Engineering,
Landscape Architecture
and Environmental Science

MILONE & MACBROOM®

December 1, 2008

To Our Clients and Friends in the Athletic and Parks Community

Over the past year, Milone & MacBroom, Inc. has been studying the water quality, temperature, and air quality of three scholastic athletic fields constructed using synthetic surfaces in-filled with crumb rubber and silica sand. The results of our findings are contained in the attached document.

We hope you find the information useful when considering what type of field surface is appropriate for your program.

Should you have questions, please feel free to contact us.

Sincerely,

MILONE & MACBROOM, INC.

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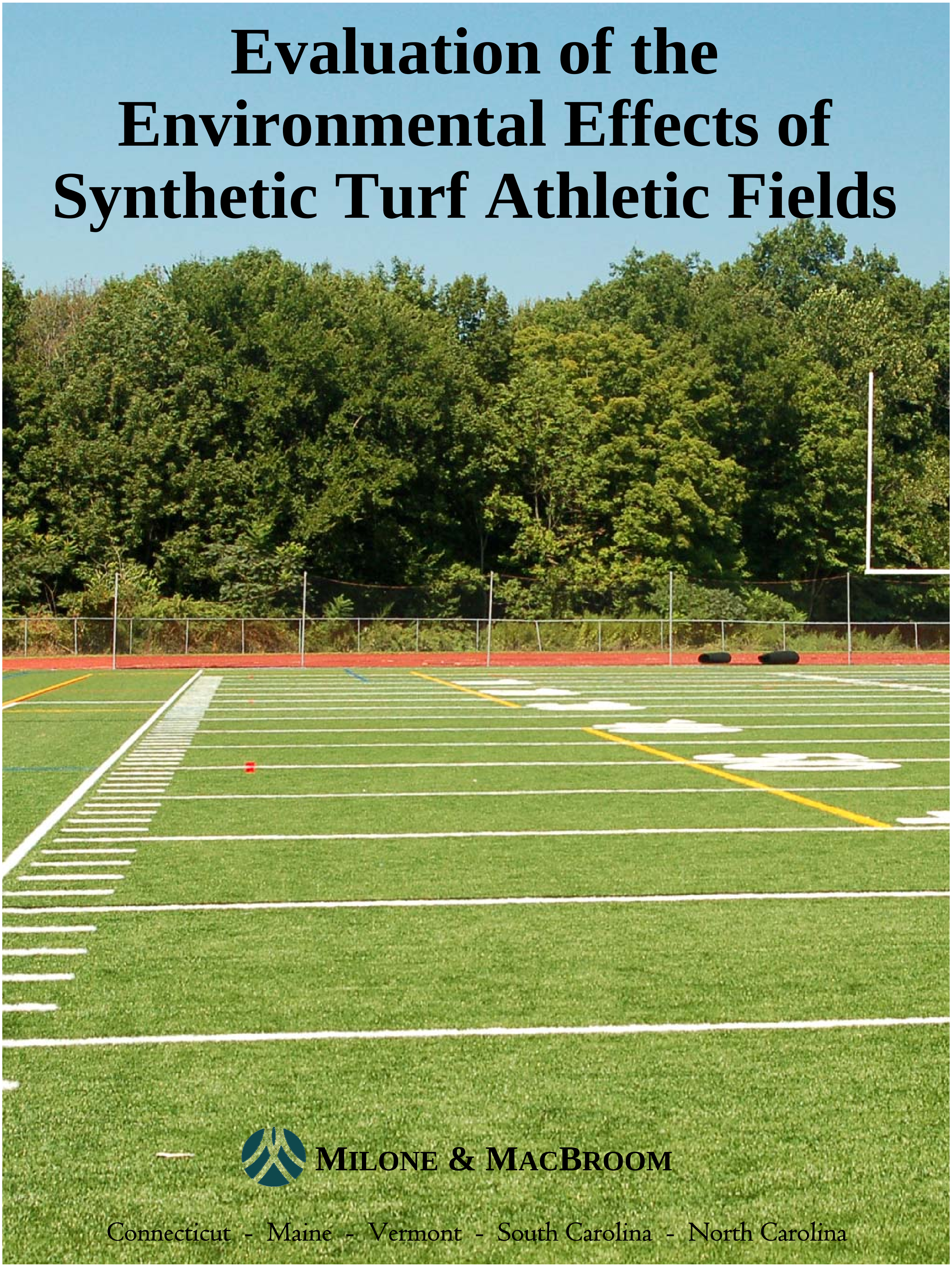
Evaluation of the Environmental Effects of Synthetic Turf Athletic Fields



MILONE & MACBROOM

Connecticut - Maine - Vermont - South Carolina - North Carolina

P R E F A C E

Evaluation of the Environmental Effects of Synthetic Turf Athletic Fields

Over the past year or so, Milone & MacBroom, Inc. (MMI) conducted a variety of tests of synthetic athletic fields in Connecticut in an attempt to contribute to the discussion regarding potential risks to the environment and human health associated with such facilities. In 2007, laboratory tests at the Connecticut Agricultural Experiment Station (CAES) raised a number of questions concerning the safety of such fields. As a company that advises clients and designs athletic fields using both natural grass and synthetic surfaces, Milone & MacBroom, Inc. believed that it would be prudent to undertake some first-hand observations and to become more confident that published literature was applicable to synthetic surfaces in the northeast.

When reading these papers, there are two points that should be clearly understood. First, by undertaking these studies, we are not promoting the installation of synthetic fields but recognize that they are a legitimate alternative to natural grass in some instances. Second, the cost of the testing was totally paid by Milone & MacBroom, Inc. and that the synthetic turf industry has had no involvement whatsoever in our testing program. We did consult, however, with representatives of the Connecticut Department of Public Health regarding testing protocols to be sure that our methodologies and the results of our efforts would be useful to the regulatory community.

The three areas of concern that Milone & MacBroom, Inc. addressed were water quality from the runoff that passes through the synthetic turf, the temperature of the surface of the turf, and the air quality on and surrounding the synthetic field. The questions we sought to answer are:

- Does the temperature of the synthetic field become excessively hot in summer months?
- Does the crumb rubber infill material have an effect on air quality?
- Do metals leach from the crumb rubber infill material at a level that would adversely affect the quality of water?

To address these issues, Milone & MacBroom, Inc. conducted three separate studies at locations where synthetic fields had been recently installed. The sites were selected for two reasons. First, we were able to secure permission from the owner of the fields to conduct the necessary tests. Second, we were familiar with the sites and understood how the fields were constructed and the materials that were used in the construction. The water quality monitoring was initiated in late 2007 and continued into the fall of 2008. The testing and observation of the temperature and the sampling of the air were done in mid-summer 2008. The results of the testing are presented in three separate documents as follows:

- **Thermal Effects Associated with Crumb Rubber In-filled Synthetic Turf Athletic Fields**
- **Evaluation of Benzothiazole, 4-(tert-octyl) Phenol and Volatile Nitrosamines in Air at Synthetic Turf Athletic Fields**
- **Evaluation of Stormwater Drainage from Synthetic Turf Athletic Fields**

We hope that our efforts will be useful to public officials and the consumer when evaluating which type of playing surface best suits their athletic field program needs.

Please contact Vince McDermott with any questions or to request additional copies of the research conducted by Milone & MacBroom, Inc.

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About Milone & MacBroom, Inc.

