maximum synthetic turf surface temperature within ± 4.41 °C, ± 5.33 °C, and ± 4.75 °C, respectively. Comparatively, our models were able to predict mean and minimum synthetic turf surface temperature within ± 1 °C using 48 and 72 h forecasted air

temperature and solar radiation data. Reduced accuracy of the maximum temperature model was due to the fact that maximum synthetic turf surface temperature occurs during peak heating hours when wind is present. Conversely, minimum and mean temperatures on synthetic turf surfaces often occur during times of low wind and minimal solar radiation (i.e., darkness). Inclusion of wind speed data may improve the accuracy of the maximum temperature model created in this research; however, wind speed data were not captured in this study.

Our findings indicate that while turf managers can use 72 h forecasted air temperature and solar radiation data to predict daily maximum, minimum, and mean synthetic turf surface temperatures, models focused on minimum or mean synthetic turf surface temperature may be more accurate than those targeting maximum surface temperature.

FUTURE RESEARCH

Our data are limited in that wind speed was not measured in our research. Wind speed can affect skin temperature by increasing evaporative cooling and thus lower heat stress experienced by exercising children (AAP, 2000). Wind speed data could improve accuracy of the maximum synthetic turf surface temperature model presented herein. Future research should include assessments of wind speed when developing models to predict maximum, minimum, and mean surface temperature on synthetic turf. Use of predictive models may also increase efficacy of irrigation for cooling synthetic turf playing surfaces. Models could be used to identify time periods where the need for evaporative cooling is most critical. Future research should evaluate efficacy of irrigation rates and timings in conjunction with predictive synthetic turf surface temperature models. Mention of trade names or commercial products in this publication is solely

for the purpose of providing specific information and does not imply recommendation or endorsement by the University of Tennessee Institute of Agriculture.

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APPENDIX

TABLES

Table 1.1. Synthetic turf surfaces and infill used at the Centre for Athletic Field Safety in Knoxville, TN during 2011 and 2012.

Fibre Type	Fibre Shape	Pile Height (cm)	Yarn	Infill Ratio (kg crumb rubber m ⁻² : kg sand m ⁻²)
			Polyethylene	
Monofilament	Diamond	5.1	and nylon (with thatch)	12.2: 4.9
Monofilament	Diamond	3.2	Nylon	No infill
			Polyethylene	
Monofilament	Horseshoe	5.1	and nylon (with thatch)	12.2: 4.9
Monofilament	Diamond	5.7	Polyethylene	13.7: 4.9
			Exp.	
Monofilament	Horseshoe	5.1	Polyethylene and nylon (with thatch)	12.2: 4.9
Slit film	Slit	5.7	Polyethylene	19.5: 14.7
			Exp.	
Monofilament	Horseshoe	5.7	Polyethylene	13.7: 4.9
Monofilament	Horseshoe	5.7	Polyethylene	13.7: 4.9

Table 1.1. Continued. Synthetic turf surfaces and infill used at the Centre for Athletic Field Safety in Knoxville, TN during 2011 and 2012.

Fibre Type	Fibre Shape	Pile Height (cm)	Yarn	Infill Ratio (kg crumb rubber m ⁻² : kg sand m ⁻²)
Monofilament/ Slit film	Slit/Horseshoe	5.1	Exp. Polyethylene and nylon	12.2: 4.9
Slit film	Slit	5.1	Exp. Polyethylene and nylon (with thatch)	12.2: 4.9

Table 1.2. Daily models for predicting maximum, mean, and minimum surface temperatures on synthetic turf surfaces at the Centre for Athletic Field Safety in Knoxville, TN during 2011 and 2012.

Synthetic Turf Surface Temperature Model	R ² -value
$\text{TurfMax}^1 = -10.25 + (1.622 * \text{Max forecasted temperature } ^\circ\text{C}) + (0.023 * \text{Max forecasted solar radiation W/m}^2)$	0.87
$\text{TurfMean}^2 = 0.58 + (0.948 * \text{Mean forecasted temperature } ^\circ\text{C}) + (0.035 * \text{Mean forecasted solar radiation W/m}^2)$	0.95
$\text{TurfMin}^3 = -0.73 + (0.98 * \text{Minimum forecasted temperature } ^\circ\text{C})$	0.94

¹TurfMax= maximum synthetic turf surface temperature in °C.

²TurfMean= average synthetic turf surface temperature in °C.

³TurfMin= minimum synthetic turf surface temperature in °C.

CHAPTER 2: LABORATORY EVALUATION OF SYNTHETIC TURF
COMPONENTS TO BETTER UNDERSTAND ARTIFICIAL TURF
SURFACE TEMPERATURE

This chapter is based on a paper that will be submitted for publication by Adam Thoms, John Sorochan, James Brosnan, Dean Kopsell, Brandon Horvath, and Jaehoon Lee:

Thoms, A.W., J.C. Sorochan, J.T. Brosnan, D.A. Kopsell, B.J. Horvath and J.Lee. 2015.

Laboratory Evaluation of Synthetic Turf Components to Better Understand Artificial Turf Surface Temperature.

My primary contributions to this paper include (i) Discovering the concept (ii) Design and conducting the experiments, (iii) processing, analyzing and interpreting data, (iv) reading literature, (v) writing the manuscript

ABSTRACT

Elevated solar radiation and ambient air temperature increase surface temperature on synthetic turf playing surfaces. However, effects of synthetic turf surface components (i.e., aggregate base, polyurethane backing, polyethylene pile fibers, black crumb rubber mixed with silica sand) on surface temperature are not well understood. Research was conducted at the University of Tennessee in 2013 to examine the effects of each component (alone and in combination with one another) on surface temperature in response to a controlled temperature rise. A companion study evaluated treatments applied to each component to lower surface temperature including: reflective paint pigments applied to the pile fibers, forced air applied through the aggregate base, forced air applied to the pile fibers, and evaporation of water from an absorbent pad under turf backing. Surface temperatures for components containing pile fibers were 15 °C greater than those measured when pile fibers were absent. No differences in temperature were observed

among fibers with and without crumb rubber infill. These data indicate that pile fibers affect surface temperature on synthetic turf more than other components such as aggregate base, polyurethane backing, or infill. This response suggests that forced air application to synthetic turf may be able to significantly reduce surface temperature. Field research is warranted to validate these results in outdoor atmospheric conditions.

INTRODUCTION

When exposed to solar radiation, synthetic turf surface temperature increases significantly (Buskirk et al., 1971; Koon et al., 1971; Kandelin et al., 1976, Williams and Pulley, 2002; Akoi, 2005; Devitt et al., 2007; McNitt et al., 2008; Petrass et al., 2014). Buskirk et al. (1971) reported non-infilled synthetic turf surface temperatures 35 to 60 °C higher than nearby natural grass. On infilled synthetic turf, temperatures ranging from 70 to 93 °C have been reported in Utah, Tennessee, and Pennsylvania (Williams and Pulley, 2002; Thoms et al., 2014; McNitt et al., 2008). The New York City Department of Health and Mental Hygiene recognized excessive surface temperatures as the number one concern with third-generation synthetic turf (Denly et al., 2008).

Increased surface temperature can negatively affect athlete performance and safety, considering that increased heat in an athlete's foot must be dissipated by blood flow. Using thermocouples on the soles of cleats, Buskirk et al. (1971) determined that the heat transfer from non-infilled synthetic turf to the athlete was significant enough to contribute to physiological stress that may result in heat related health problems. Torg et al. (1996) and Kent et al. (2012) both reported that increasing surface temperature (11.1 to 43.3 °C and 5.3 to 29.8 °C) changed the shoe-surface interaction increasing the risk of knee and ankle injuries. Meyers and Barnhill (2004) reported higher injury rates on infilled synthetic turf in Texas with air temperature above 21.1 °C. DeVitt et al. (2007) also recorded increased surface temperatures on synthetic turf and indicated the increased potential for heat related stress for athletes. Williams and Pulley (2002) suggested a 49 °C threshold for conducting events on synthetic surfaces because skin injury can occur in less than ten minutes following exposure to 50 °C. Moreover, failure to dissipate heat can result in health problems (Kerr et al., 2013). From 1995 to 2010, 46 football players died

from heat stroke and 9,000 high school athletes are treated each year for heat-related injuries (Mueller and Colgate, 2010; Gilchrist et al., 2010). Increased surface temperature can also negatively affect the environment. Urban temperature modeling of areas where natural turfgrass cover has been removed and replaced with synthetic turf has been shown to increase atmospheric temperature by up to 4 °C (Yaghoobin et al., 2009).