Milone & MacBroom, Inc. is a privately-owned, multidisciplinary consulting firm founded in 1984. The firm maintains a staff of over 145 technical and administrative personnel, with its main office located in Cheshire, Connecticut, and regional offices in Stamford and Branford, Connecticut; Greenville, South Carolina; Raleigh, North Carolina; Freeport, Maine; and South Burlington, Vermont. The team of professionals at Milone & MacBroom, Inc. is committed to building strong partnerships with our clients to deliver creative solutions that are technically sound, cost-effective, and environmentally sensitive. We strive to integrate the disciplines of engineering, landscape architecture, and environmental science in an exceptional work environment that is founded upon respect among ourselves, our clients, and our professional colleagues.

Thermal Effects Associated with Crumb Rubber In-filled Synthetic Turf Athletic Fields

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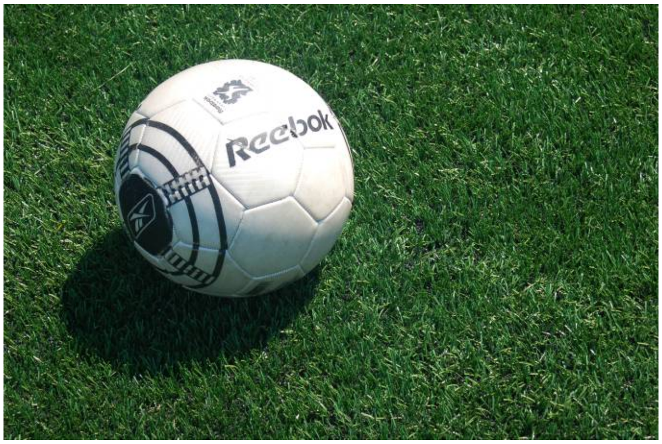
Substantial focus has been given to possible environmental effects associated with the installation of synthetic turf athletic fields. Questions concerning the potential health effects have been raised by several groups. Generally, these questions have been related to claims that insufficient data has been collected to reach a conclusion regarding possible detrimental health effects. One component of these claims is the question concerning the effect of solar heating on the fields and in particular upon the crumb rubber that is used as in-fill material (Figure 1). A temperature evaluation study was designed and conducted to determine the temperature rise of the synthetic materials under a number of conditions.



Two fields within Connecticut were selected for this study. Both fields were constructed by FieldTurf in 2007. One field, identified as Field F, is located in the northern portion of the state, while Field G is located in the southern portion of the state. Selection of the fields was based upon the ability to obtain permission to perform the testing and was not based upon manufacturer or geographic location. Temperature monitoring occurred on June 10 and July 11, 2008, at Field F and on June 17, 2008, at Field G.

During the testing procedure, the air temperature was monitored at two elevations directly over the synthetic playing surface and at a location adjacent to the synthetic surface but within an area of natural grass. Also measured during the testing were the temperatures of the crumb rubber

Figure 1

and the surface temperature of the polyethylene and polypropylene blended fibers used to simulate grass. Additional measurements were made of the soil at various depths in the area of the natural grass and the surface temperature of the natural grass itself. The air temperatures were measured using six-inch Enviro-Safe Easy Read Armor Case thermometers with a protective plastic jacket. These thermometers have a working temperature range of 0 degrees Fahrenheit (° F) to 220° F with two-degree graduations and are National Institute of Standards and Technology (NIST) certified. The thermometers were suspended within Styrofoam insulating cylinders. The inside dimensions of the cylinders were approximately $3^3/_8$ inches in diameter by 7¼ inches tall. Outside dimensions were approximately 4¼ inches in diameter by 7¾ inches tall. Twelve one-half inch holes were drilled into four sides of the cylinders to allow for airflow through the cylinder while still providing protection from the heating effect of the sunlight (Figures 2 and 3).

Figure 2

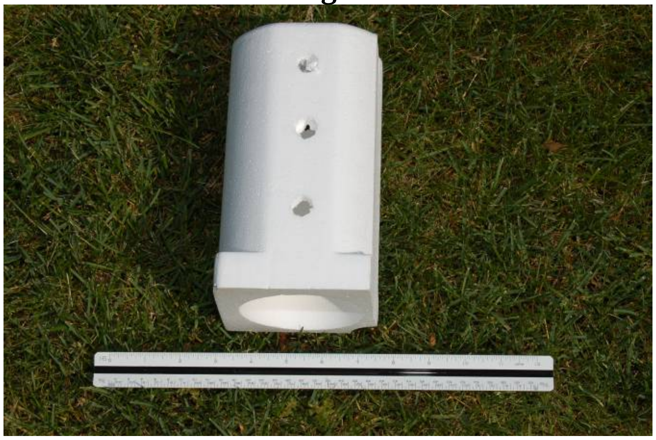


Figure 3

The Styrofoam cylinders were then mounted to a wooden pole measuring approximately 1¾ inch x 1¾ inch x 5½ feet tall using plastic wire ties (Figure 4). Each pole was then mounted to a metal and wooden surveyor's tripod (Figure 5).

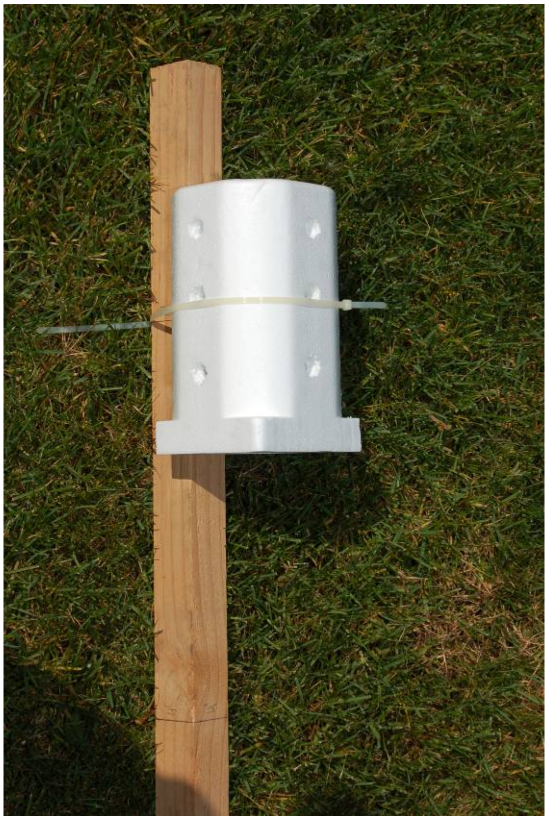


Figure 4

Figure 5

The surface temperatures of the natural grass and the synthetic fibers were measured using an infrared thermometer manufactured by EXTECH Instruments (EXTECH Pocket IR thermometer). The thermometer has a stated sensing range of -58° F to 518° F with an accuracy of +/- 2.5% of reading plus three degrees.

The temperature of the soil and the crumb rubber in-fill material was measured using a digital pen thermometer with a stated sensing range of -58° F to 536° F in 0.1-degree divisions with an accuracy of one degree. The sensing probe measured eight inches long and was constructed of stainless steel.

Methodology

The temperature monitoring stations were placed to allow a comparison of temperatures between the synthetic and natural turf surfaces. One station was placed in the center of the synthetic turf field, while the second station was placed approximately 50 feet (Field G) or 125 feet (Field F) away from the synthetic surface on natural turf. The natural turf monitoring station was located based upon the location of nearby structures (bleachers, parking lots, synthetic running track surfaces) that had the potential to affect the temperature readings (Figure 6).

Figure 6

Air temperatures were measured at two feet and five feet above the ground surface during the June 10 and June 17, 2008, monitoring events. The methodology was adjusted for the July 11, 2008, event, at which time the temperatures were measured at one foot and five feet.