Surface temperatures on synthetic turf are influenced greatly by electromagnetic radiation (light) (Williams and Pulley, 2002). Increased air temperature in urban areas where natural turfgrass cover was replaced with synthetic turf can be directly linked to the differences in solar reflectance (albedo) of turfgrass (0.26) and synthetic turf (0.08) (Yaghoobian et al., 2009). Thoms et al. (2012) reported significant differences between ten different synthetic surfaces during periods of peak solar radiation (12:00-20:00 HR) but not during other times. The ten different synthetic surfaces (9 infilled and 1 non-infilled) had a small range in maximum surface temperature from 49 to 55 °C during the eight-week testing period that began on 22 August 2011.

Solar radiation and air temperature can be used to predict maximum, minimum, and mean surface temperatures on synthetic turf surfaces (Thoms et al., 2014). These explained $\geq 87\%$ of the variation in synthetic turf surface temperature during a 24-week data collection period during 2012-2013. Petrass et al. (2014) and Devitt et al. (2007) reported similar findings with solar radiation, air temperature, and humidity affecting surface temperature. Devitt et al. (2007) reported that solar radiation ($r^2 = 0.95$) accounted for the majority of the variation in infilled synthetic turf surface temperature, even more than air temperature ($r^2 = 0.32$).

Minimal research has explored the source of the heat in synthetic turf surface systems. Petrass et al. (2014) examined 34 different synthetic turf systems in the field, investigating

backing type (latex or polyurethane), tuft gauge (1.6 cm or 1.9 cm), two stitch rates, three pile heights (45, 50, and 60 mm), with or without a shock pad, and infill materials (sand with crumb rubber, sand with organic infill, sand with thermo-plastic elastomer “TPE”). Plots without a shock pad and infill containing sand with TPE had a lower surface temperature (43.4 °C and 42.7 °C) than plots with a shock pad and infill containing sand with black crumb rubber (55.7 °C and 54.0 °C). Petrass et al. (2014) went on to explain that perhaps the shock pad passed the heat energy back into the turf thus raising the temperature and that more water was held longer in the TPE products, but that more research is needed to explain this hypothesis.

While it is well documented that synthetic turf can have elevated surface temperatures during periods of high light, limited peer-reviewed work exists on how to lower these surface temperatures. Previous efforts to lower surface temperature have focused on irrigating the synthetic turf surface (Williams and Pulley, 2002; McNitt et al., 2008; Reasor, 2014). Effects of irrigation is transient, cooling surfaces for a limited period of time. Reflective pigments are commonly used on building materials to lower solar absorption and can reduce surface temperatures by up to 10 °C (Uemoto et al., 2010). These compounds may be able to lower synthetic turf surface temperature by reflecting light waves, constant forced air movement should also be able to lower surface temperature by moving heat off through air movement compared to a control treatment.

The objectives of this study were: 1) to determine effects of synthetic turf surface components on surface temperature; and 2) to investigate alternative ways to cool synthetic turf surfaces aside from irrigation.

MATERIALS AND METHODS

Study 1: Determining Sources of Heat.

Two temperature chambers were constructed according to methods outlined in American Society of Testing and Materials Standard D4803-10, Standard Test Method for Predicting Heat Buildup in PVC Building Products. Chambers were constructed out of plywood and measured 53.3 cm x 33.0 cm x 29.2 cm (+/- 25 mm). The front and top of the chamber remained open, while interior walls were lined with rigid hydrous calcium silicate heat insulation (25.4-mm thick). A 250-watt white infrared heat lamp (General Electric, Fairfield, CT) provided the source of heat and light. The base of the bulb was 39.4 cm (+/- 2.5cm) from the bottom of the box.

Temperature rise was monitored on components of an infilled synthetic turf system was by placing them into the chamber for 4 h with the heat lamp on. Components tested included an aggregate base, backing alone, pile fibers with backing, and a complete system of aggregate base + pile fibers + backing + crumb rubber infill. The aggregate base was comprised of 15.2 cm layer of gravel (25 to 2.4 mm particle size diameter) capped with 5.1 cm layer of fine gravel (9.5 to 0.3 mm), similar to research plots at the University of Tennessee Center for Athletic Field Safety (CAFS). Backing consisted of multiple layers of woven black polyurethane coated with BioCel (a trademarked process that uses polymers made from natural oils including soy bean oil). Holes are punctured into the backing every 6.3 cm by 7.6 cm spacing to allow for water infiltration from the surface. Pile fibers are stitched through this backing. Pile fibers were a sports green monofilament fiber extruded into a diamond shape fiber (Tencate, Dayton, TN). Pile height measured 5.7 cm and specified face weight of the fibers measured 1,390 g m⁻² (ASTM Test F-1551; Method D-5848). Synthetic turf fibers were extruded from polyethylene yarn and coated with polyurethane (LS21; AstroTurf USA, Dalton, GA). Monofilament fibers were selected to

provide greater temperature rise compared to slit-film fibers (Thoms et al., 2014). Infill was a mixture of black crumb rubber and silica sand blended according to manufacturer specifications at a ratio of 13.7 kg of crumb rubber m^{-2} to 4.9 kg of silica sand m^{-2} (Matthew Boggs AstroTurf USA personal communication, 2013). Crumb rubber particles (Liberty Tire Recycling, Pittsburgh, PA) varied in size from 2 mm to 0.15 mm in diameter with a bulk density of 0.52 g cm^{-3} . Silica sand particles varied from 2 mm to 0.05 mm in diameter with a bulk density of 1.36 g cm^{-3} . Infill was added to the synthetic turf to depth of 34 mm (leaving 23 mm of exposed fibers) using a stiff bristle brush. Infill depth was verified with a three prong infill depth gauge (3 prong digital depth gauge; Canadian Playground Advisory Group. Toronto, ON, Canada).

Experimental design was completely randomized with sampling and three separate controlled temperature rises serving as replications of each treatment (i.e., component). The experiment was repeated in time, once in each chamber.

Study 2: Alternative Methods of Cooling Synthetic Turf.

An additional study was conducted in the aforementioned temperature chambers to investigate alternative methods of lowering synthetic surface temperature other than irrigation. All treatments were conducted on a complete infilled synthetic turf system (aggregate base + pile fibers + backing + crumb rubber infill) as previously described. Treatments included: forced air, a reflective paint pigment, a moisture absorbent pad placed under the backing to facilitate evaporative cooling, and a standard infilled synthetic turf surface as a control.

Forced air was applied using a three-speed pivoting utility blower (655704; Stanley Black and Decker. New Britain, CT) at the highest setting. This utility blower (hereafter referred to as “fan”) supplied 69.6 cubic m of forced air min^{-1} . Forced air was applied immediately after heat

lamps were turned on and allowed to run for 4 h while temperature data were collected. Forced air was applied both the synthetic turf surface (i.e., pile fibers and crumb rubber infill) and the aggregate base. Forced air was applied to the surface by placing the fan along the open edge of the heat chamber. Forced air was applied to the aggregate base using the same fan equipped with a custom made sheet metal baffle connected to a flat drainage tile (53 cm long x 30 cm wide x 2.5 cm in thickness) underneath the aggregate base. The end of the drain away from the baffle was closed off, forcing air to move through prefabricated holes in the drain tile and into the aggregate base.

The green reflective paint pigment (Cobalt Titanate Green Spinel; Shepherd Color Co. Cincinnati, OH) was applied (1200 g) in 7.6 L of base athletic field paint (Extremeline Clear; Pioneer Athletics. Cleveland, OH). This solution was applied to the pile fibers and infill at 0.4 L m^{-2} using a high-pressure airless field painter (FieldLazer S200; Graco Inc. Minneapolis, MN) equipped with a RAC 5 Switch tip (RAC 5; Graco Inc. Minneapolis, MN).

The moisture absorbent pad treatment was applied by placing an absorbent pad (Chilly Pad; Frogg Toggs. Arab, AL) between the aggregate gravel layer and the synthetic turf backing. The absorbent pad was submerged in water for 10 min following wetting guidelines from the manufacturer. This process added 220 ml of water to the pad. The pad was removed from the water and placed under the polyurethane backing, at which time the heat lamps were initiated. At the conclusion of the 4-h data collection period, the absorbent pad was dry to touch as determined by the investigator.

Data Collection.

Preliminary research indicated that a period of 4 h was required to reach maximum surface temperature within the heat chamber. Therefore, in both experiments surface temperature data were collected at five locations for each component in the temperature chamber during the 4 h of exposure to the heat lamp. Temperature was measured with 40-gauge Type J (iron-constantan) or equivalent thermocouple inserted through the bottom of the chamber and extended into the chamber. The thermocouple could bend for installation to each of the components, but did not remain in contact with the component being tested. A hole (25 mm diameter) was cut into the moisture absorbent pad in Study 2 to facilitate placement of the thermocouples. Placement of the heat lamp was directly over the surface being tested. Efforts were made to place the temperature chamber away from paths of direct airflow paths.

Experimental design was completely randomized with sampling and three separate controlled temperature rises serving as replications of each treatment (i.e., component). The experiment was repeated in time, once in each chamber.

Data analysis.

Temperature data over the 4 h time period was subjected to non-linear regression techniques in GraphPad Prism 6 for Windows (GraphPad Software, San Diego, CA). A sums of squares reduction F-test was conducted to compare sums of squares from a global model (all treatments shared the same parameter estimates) to a cumulative model where unique parameter estimates were calculated for each treatment. Maximum surface temperature data from each experiment were subjected to a repeated measures single-factor analysis of variance (ANOVA) in SAS (version 9.3, SAS Institute, Cary, N.C.) at $\alpha=0.05$. Fisher's protected LSD ($\alpha = 0.05$) was used to separate treatment means.

RESULTS AND DISCUSSION

Treatment interactions with sampling or experimental run were not detected ($P \leq 0.05$) in either experiment; therefore, data were combined across experimental runs. Significant differences ($P \leq 0.05$) in surface temperature were detected between treatments in each experiment.

Study 1: Determining Sources of Heat.

Surface temperatures were greatest on components containing pile fibers compared to those without pile fibers (**Table 2.1**). For example, temperature on the polyurethane backing and pile fibers without infill measured 61.1° C, compared to 48.2 °C for the aggregate base only and 54.4 °C for the polyurethane backing without fibers. A similar relationship was observed when comparing polyurethane backing and pile fibers with infill to the aggregate base or backing alone. No differences in temperature were detected between pile fibers and backing with and without infill, suggesting that infill has minimal affect on synthetic turf surface temperature. According to temperature limits set by Williams and Pulley (2002), only the aggregate base would be less than the 49 °C limit deemed safe for play. While surface temperatures in this study did not reach levels reported by Williams and Pulley (2002) and Thoms et al. (2014) in the field, we did observe a significant surface temperature rise in response to light and heat.

Similar to observations from non-infilled synthetic turf systems (Kandelin et al., 1976; Buskirk et al., 1971) our findings indicate that pile fibers affect surface temperature more than other components. Petrass et al. (2014) reported that greater infill depths did not affect surface temperature. However, this study lacked a non-infilled surface for comparison. Petrass et al. (2014) work suggests that burying more of the fiber from solar radiation will not lower the surface temperature. Both Thoms et al. (2012) and McNitt et al. (2008) reported that non-infilled

synthetic turf surface temperature were less than 5 °C different from infilled synthetic turf surface temperature, again indicating that the pile fibers affect temperature rise on synthetic turf more than other components.

Surface temperature over the 4 h period was also compared for each component (**Fig. 2.1**). A significant difference in the change of heating existed between components ($P \leq 0.0001$). The greatest rise in surface temperature per minute was the infilled synthetic turf over an aggregate base (R^2 of 0.54) which was slightly higher than polyurethane backing and pile fibers without infill (R^2 of 0.50). The two best regression fits were with the polyurethane backing only (R^2 of 0.62) and the aggregate base alone (R^2 of 0.84).

Study 2: Alternative Methods of Cooling Synthetic Turf.

Forced air effectively reduced surface temperatures on synthetic turf in this study (**Table 2.2**). Application of forced air reduced surface temperature to 31.5 °C compared to 63.2 °C for the control. The forced air from outside of the heat chamber was blown across surface and this air was much cooler than the surface air. The resulting cooling was from convection cooling, of cooler air being applied to a surface and cooling that surface. When applied to aggregate base, forced air reduced surface temperature to 47.8 °C. Again the forced air was cooler than the air inside of the heat chamber, the result was a lowering of surface temperature through conduction cooling. The cooler base allowed the warmer surface to move heat into the cooler aggregate base layer through conduction cooling and acting as a heat sink. Convection cooling is twice as efficient as conduction cooling, perhaps explaining the large difference in surface temperatures between the surface applied air compared to the aggregate base applied air which relied on conductive cooling.

When looking at forced air applications over the duration of 4h (**Fig. 2.2**) the slope for forced air applications to the surface (0.05) and forced air applied through the aggregate base (0.16) as compared to the control (0.31). The goodness of fit for the nonlinear regression ranged from an R^2 of 0.54 for the control compared to an R^2 of 0.57 for forced air applications to the surface as well as an R^2 of 0.43 for forced air applied through the aggregate base.

Forced air applications to the surface of creeping bentgrass (*Agrostis stolonifera* L.) putting greens has repeatedly been demonstrated to lower the surface temperature (Guertal and Han, 2002; Guertal et al., 2005; Han et al., 2006; Guertal and Han, 2009). Although Petrass et al. (2014) reported wind to have little effect on synthetic turf surface temperature in the field; forced air imparts constant air movement which could alter surface temperature compared to wind that may be intermittent. Our data indicate that that forced air applications directly to synthetic turf surface will have a greater effect on surface temperature than forced air applied through the aggregate base.

Reflective paint treatment also reduced surface temperature (50.3 °C) compared to the control. These results support both Devitt et al. (2007) and Williams and Pulley (2002) who found more reflective colored fibers (white) to measure lower in surface temperature than less reflective colors (green) due to differences in albedo. Uemoto et al. (2010) also reported surfaces coated with reflective pigments to be about 10 °C lower than surfaces that lacked reflective pigments. Devitt et al. (2007) reported less than 10% of incoming radiation between 350-2500 nm wavelengths was reflected from green infilled synthetic turf, perhaps if the reflective pigments are a different color even more solar radiation can be reflected to lower the surface temperature even greater. The change of the reflective pigments over the 4h was (0.17) with an R^2 of 0.55, as compared to the control (0.31) with an R^2 of 0.54.

An absorbent pad placed beneath the polyurethane backing did not reduce surface temperature compared the control. This supports previous reports of limited efficacy for cooling synthetic turf via evaporative cooling (via irrigation) (Reasor, 2014; Williams and Pulley 2002). McNitt et al. (2008) speculated that efficacy of pads may be limited because water is forced to travel a longer distance to affect the synthetic turf surface. The change of the absorbent pad placed beneath the polyurethane backing had a lower slope (0.17) with an R^2 of 0.75. Since water has a very high specific heat ($4.179 \text{ J g } ^\circ\text{C}^{-1}$) the absorbent pad was able to lower the surface temperature compared to the control with the water present (**Fig 2.2**) however, as water evaporated, there was less water present to lower the surface temperature.

Our findings indicate that pile fibers affect surface temperature on synthetic turf more than other components such as aggregate base, polyurethane backing, or infill. Applications of forced air and reflective paint pigments can lower surface temperature in a controlled environment; however, research needs to be conducted in the field to verify this response. Future research should be conducted to see if applications of forced air and reflective pigments to the surface of infilled synthetic turf can lower surface temperature for extended periods of time during periods of high solar radiation.