Surface temperatures of both the synthetic "grass" fibers and the natural grass were measured using the infrared thermometer, while soil and crumb rubber temperatures were measured using the digital pen thermometer.

The air temperature measured at a distance of five feet above the natural turf was assumed to best approximate the actual ambient air temperature at the location of the monitored field.

Results

June 10, 2008

Temperature measurements were obtained at Field F on June 10, 2008. Official temperature data for this date was obtained from Weatherunderground.com for Bradley International Airport in Windsor Locks, Connecticut. The official high temperature was 98° F. Additional temperature and wind data was obtained from a private weather station associated with Weatherunderground.com. This weather station is located approximately 2.3 miles from Field F. A high temperature of 95.6° F and maximum winds of three miles per hour (mph) were recorded at this station during the study time period. Skies were clear throughout the study.

Collected data indicated that the air temperature as measured at a distance of two feet above the synthetic turf surface ranged from one to five degrees greater than the observed ambient air temperature, while the temperature at the same height above the natural turf ranged from 3° F lower to 1° F greater than the ambient air temperature (Figure 7).

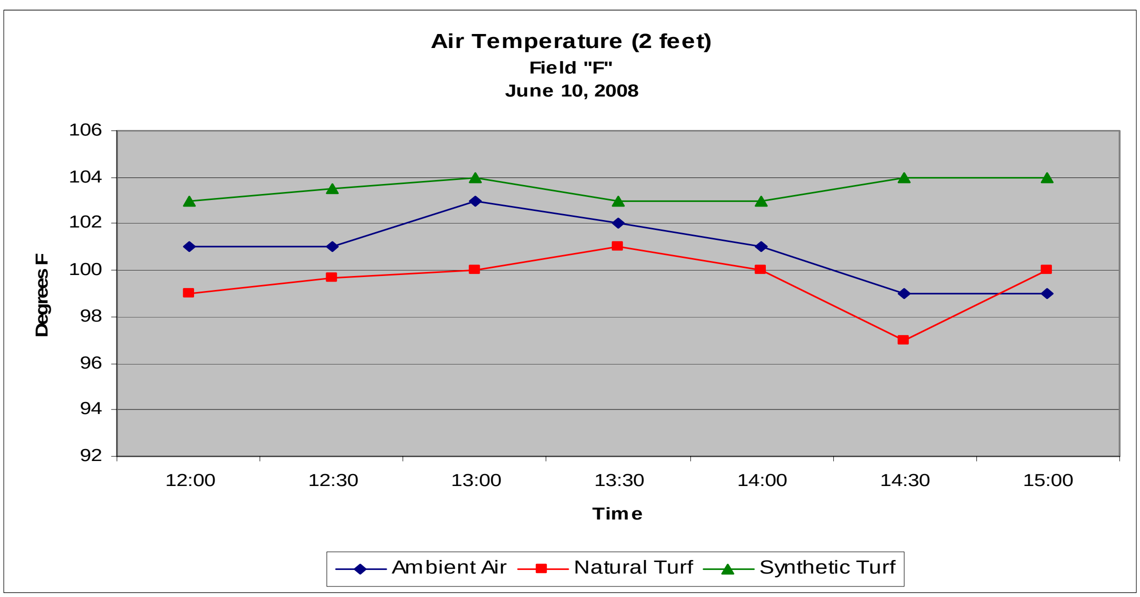


Figure 7

The measured air temperature at a height of five feet above the synthetic turf more closely approximated the ambient air temperature. Measured air temperatures ranged from 2° F lower to 2° F greater than the ambient air temperature (Figure 8).

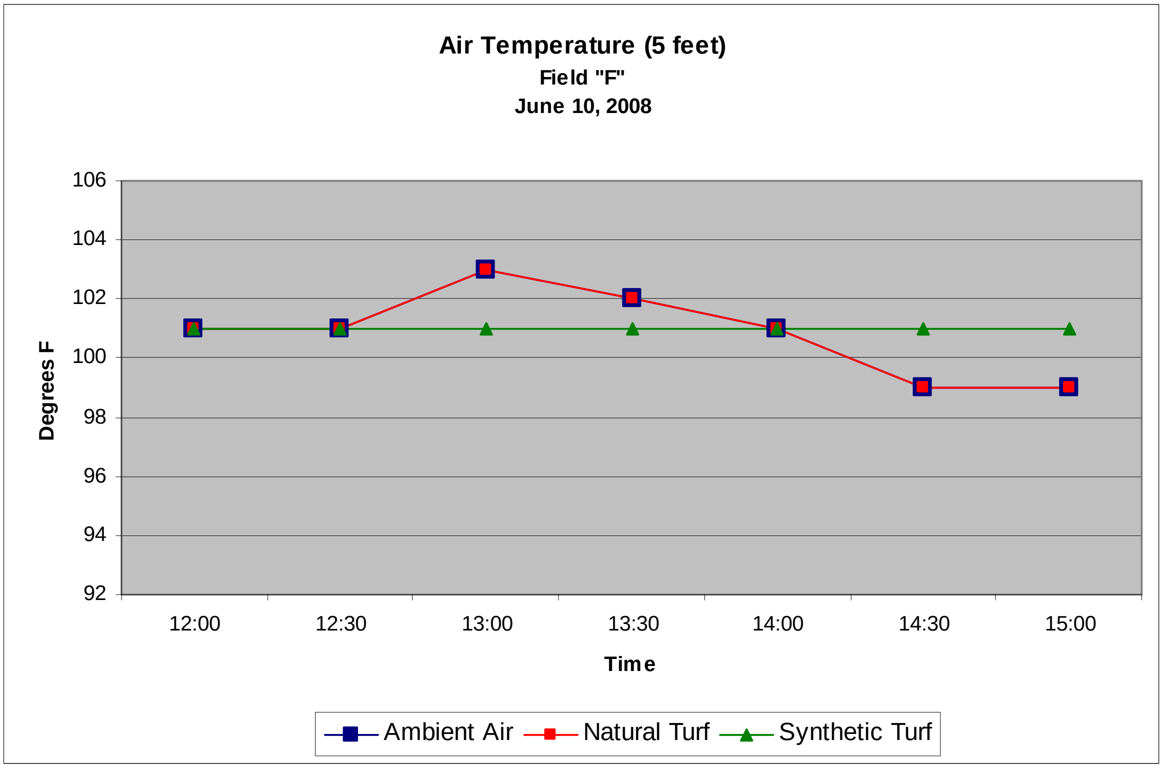


Figure 8

Note in Figure 8 the temperature identified as the ambient air temperature is the same as the temperature measured at a distance of five feet above the natural turf.

The temperature observed for the surface of the synthetic "grass" fibers was measured using an infrared thermometer and compared to the observed air temperatures and also the temperature of the crumb rubber in-fill material as measured at a depth of one inch. The surface of the synthetic fibers reached a maximum temperature of 156° F. The crumb rubber reached a maximum temperature of 111.5° F or approximately 44 degrees cooler than the surface temperature of the synthetic "grass" fibers. As noted above, the elevated temperature of the fibers did not result in a significant elevation of the air temperature above the synthetic field as compared to the air temperature over the natural grass field (Table 1 and Figure 9).