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APPENDIX
TABLES AND FIGURES

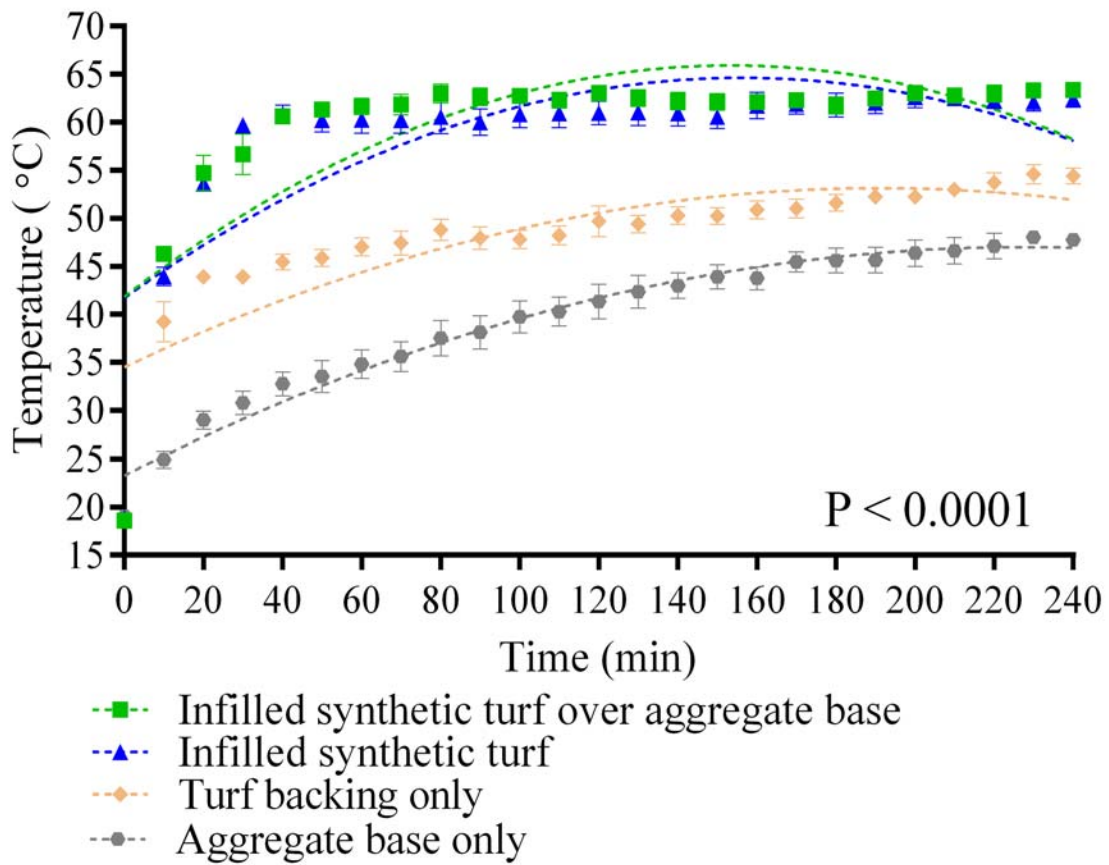


Figure 2.1. Non-linear regression of surface temperature of various synthetic turf components when subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

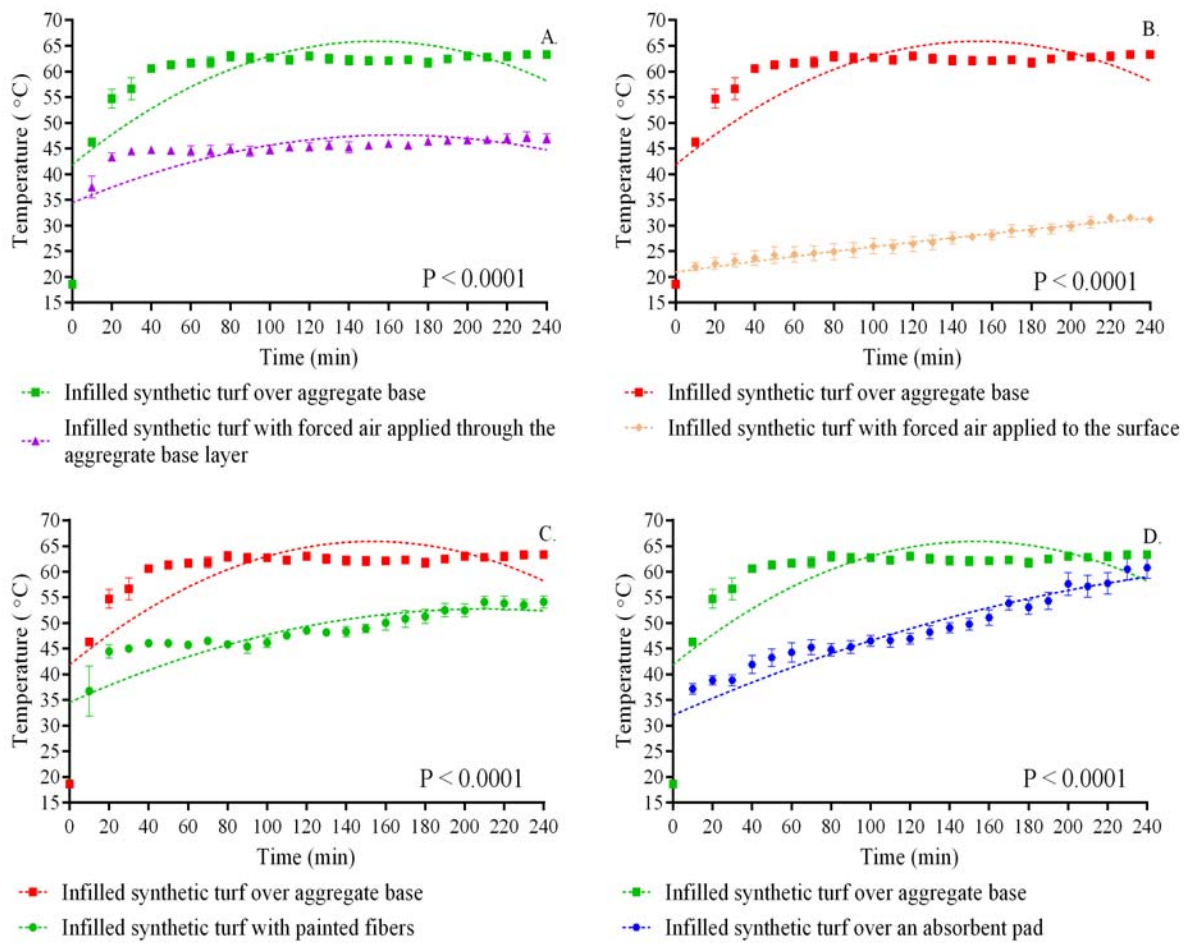


Figure 2.2. Non-linear regression of surface temperature of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Table 2.1. Surface temperature[†] of various synthetic turf components when subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Treatments	Surface Temperature (°C)
Infilled synthetic turf over aggregate base [‡]	63.2 A [§]
Infilled synthetic turf	62.4 A
Synthetic turf without infill	61.1 A
Turf backing only [¶]	54.4 AB
Aggregate base only	48.2 B

[†] Surface temperature was measured with 5 type J 40-gauge thermocouples directly under the heat lamp.

[‡] Synthetic turf consisted of a 5.7 cm tall monofilament diamond shaped synthetic turf infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻² over 15 cm base of washed aggregate (25 to 2.4 mm) capped with 5 cm of fine aggregate (9.5 to 0.3 mm).

[§] Means with the same letter are not significantly different at the $\alpha = 0.05$ level of probability.

[¶] Turf backing consisted of multiple layers of woven black polyurethane coated with BioCel, holes are punctured into the backing every 6.3 cm by 7.6 cm spacing.

Table 2.2. Surface temperature[†] of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Treatments	Surface Temperature (°C)
Infilled synthetic turf [‡]	63.2 A [§]
Infilled synthetic turf over an absorbent pad [¶]	58.8 AB
Infilled synthetic turf with painted fibers [#]	50.3 BC
Infilled synthetic turf with forced air ^{††} applied through the aggregate base layer	47.0 C
Infilled synthetic turf with forced air applied to the surface	31.2 D

† Surface temperature was measured with 5 type J 40-gauge thermocouples directly under the heat lamp.

‡ Synthetic turf consisted of a 5.7 cm tall monofilament diamond shaped synthetic turf with a multiple layers of polyurethane coated with BioCel for a backing. Turf was infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻² over a 15.2 cm deep base of aggregate gravel (25 to 2.4 mm) capped with 5.1 cm of fine aggregate gravel (9.5 to 0.3 mm).

§ Means with the letter are not significantly different at the 0.05 level of probability.

¶ An absorbent pad or cooling towel (Chilly Pad; Frogg Toggs; Arab, AL) soaked with 220 mL of water was placed between the infilled turf and gravel layer before the temperature rise was initiated.

Table 2.2. Footnotes Continued. Surface temperature[†] of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

1200 grams of a green reflective paint pigment (Cobalt Titanate Green Spinel; Shepherd Color Co, Cincinnati, OH) was added to 7.6 liters of base athletic field paint (Extremeline Clear; Pioneer Athletics; Cleveland, OH). The paint was applied at a rate of 0.4 L m⁻² with a high pressure airless field painter (FieldLazer S200; Graco Inc. Minneapolis, MN) using a RAC 5 Switch tip (RAC 5; Graco Inc. Minneapolis, MN) applied to the same turf as used in the infilled synthetic turf.

†† Forced air was supplied by a three-speed pivoting utility blower (655704; Stanley Black and Decker; New Britain, CT) which provided 69.6 cubic m of forced air minute⁻¹ which was running through the duration of the temperature rise.

Table 2.3. Raw surface temperature[†] data of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Run	Rep	Treatment	Sample	Sample	Sample	Sample	Sample
			1	2	3	4	5
1	1	Backing [†]	56.2	55.2	55.9	55.8	57.4
1	2	Backing	50.9	50.7	51.3	55.8	56.1
1	3	Backing	58.1	56.5	56.3	58.1	56.0
2	1	Backing	52.0	51.8	51.7	55.5	51.9
2	2	Backing	50.7	51.6	51.3	56.9	49.4
2	3	Backing	52.6	57.4	55.2	58.2	54.4
1	1	Complete [§]	65.6	64.7	60.4	62.3	60.8
1	2	Complete	60.1	63.3	62.3	64.7	65.2
1	3	Complete	66.4	61.4	65.3	64.2	59.9
2	1	Complete	61.2	59.5	62.3	61.2	59.6
2	2	Complete	62.4	65.3	64.7	61.9	66.6
2	3	Complete	63.2	67.8	66.9	63.4	67.2
1	1	Gravel	52.1	47.9	50.5	48.2	49.3
1	2	Gravel	44.9	50.3	47.5	44.8	46.7
1	3	Gravel	48.3	46.9	47.5	43.4	48.5
2	1	Gravel	45.9	48.3	44.1	44.5	44.4
2	2	Gravel	51.7	49.9	49.2	48.9	50.2

Table 2.3. Continued. Raw surface temperature[†] data of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Run	Rep	Treatment	Sample	Sample	Sample	Sample	Sample
			1	2	3	4	5
2	3	Gravel	45.5	49.2	47.9	46.0	50.1
1	1	Turf only	63.9	60.0	63.7	61.8	59.7
1	2	Turf only	60.1	63.9	56.7	59.6	62.4
1	3	Turf only	65.4	60.9	61.2	62.7	59.6
2	1	Turf only	59.2	62.7	60.4	63.7	60.2
2	2	Turf only	53.9	55.2	60.3	58.4	55.1
2	3	Turf only	67.8	62.4	63.1	65.9	64.0
1	1	Air to base [¶]	51.6	49.2	50.7	50	48.6
1	2	Air to base	45.4	49.3	44.2	48	42.8
1	3	Air to base	40.9	46.7	47.1	47.6	42.7
2	1	Air to base	42.8	45.3	46.7	44.1	45.5
2	2	Air to base	50.2	48	52.7	49	47.3
2	3	Air to base	45.1	52.7	46.1	45.8	43.1
1	1	Surface air	33.1	30.8	35.0	32.5	34.0
1	2	Surface air	27.5	26.7	27.6	32.1	29.2
1	3	Surface air	34.2	32.4	33.2	33.2	32.8
2	1	Surface air	29.2	32.5	29.7	26.2	31.7

Table 2.3. Continued. Raw surface temperature[†] data of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Run	Rep	Treatment	Sample	Sample	Sample	Sample	Sample
			1	2	3	4	5
2	2	Surface air	30.8	32.3	29.9	31.9	31.0
2	3	Surface air	29.5	30.8	32.9	30.1	32.7
1	1	Pad [#]	62.7	65.4	59.4	60.3	61.9
1	2	Pad	61.5	60.7	58.4	57.2	62.1
1	3	Pad	58.3	55.2	58.8	55.3	57.8
2	1	Pad	60.7	63.2	58.5	58.3	61.1
2	2	Pad	54.7	60.5	59.5	59.7	54.0
2	3	Pad	55.7	57.2	54.1	55.7	57.5
1	1	Reflect ^{††}	50.6	46.7	54.0	51.5	49.5
1	2	Reflect	54.5	48.5	52.4	55.2	47.7
1	3	Reflect	49.7	44.5	47.3	48.3	44.6
2	1	Reflect	49.0	44.6	49.6	49.6	48.5
2	2	Reflect	50.3	52.1	52.7	50.9	52.9
2	3	Reflect	52.4	51.1	55.4	50.9	52.7
1	1	Infill	60.4	64.7	59.8	60.8	62.3
1	2	Infill	59.4	61.7	64.8	62.2	63.3
1	3	Infill	63.6	60.5	64.7	58.8	62.2

Table 2.3. Continued. Raw surface temperature[†] data of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

Run	Rep	Treatment	Sample	Sample	Sample	Sample	Sample
			1	2	3	4	5
2	1	Infill	59.2	58.4	59.6	59.3	59.6
2	2	Infill	63.2	64.4	64.7	62.8	65.7
2	3	Infill	64.1	64.9	67.2	65.4	64.9

[†] Surface temperature was measured with 5 type J 40-gauge thermocouples directly under the heat lamp.

[‡] Backing consisted of multiple layers of polyurethane coated with BioCel for a backing.

[§] Complete consisted of synthetic turf 5.7 cm tall monofilament diamond shaped synthetic turf with a multiple layers of polyurethane coated with BioCel for a backing. Turf was infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻² over a 15.2 cm deep base of aggregate gravel (25 to 2.4 mm) capped with 5.1 cm of fine aggregate gravel (9.5 to 0.3 mm).

[¶] Forced air was supplied by a three-speed pivoting utility blower (655704; Stanley Black and Decker; New Britain, CT) which provided 69.6 cubic m of forced air minute⁻¹ which was running through the duration of the temperature rise either to the surface or to the base through the sub-surface.

Table 2.3. Footnotes Continued. Raw surface temperature[†] data of various treatments to attempt to lower surface temperature of infilled synthetic turf subjected to a 4 hour controlled temperature rise in 2013, Knoxville, TN.

An absorbent pad or cooling towel (Chilly Pad; Frogg Toggs; Arab, AL) soaked with 220 mL of water was placed between the infilled turf and gravel layer before the temperature rise was initiated.

†† 1200 grams of a green reflective paint pigment (Cobalt Titanate Green Spinel; Shepherd Color Co, Cincinnati, OH) was added to 7.6 liters of base athletic field paint (Extremeline Clear; Pioneer Athletics; Cleveland, OH). The paint was applied at a rate of 0.4 L m⁻² with a high pressure airless field painter (FieldLazer S200; Graco Inc. Minneapolis, MN) using a RAC 5 Switch tip (RAC 5; Graco Inc. Minneapolis, MN) applied to the same turf as used in the infilled synthetic turf.

**CHAPTER 3: SYNTHETIC TURF SURFACE TEMPERATURE FIELD
EVALUATION USING FORCED AIR**

This chapter is based on a paper that will be submitted for publication by Adam Thoms, John Sorochan, James Brosnan, Dean Kopsell, Jaehoon Lee, and Brandon Horvath:

Thoms, A.W., J.C. Sorochan, J.T. Brosnan, D.A. Kopsell, J. Lee, and B.J. Horvath. 2015. Synthetic Turf Surface Temperature Field Evaluation Using Forced Air.