Table 1

Time of Day (hrs)	Ambient Temperature	Synthetic Turf Temperatures			
		Surface Temperature Synthetic "Grass" Fibers	Crumb Rubber Temperature (1 inch depth)	Air Temperature 2 feet above surface	Air Temperature 5 feet above surface
	°F	°F	°F	°F	°F
12:00	101	153	102.5	103	101
12:30	101	155	103	104	101
13:00	103	151	104.5	104	101
13:30	102	156	111.5	103	101
14:00	101	154	109.5	103	101
14:30	99	138	107.2	104	101
15:00	99	149	105.8	104	101

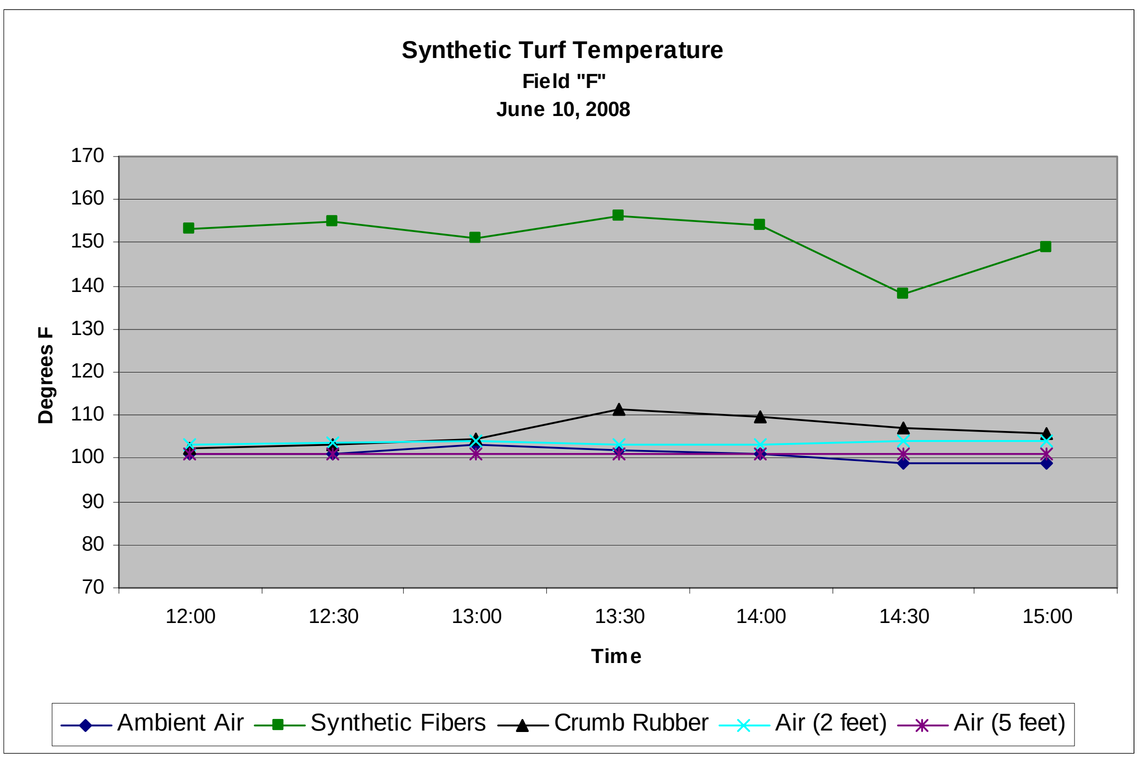


Figure 9

Temperatures measured in the area of the natural turf indicated that the surface of the natural grass blades closely approximated the ambient air temperature. The grass blades ranged from 3° F cooler to 5° F warmer than the measured ambient temperature. Soil temperatures were determined to decrease with increasing depth. The highest soil temperatures were noted at the end of the study period with a maximum temperature of 90.1° F being measured at 15:00 at a depth of one inch below the surface. The temperature of the soil at that depth increased approximately nine degrees over a span of three hours, while the temperature at a depth of six inches increased just two degrees.

Table 2

Time of Day (hrs)	Ambient Temperature	Natural Turf Temperatures					
		Surface Temperature Natural Grass	Soil Temperature			Air Temperature 2 feet above surface	Air Temperature 5 feet above surface
			1 inch depth	3 inch depth	6 inch depth		
	°F	°F	°F	°F	°F	°F	°F
12:00	101	100	81.5	78.8	77.3	99	101
12:30	101	101	86.5	79	77.3	99.7	101
13:00	103	102	89.2	79.8	77.3	100	103
13:30	102	99	86	81.6	78.2	101	102
14:00	101	101	89.4	82.5	79.5	100	101
14:30	99	104	87	81	78.9	97	99
15:00	99	100	90.1	85.1	79.3	100	99

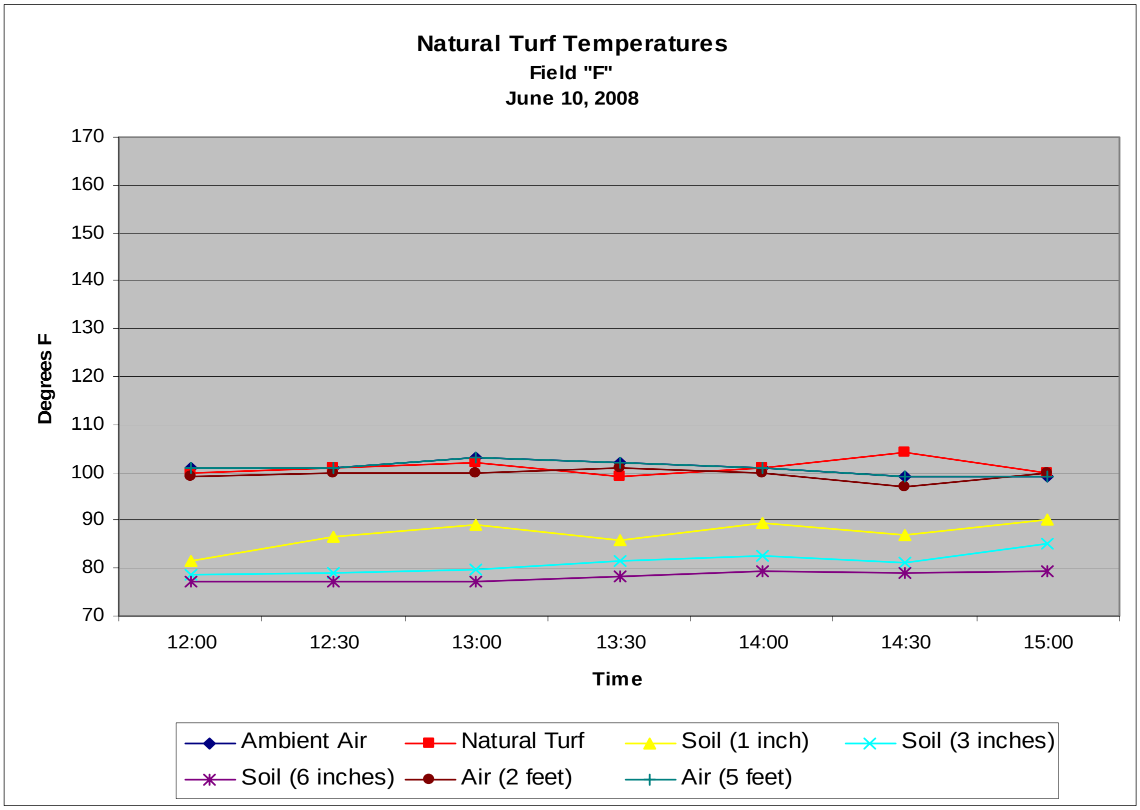


Figure 10

<u>June 17, 2008</u>

Temperature measurements were obtained at Field G on June 17, 2008. Field G is located in the southern portion of Connecticut and is believed by the authors to be susceptible to localized weather variations caused by Long Island Sound. Once again, temperature and wind data were obtained from a private weather station associated with Weatherunderground.com and located approximately 1.5 miles from Field G. A high temperature of 75.7° F and maximum winds of four mph were recorded at this station during the study time period. Intermittent clouds and sunshine were noted during the study period.