My primary contributions to this paper include (i) Discovering the concept (ii) Design and conducting the experiments, (iii) processing, analyzing and interpreting data, (iv) reading literature, (v) writing the manuscript

ABSTRACT

Synthetic turf playing surfaces have been in use since 1964. No matter what changes have been made to the turf design, surface temperature has remained a concern when the turf was exposed to sunlight. Previous efforts have focused on trying to lower surface temperature through irrigation, but little investigation has been done on air movement and cooling. Fans have demonstrated the ability to lower temperatures on putting greens in the southeastern United States during summer months. The objective of this study was to determine if synthetic turf surface temperature can be reduced using fans to force air movement across the synthetic turf surface. Research was conducted at the University of Tennessee Center for Athletic Field Safety (Knoxville, TN) during the fall of 2014, which coincided with the highest temperatures experienced during the high school football season in Tennessee. All plots (6 x 4.6 m) were a polyethylene 5.7 cm tall monofilament diamond shape synthetic turf infilled with a blended infill

consisting of 13.7 kg of crumb rubber m^{-2} and 4.9 kg of silica sand m^{-2} . Two treatments were tested: plots that received forced air or plots that did not receive forced air. Plots receiving forced air had significantly lower maximum and minimum surface temperatures on 10 out of 14 dates. Mean surface temperature was calculated during the duration of forced air treatments which resulted in lower surface temperatures ($P < 0.05$) on every rating date for plots that received forced air as compared to those that did not. These results indicate that forced air can slightly lower surface temperatures of synthetic turf playing surfaces. Additional research is needed to evaluate effects of forced air on different synthetic turf playing surfaces, particularly those with slit-film fibers.

INTRODUCTION

Foot traffic is the dominant stress on athletic fields (Minner and Ververde, 2005). Traffic stress often affects a concentrated portion of the playing surface (Cockerham, 1989). Cockerham (1989) reported that 78% of the traffic on a football field occurs on 7% of the playing surface, an area concentrated traffic between the hash marks on the 40 yard line. On natural turf athletic fields, traffic results in both soil compaction and plant wear that reduce turf cover, produce divots, and lower surface uniformity (Carrow and Weicko, 1989; Carrow and Petrovic, 1992). Cockerham et al. (1990) demonstrated that with increasing traffic turfgrass injury rate was increased as well. Soil moisture can also drastically alter the playing surface by lowering traction, lowering surface hardness, and increasing turfgrass wear (Dunn et al., 1994). Reductions in turfgrass cover and increases in surface hardness due to traffic stress have been associated with 50% increased likelihood of suffering a head injury (Brosnan et al., 2014). Players and coaches demand a uniform, safe, and attractive green playing surface at all times (Christians, 2011). As a result, synthetic turf is often used in place of natural turfgrass to provide uniform cover on highly trafficked athletic fields.

Elevated surface temperatures have been a concern on synthetic turf surfaces (exposed to sunlight) for decades (Koon et al. 1971; Kandelin et al. 1976). Original nylon synthetic turf surfaces without any infill measured 35 to 60 °C higher than natural turfgrass (Buskirk et al., 1971). Thermocouples on the soles of athletic shoes were used to determine that the amount of heat transferred from synthetic turf to the athlete, which could contribute to physiological stress that may result in heat related health problems dependent of similar air temperatures 1 m above the playing surface (Buskirk et al., 1971).

Surface temperatures on third-generation synthetic turf (with infill) have been reported to be as high as 93 °C on a day when air temperatures measured 37 °C (Williams and Pulley, 2002). Synthetic turf surface temperatures were greatest between 12:00 and 16:00 HR corresponding to the period of greatest solar radiation (Thoms et al., 2012). Thoms et al. (2014) reported surface temperatures as high as 86.4 °C on infilled synthetic turf, and while turf fibers (monofilament, slit-film, and a combination of monofilament and slit-film) and infill levels in the study varied from 0 kg m to 34.2 kg m⁻² of crumb rubber and sand surface temperatures varied by less than 6 °C. DeVitt et al. (2007) also recorded increased surface temperatures on synthetic turf and indicated the increased potential for heat related stress for athletes. Williams and Pulley (2002) set 49 °C thresholds as the surface temperature limit for conducting events on synthetic surfaces, because it takes less than ten minutes to cause an injury to skin when temperatures rise to 50 °C. The surface temperature of the synthetic turf was so hot that a coach complained of blisters on their feet through the tennis shoes that were being worn.

Exposure to elevated temperatures for prolonged periods of time can cause changes to physiological and regulatory functions of the human body (Laitano et al., 2010). Heat stress can increase both skin and core body temperature, core body temperature increases as low as 1 °C resulted in an increase of 47 heat beats per min as well as reductions in blood and plasma volumes (Laitano et al., 2010). Changes to the core body temperature can happen quicker on children due to their smaller size (mass) and smaller body surface area (Havenith, 2001). These body conditions make children even more susceptible to the high temperature conditions of synthetic fields.

The playing surface characteristics also change at elevated surface temperatures. Torg et al. (1996) and Kent et al. (2012) both reported increasing surface temperature changes the shoe-

surface interaction increasing the risk of injuries to knees and ankles. Meyers and Barnhill (2004) reported higher rates of athlete injury with increased surface temperature on third-generation synthetic playing surfaces in Texas. Orchard and Powell (2003) reported lower rates of ankle sprains, knee sprains, and ACL injuries on synthetic turf in cooler weather than when temperatures were higher, perhaps indicating the surface characteristics change with increased temperatures. A survey of Italian football players showed that individuals disliked playing on synthetic turf during high temperature conditions because the players felt the surface characteristics changed (Zanetti, 2009).

Methods of lowering synthetic turf surface temperature have only been marginally effective. Williams and Pulley (2002) reported that after 30 min of irrigation on an infilled synthetic turf playing surface, the surface temperature was lowered to 29 °C. However, surface temperature rose very quickly, and within 5 min of ending irrigation surface temperature measured 49 °C. McNitt et al. (2008) observed a similar response with 2 cm of irrigation lowering surface temperature by 30 °C for only 20 min for both infilled and non-infilled synthetic turf. While the researchers observed temperatures to increase after 20 min, they did find that irrigation kept synthetic surfaces 10 °C cooler than non-irrigated synthetic turf for 3 h (McNitt et al., 2008). Environmental factors such as wind speed, humidity, solar radiation, and ambient air temperature affect the efficacy of irrigation for reduce synthetic turf surface temperature (McNitt et al., 2008). Reasor (2014) found inconsistent results when attempting to lower infilled synthetic turf surface temperature with irrigation and modifying crumb rubber infill with calcined clay.

Synthetic turf fiber selection can also make a difference in surface temperature. A previous experiment (Thoms et al., 2012) has indicated that a monofilament fiber synthetic turf

surface will be have a greater surface temperature than a slit-film fiber synthetic turf surface or a combination of silt-film fibers and monofilament fibers by up to 6 °C. The lowest surface temperature in the study was a slit-film fiber (5.7 cm tall fiber with the infill at a ratio of 19.5 kg crumb rubber m⁻²:14.7 kg sand m⁻²) which was as tall or taller and had more infill than all other monofilament fibers tested (5.1 to 5.7 cm fiber height and infill ratios of 12.2 kg crumb rubber m⁻²:4.8 kg sand m⁻² to 13.7 kg crumb rubber m⁻²:4.9 kg sand m⁻²). Additionally, when slit-film fibers were added to a monofilament turf, the maximum surface temperatures were lower (51.8 °C) than monofilament fibers alone (54.5 °C) and with similar fiber height and infill ratios (Thoms et al., 2012). These results indicate a slit-film fiber will have a lower surface temperature than a monofilament fiber.

Fans and light applications of water (e.e., synringing) have been used to cool putting green surfaces on golf courses in the southern United States (Guertal and Han, 2009). However, applications of water do not lower the surface temperature of synthetic turf for extended periods of time (Williams and Pulley, 2002; McNitt et al., 2008, Reasor, 2014). Duff and Beard (1966) observed in an un-replicated trial, that air movement reduced surface temperatures of a putting green. Taylor et al. (1994) reported as fans created higher velocities air temperature did not change. Guertal and Han (2002) reported that the effect from running a fan during the hottest part of the day 11:15 to 16:15 HR lasted 4 h after the fan was stopped. The fan treatments produced the greatest difference when air temperature was above 32 °C (Guertal and Han, 2002).

Synthetic turf surface temperatures have been recorded to be the highest between 12:00 and 16:00 HR, regardless of infill or turf type (Thoms et al., 2012). Efforts need to focus on cooling the synthetic surfaces during this period. Therefore the objective of this study was to evaluate if air could be forced across an infilled synthetic turf surface to reduce surface

temperature during the warmest part of the day. The working hypothesis for this experiment is that synthetic turf will have a lower surface temperature during applications of forced air.

MATERIALS AND METHODS

Plot Construction.

An outdoor field study was conducted at the University of Tennessee Center for Athletic Field Safety in Knoxville, TN in the fall of 2014. Plots were constructed in 2010 and 2011 by first removing the native soil (Sequatchie loam; fine-loamy, siliceous semiactive, termic Hapludult) and compacting the remaining sub-base soil with a 0.5% slope. Then a 15 cm base of washed aggregate (25 to 2.4 mm) capped with 5 cm of fine aggregate (9.5 to 0.3 mm) was placed above the soil. A synthetic turf playing surface was installed over the gravel base on 12 April 2011. The synthetic turf was comprised of monofilament, diamond shaped, fibers (Tencate, Dayton, TN) with a pile height of 5.7 cm and a specified face weight of 1,390 g m⁻² (Matthew Boggs personal communication, 2014). Synthetic turf fibers were extruded from polyethylene yarn and coated with polyurethane (Diamond shape; AstroTurf USA, Dalton, GA). Plots were infilled to manufacturer's specifications with a blended mixture of 13.7 kg of crumb rubber m⁻² and 4.9 kg of silica sand m⁻². Crumb rubber particles (Liberty Tire Recycling, Pittsburgh, PA) varied in size from 2 mm to 0.15 mm in diameter and the silica sand particles varied from 2 mm to 0.05 mm in diameter. Before the initiation of the study, synthetic turf plots were groomed and crumb rubber was loosened with a synthetic turf groomer (TurfCare TCA1400; SMG Equipment, Auburn, WA). The research plots were 6 m by 4.6 m.

Treatments.

Two treatments were evaluated in this study: plots that received forced air and those that did not receive forced air. Forced air was added to the synthetic turf surface using a non-oscillating 51 cm box fan (22YK19, Air Circulator, Dayton Electrical Manufacturing, Niles, IL) that produced $184 \text{ m}^3 \text{ min}^{-1}$ of air movement. One fan was set on each end of the plot to provide air movement, and fans were set on 4.6 m spacing from each other (**Figure 3.1**). Forced air treatments were applied on 14 dates, between 22 August 2014 to 10 September 2014. Fans were run when predicted maximum air temperatures were above $29 \text{ }^\circ\text{C}$, similar to Han et al. (2006). Fans were started at 1300 and shut off at 1600 HR. This duration was based methods similar to Guertal et al. (2005).

Data Collection.

Surface temperature data were collected with sensors (TidbitT v2 Temp Logger; Onset Computer Corp., Bourne, MA) placed at either 1.1 m or 2.3 m in a direct line from the fan. Volumetric air movement provided by the fans at the 1.1 m location was $137 \text{ m}^3 \text{ minute}^{-1}$ and $93 \text{ m}^3 \text{ minute}^{-1}$ at the 2.3 m location on a day without natural wind. No correction was done to limit natural wind on this experiment. Data were collected on 10-min intervals, similar to Thoms et al. (2012). Each sensor was waterproof and had a sensitivity range from -20 to $80 \text{ }^\circ\text{C}$ with an accuracy of $\pm 0.2 \text{ }^\circ\text{C}$. Data collection concluded the day after the last treatment on 11 September 2014. Data were removed from the sensors using Hoboware Pro Software (Hoboware Pro version 2, Onset Computer Corp., Bourne, MA). Atmospheric air temperature ($^\circ\text{C}$) was also collected during the experimental time period using a weather station (HOBO U30; Onset Computer Corp., Bourne, MA) located 457 m from the field site located over mowed grass away from buildings.

Since the objective of this study was to evaluate if forced air could cool synthetic turf, data were analyzed for the duration the fans were in operation. During this time period, maximum, minimum, and mean temperature for each data logger was collected and analyzed. This data collection method of examining maximum, minimum, and mean temperatures over a period of time has been used before by Thoms et al. (2014). The mean temperature is the average of the temperatures recorded on each data logger for that time period. Previous literature suggests that synthetic turf surface temperature is not elevated to concerning levels when sunlight is not present at intense levels (Aoki, 2011; Williams and Pulley, 2002; Devitt et al., 2007; McNitt et al., 2008; Petras et al., 2014).

Data analysis.

The statistical design for this study was a randomized complete block design with repeated measures and three replications. Data were subjected to single factor analysis of variance (ANOVA) in SAS (version 9.3, SAS Institute, Cary, N.C.) at $\alpha = 0.05$ level. A significant date-by-treatment interaction was detected so each day is presented separately. Surface temperature means were separated using Fisher's Protected Least Significant Difference.

RESULTS AND DISCUSSION

Maximum Temperature.

Maximum surface temperature was significantly lower on synthetic turf plots subjected to forced air treatments on 10 out of 14 dates (**Table 3.1**). Plots that received the forced air applications yielded a lower maximum temperature (57 °C) compared to the plots that did not have the force air applications (61 °C) on 24 August 2015. Similar results were reported on 2 September 2014 with plots receiving forced air (51 °C) having a lower maximum surface

temperature than plots without force air (60 °C). However on the other eight dates, the significant differences were not as great with temperatures between plots receiving forced air being 5 °C or less lower than plots not receiving forced air. Guertal et al. (2005) reported a similar response with a combination of forced air and syringing (a light application of water) only reducing the soil temperature of putting greens to 32 °C down from 36 °C. This indicates that perhaps fans can only lower temperature a few degrees, while water can help lower the temperature through evaporative cooling. These results suggest that fans moving 93 m³ min⁻¹ of air movement in the middle of the plots can lower the surface temperature of synthetic turf.

Minimum Temperature.

Minimum surface temperature was statistically lower on 10 out of 14 dates for plots that received forced air applications compared to those without (**Table 3.2**). For example, on 24 August plots that received forced air treatments had a lower minimum surface temperature (40 °C) as compared to those plots that did not receive forced air treatments (44 °C). The largest difference between treatments occurred on 28 August when the plots that received forced air applications (39 °C) measured 7 °C lower than plots without air treatments (46 °C). On all other dates, the difference between plots with and without forced air measured less than 5 °C. These reductions in minimum temperature are similar to those found on creeping bentgrass by Guertal and Han (2002), who reported a reduction of 2 °C for a fan treatment on a putting green as compared to a plot that received no additional air movement.

Mean Temperature.

While sampling location was not a factor for either maximum or minimum surface temperature, a significant treatment-by-sampling location effect for mean surface temperature was detected for 14 of 14 dates. This treatment-by-sampling can be explained since sensors were placed at three locations on each plot. Each plot was divided into half and two sensors were placed in the middle (2.3 m away from a fan), two sensors were also placed 1.1 m away from each plot edge where the fan would be located (**Figure 3.1**). Regardless of temperature sensor location, plots that did not receive forced air treatments varied by only 1 °C (**Table 3.3**). This indicates that surface temperature is fairly uniform across the synthetic turf surface.

On every date the temperature loggers placed nearest to the fans (1.1 m away from the fan) had a lower mean surface temperature than plots that did not receive any forced air regardless of location. Additionally, sensors placed closest to the fan (1.1 m) yielded lower mean surface temperatures than those placed 2.3 m away from the fan. This could be due to the fact that at 1.1 m distance resulted in an air volume moved of $137 \text{ m}^3 \text{ min}^{-1}$ compared to only $93 \text{ m}^3 \text{ min}^{-1}$ at a 2.3 m distance from the fan. These results indicate more research is needed to determine the optimal air velocity ($\text{m}^3 \text{ m}^{-1}$) to reduce surface temperature on synthetic turf since this experiment only tested two air speeds.

Plots receiving forced air yielded lower mean temperature values for the duration of the four hour data collection period compared to plots not receiving forced air. This suggests that forced air may be an improved option for cooling synthetic turf than irrigation, as several researchers have reported transient reductions in cooling with irrigation of less than 60 min (Williams and Pulley, 2002; McNitt et al., 2008; Reasor, 2014). This could be beneficial as in many situations synthetic turf surfaces are installed to reduce water used for turfgrass irrigation

(Synthetic Turf Council FAQ's, 2014), much of California is under a severe drought and outdoor water use is restricted (California.gov, 2014), using surface irrigation to cool a synthetic surface for only a few hours at most could be considered against the law. According to the Southern Nevada Water Authority (2014), 19 L of water per year are saved when converting a square meter of natural turfgrass to synthetic turf, but this water savings does not add up if irrigation is being used to cool the surface.