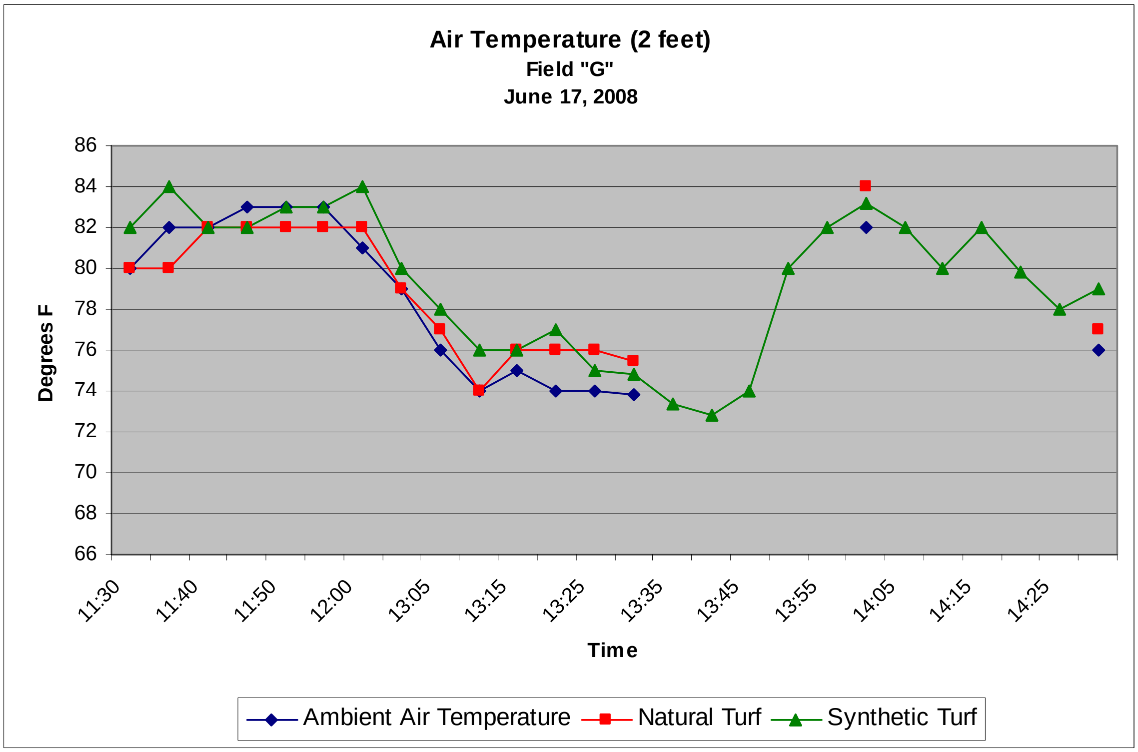


Figure 11

Collected data indicated that the air temperature as measured at a distance of two feet above the synthetic turf surface ranged from 1 degree lower to three degrees greater than the observed ambient air temperature, while the temperature at the same height above the natural turf ranged from 2° F lower to 2° F greater than the ambient air temperature (Figure 11). The air temperature two feet above the synthetic turf field was generally two degrees to four degrees greater than the temperature above the natural turf.

The time period between approximately 13:00 and 13:45 was characterized by clouds. The cooling effect of the cloud cover can be clearly noted in the data. This effect is also noted in the graph of the air temperature at five feet above the fields. At this height, the air temperature above the synthetic turf was generally two to three degrees greater than the natural turf field.