These results indicate a synthetic turf playing surface temperature can be lowered on a consistent basis with the addition of forced air for extended times during periods of high sunlight. Further efforts also need to be made to determine an optimal air flow rate across the playing surface to maximize the reduction in surface temperature of synthetic turf. Thoms et al. (2012) reported synthetic turf with slit-film fibers yield lower surface temperatures (up to 5 °C) compared to monofilament fibers. Additional research is needed to determine if using a combination of forced air on synthetic turf with slit-film fiber could keep surface temperatures below the 49 °C limit set by Williams and Pulley (2002) for safe athletic field use during periods of high light intensity and ambient air temperature.

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APPENDIX
TABLES AND FIGURES

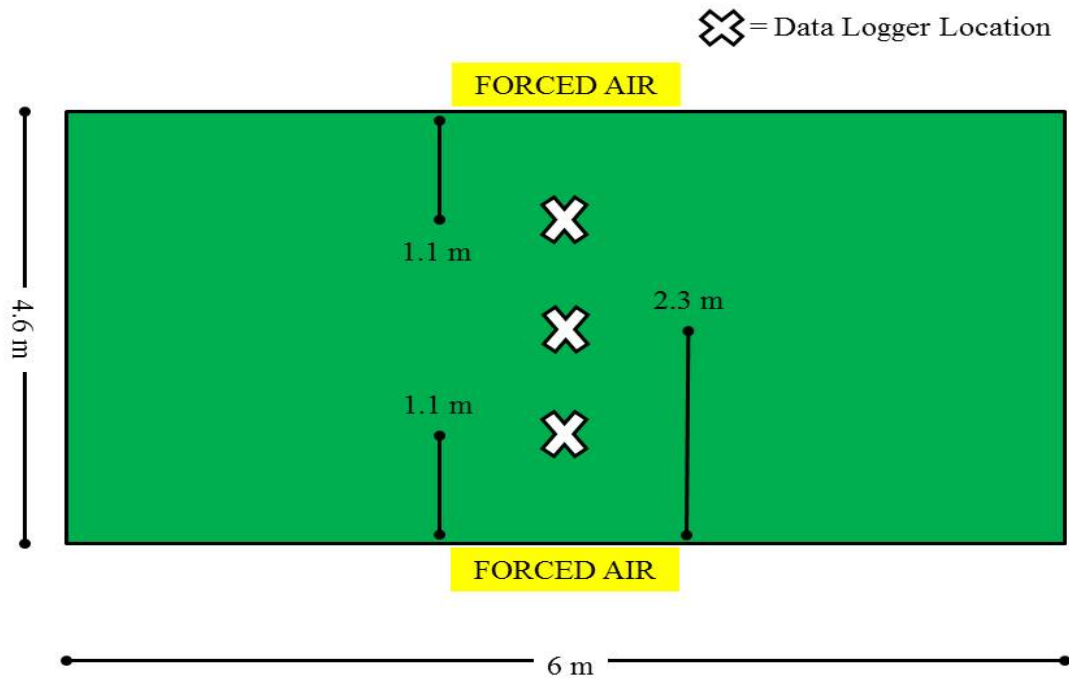


Figure 3.1. Plot map of the 5.7 cm tall monofilament diamond shaped synthetic turf infilled with 13.7 kg of crumb rubber m^{-2} and 4.9 kg silica sand m^{-2} with locations marked for forced air treatments and data logger locations located at the University of Tennessee Center for Athletic Field Safety, Knoxville, TN 2014.

Table 3.1. Maximum surface temperature for infilled synthetic turf[†] subjected to forced air treatments or non-air treated plots in Knoxville, TN 2014.

Dates [‡]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Treatments	Maximum Temperature (°C)													
No Forced Air	61	61	68	69	69	71	61	60	61	63	58	65	56	55
Forced Air [§]	60	57	63	66	66	69	60	51	55	61	54	63	52	54
LSD (0.05)	1.2	2	1.7	1.8	1.7	1.7	1.8	1.6	1.4	1.2	1.9	1.6	1.3	1.4

[†] Synthetic turf consisted of a 5.7 cm tall monofilament diamond shaped synthetic turf infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻².

[‡] Dates for air treatments were as follows: 22, 24, 25, 26, 27, 28, and 29 August and 2, 3, 4, 5, 7, 8, 9, and 10 September 2014.

[§] Forced air treatments were applied with two box fans each providing 186 m³ min⁻¹ of air.

Table 3.2. Minimum surface temperature for infilled synthetic turf[†] subjected to forced air treatments or non-air treated plots in Knoxville, TN 2014.

Dates [‡]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Treatments	Minimum Temperature (°C)													
No Forced														
Air	46	44	46	48	49	46	44	41	41	36	38	46	38	27
Forced Air [§]	44	40	44	45	47	39	44	37	37	35	37	42	38	27
LSD (0.05)	1.0	0.91	1.4	1.5	1.5	1.8	2.0	0.86	0.60	0.47	1.7	1.1	1.7	0.91

[†] Synthetic turf consisted of a 5.7 cm tall monofilament diamond shaped synthetic turf infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻².

[‡] Dates for air treatments were as follows: 22, 24, 25, 26, 27, 28, and 29 August and 2, 3, 4, 5, 7, 8, 9, and 10 September 2014.

[§] Forced air treatments were applied with two box fans each providing 186 m³ min⁻¹ of air.

Table 3.3. Mean surface temperature by sampling location for infilled synthetic turf[†] subjected to forced air treatments or non-air treated plots in Knoxville, TN 2014.

	Dates [‡]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Treatments	Location	Mean Temperature (°C)													
No Forced															
Air	2.3 m from plot edge	54	53	59	62	64	60	56	50	52	51	51	58	50	44
No Forced															
Air	1.1 m from plot edge	54	54	60	62	63	61	56	49	51	51	49	58	49	44
Forced Air [§]	2.3 m from plot edge	54	50	54	57	58	56	56	47	50	47	49	55	49	44
Forced Air	1.1 m from plot edge	48	46	50	52	54	52	49	42	44	43	43	48	42	40
	LSD (0.05)	1.6	1.5	2.3	2.6	2.6	2.0	2.3	2.0	1.4	1.6	2.2	2.0	1.7	1.4

[†] Synthetic turf consisted of a 5.7 cm tall monofilament diamond shaped synthetic turf infilled with 13.7 kg of crumb rubber m⁻² and 4.9 kg silica sand m⁻².

[‡] Dates for air treatments were as follows: 22, 24, 25, 26, 27, 28, and 29 August and 2, 3, 4, 5, 7, 8, 9, and 10 September 2014.

[§] Forced air treatments were applied with two box fans each providing 186 m³ min⁻¹ of air.

CONCLUSIONS

Efforts to improve synthetic turf to be more like natural turfgrass playing surfaces have focused on aesthetics and athlete-to-surface interactions, but little progress has been made on cooling the surface of synthetic turf. In many cases, synthetic turf is installed due to urban water restrictions. Yet, previous efforts to reduce synthetic turf surface temperature have focused on using irrigation as the method for cooling. However, results have shown irrigation has little effect for cooling synthetic turf surfaces. Therefore, efforts need to focus on alternative ways to lower synthetic turf surface temperature without using water.

In order to better understand the causes for increased synthetic turf surface temperature, it was necessary to study each component that comprises third-generation synthetic turf systems. This research study determined that the primary component for increased surface temperatures were the actual synthetic turf fibers.

Forced air applied either to the synthetic turf surface or forced through the sub-surface aggregate base lowered the synthetic turf surface temperature. Synthetic turf painted with reflective pigments also reduced surface temperature compared to the non-treated control. These findings indicate that synthetic turf surface temperatures can be reduced without the use of water. Further research is needed in the field to investigate how much air is needed to cool an entire athletic field, and if reflective pigments could be incorporated into the synthetic turf fibers at manufacturing.

VITA

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