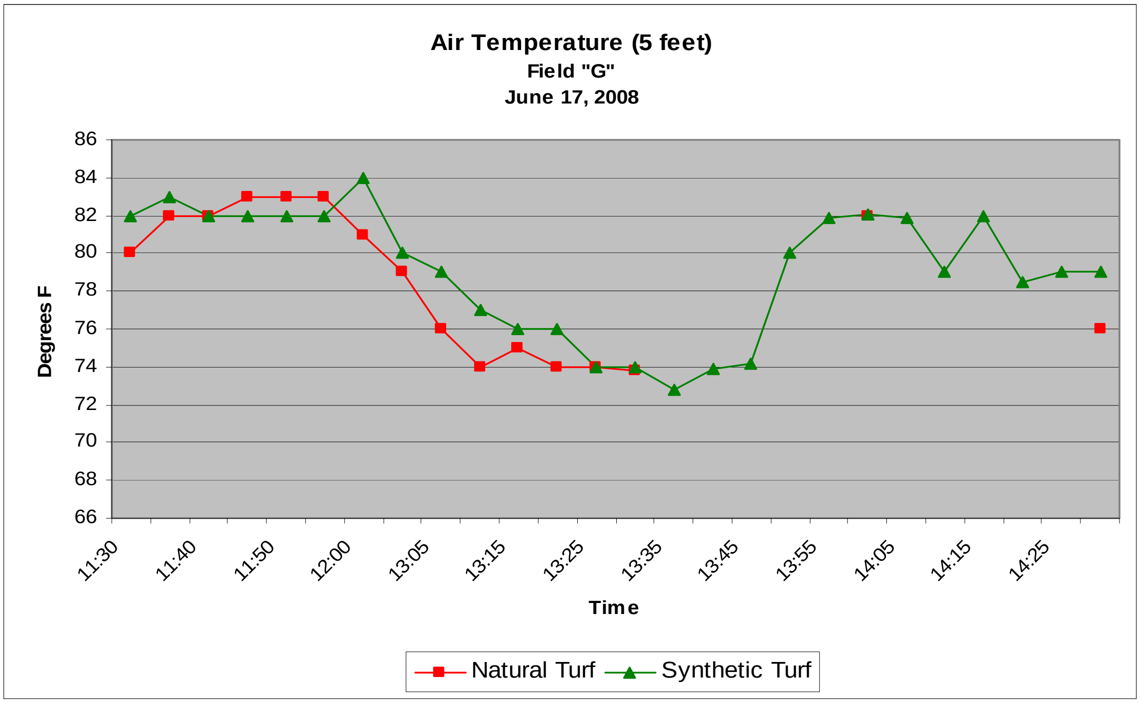


Figure 12

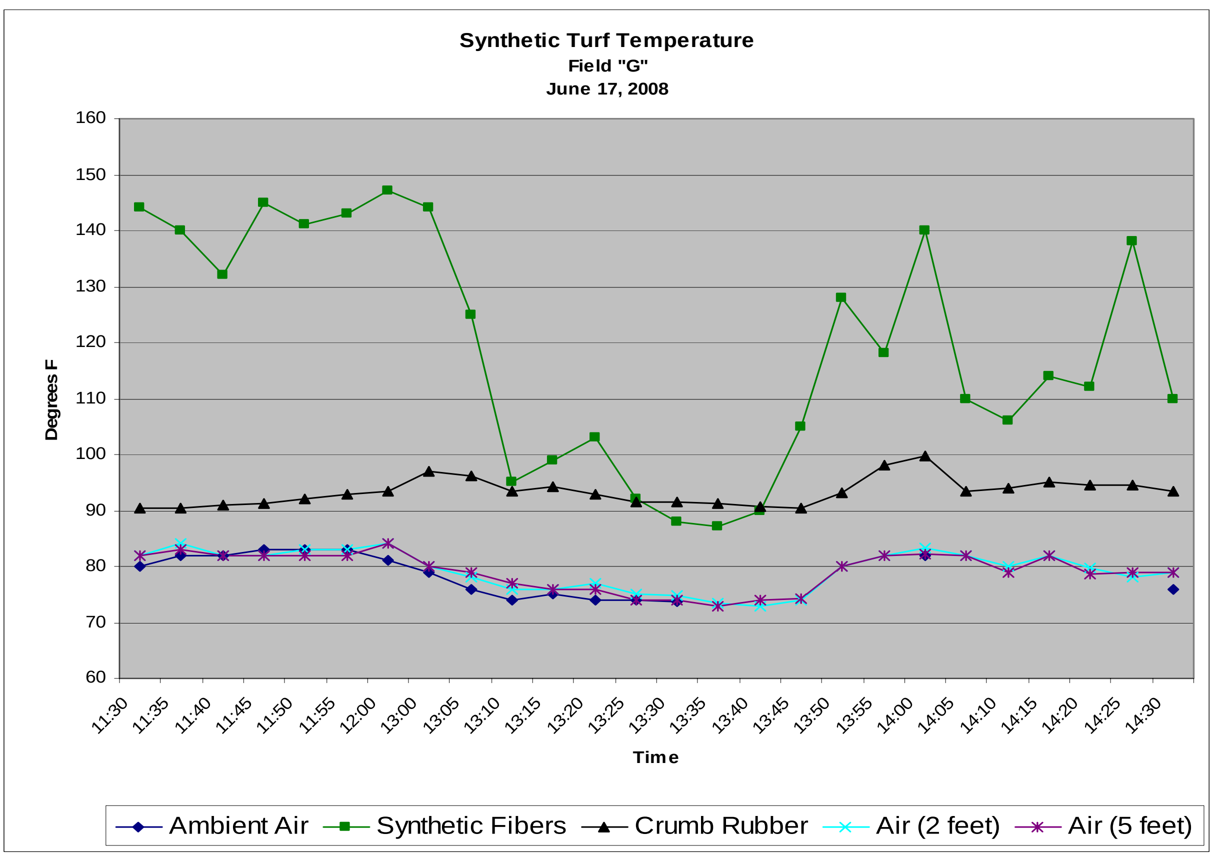


Figure 13

The results of the measurements of the temperature of surface of the synthetic "grass" fibers were similar to those obtained for Field F. A maximum temperature of 147° F was noted during periods of sunshine. The temperature dropped rapidly during cloudy periods and reached a minimum temperature of 87° F or approximately 15 degrees greater than the observed ambient air temperature. The crumb rubber in-fill material maintained a relatively steady temperature and averaged approximately 93° F or approximately 15 degrees greater than the average ambient air temperature (Figure 13). Once again, the elevated temperature of the fibers did not result in a significant elevation of the air temperature above the synthetic field as compared to the air temperature over the natural grass field.

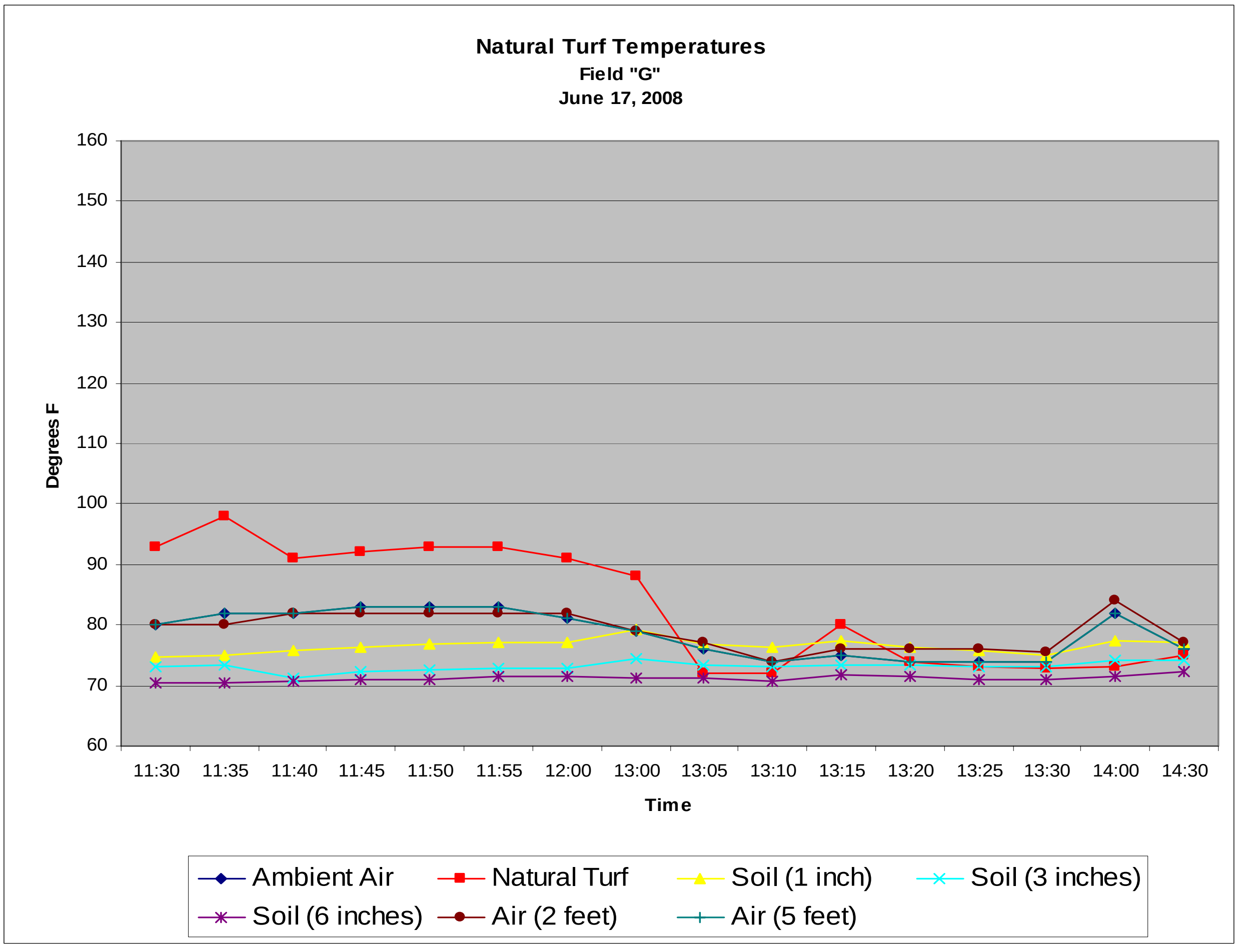


Figure 14

Measurements in the area of the natural turf near Field G indicated that the surface temperature of the natural grass blades was approximately 10 to 15 degrees greater than the ambient air temperature during periods of sunshine. The temperature decreased quickly to nearly the ambient air temperature once cloud cover was present. The soil temperatures were nearly constant throughout the monitoring period and averaged approximately 74° F (Figure 14).

July 11, 2008

The temperature monitoring was repeated at Field F on July 11, 2008. The exception to the above procedures was that the air temperature was measured at heights of one foot and five feet above the synthetic turf and the natural turf fields. The results are detailed in Figures 15 through 19 below. As noted previously, the elevated surface temperature of the synthetic "grass" fibers appeared to have minimal effect on the air temperature directly over the synthetic turf field. Likewise, only a moderate rise in the temperature of the crumb rubber was noted. The temperature rise noted at one foot above the synthetic turf field was generally two to four degrees as compared to the measured ambient air temperature, although a maximum of a nine-degree rise was noted to occur over a short time period early in the study. The temperature rise noted at five feet above the synthetic turf surface was generally between one to five degrees, which is comparable to the previously observed measurements.

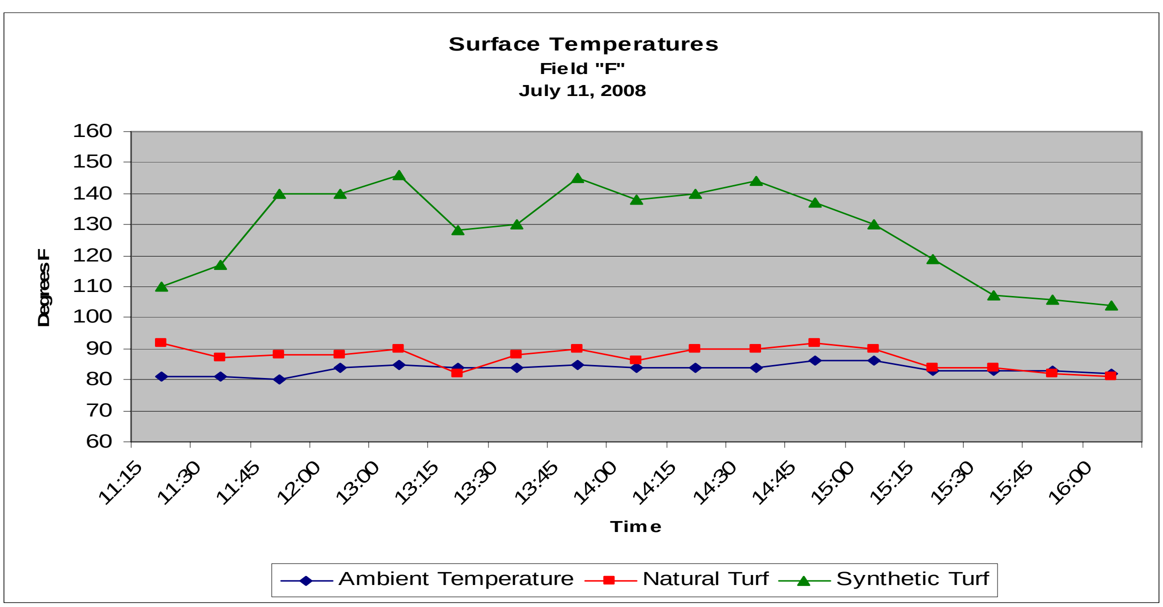


Figure 15

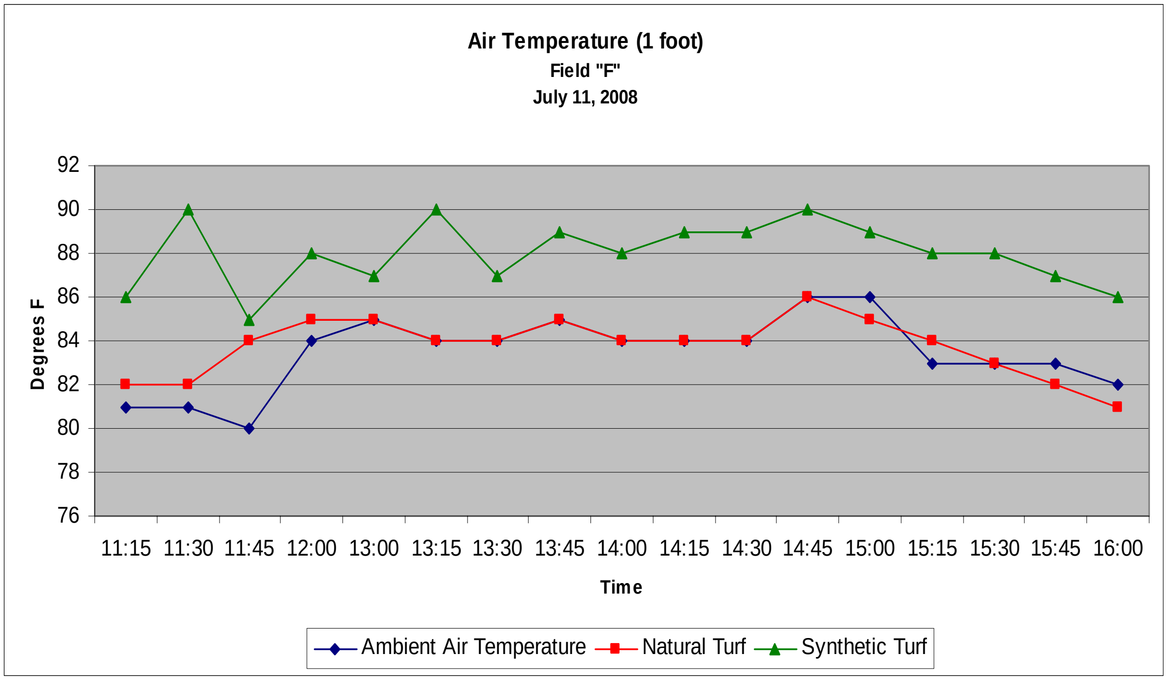


Figure 16

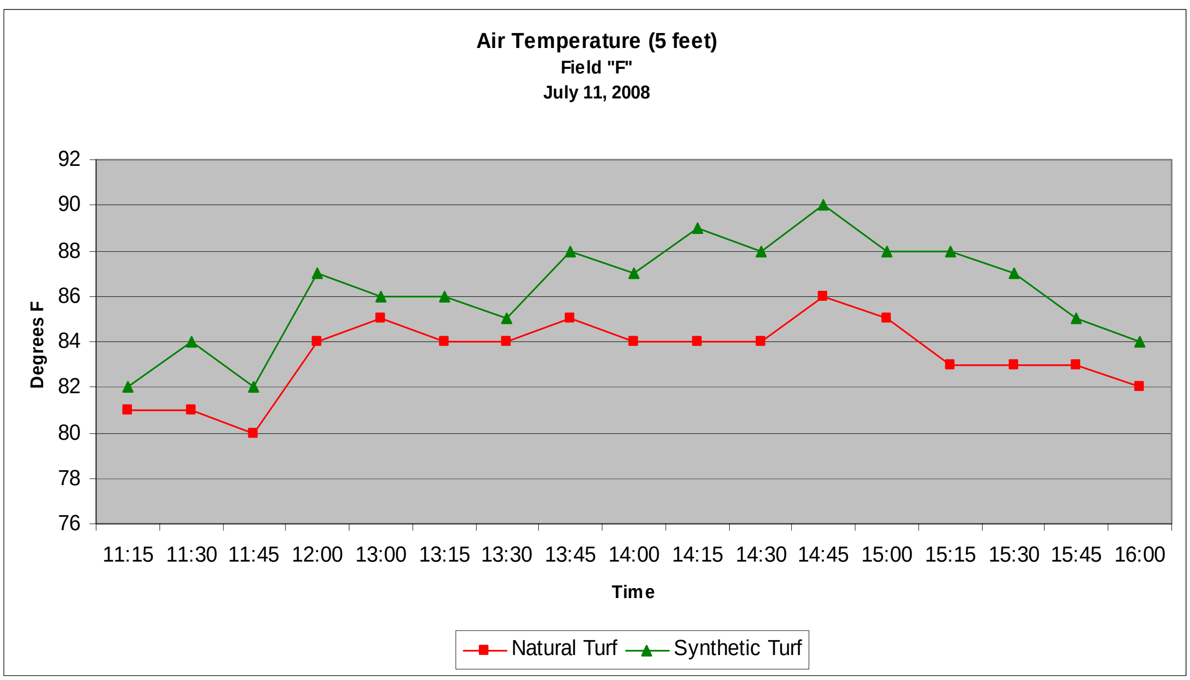


Figure 17

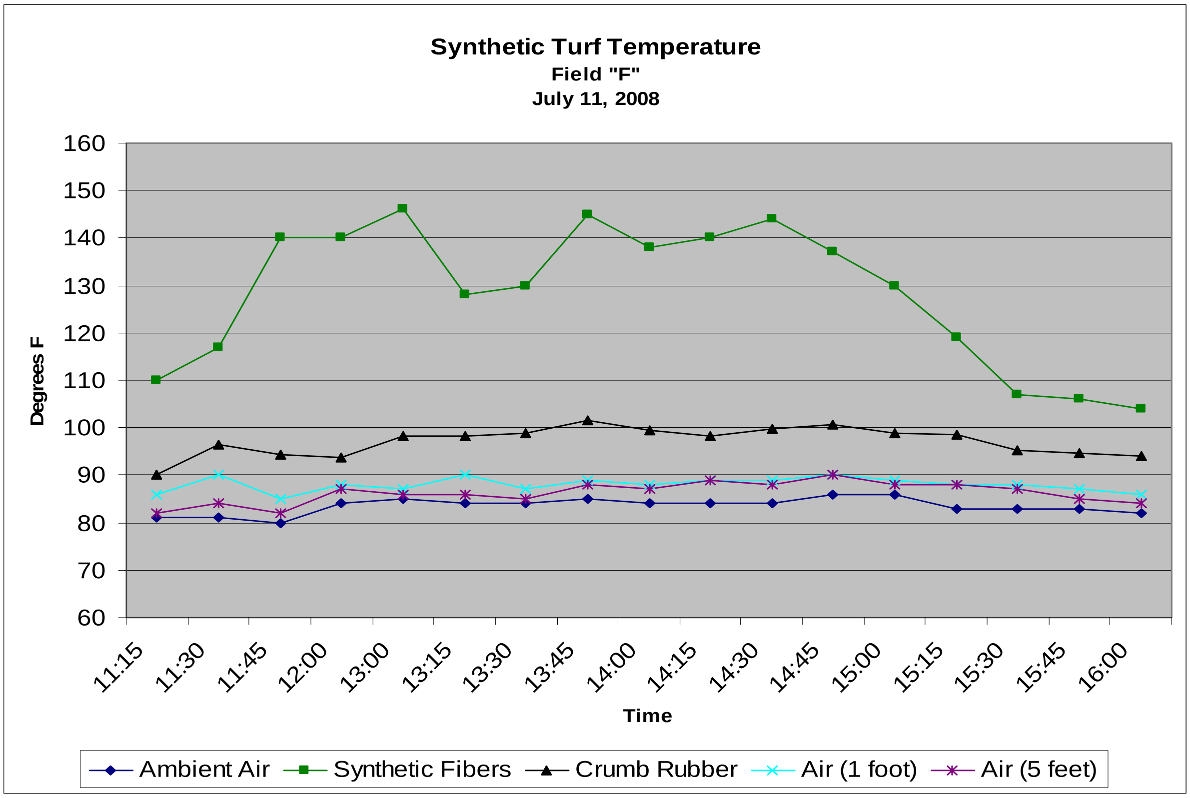


Figure 18

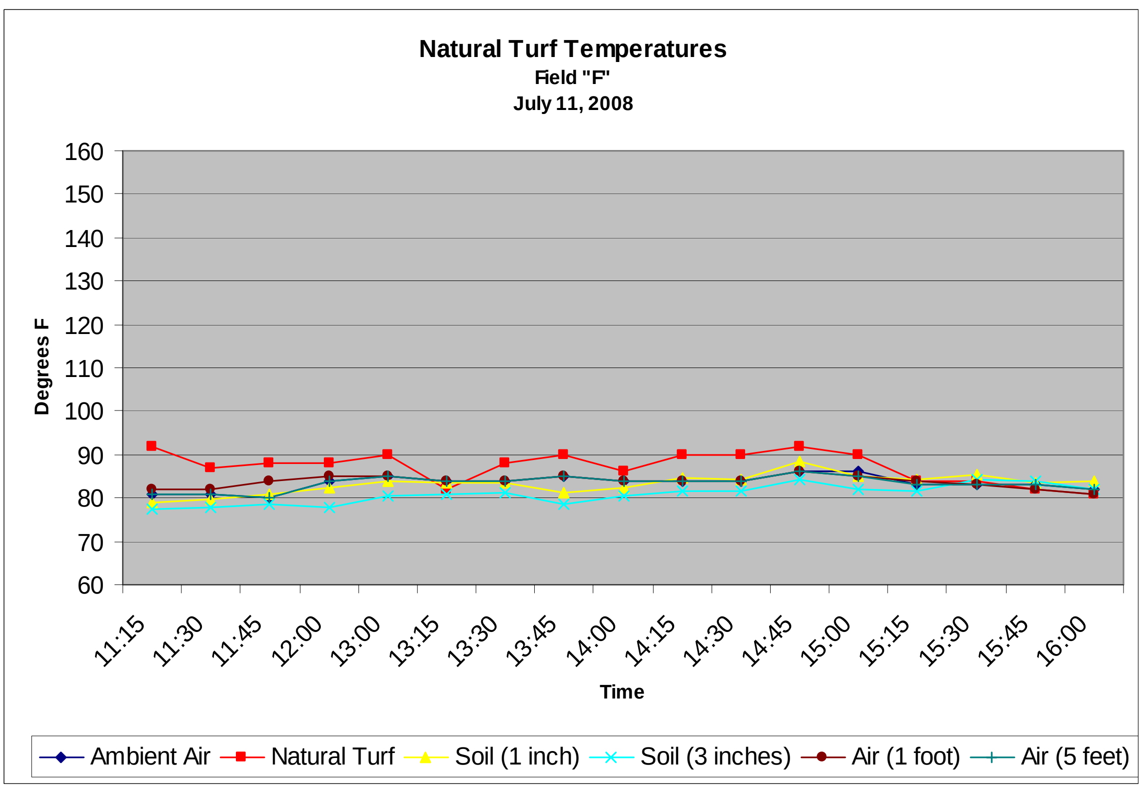


Figure 19

The sampling methodology on this date was also adjusted to evaluate the potential cooling effect due to the evaporation of water from the synthetic "grass" fibers. Two squares measuring one foot square were cut from a single sheet of white foam board (Figure 20). The surface temperature of the synthetic fibers was then measured using an infrared thermometer. One square was kept dry while the other side was wetted with one ounce of water using a spray bottle. The surface temperatures were measured and recorded over a period of 20 minutes. The foam board was then moved to a dry location, and the measurements were repeated using two ounces and then three ounces of water.

The results indicated that the applied water provided at least 20 minutes of effective cooling to the synthetic fibers. The amount of the cooling effect was generally between 10 and 20 degrees although slightly more of a cooling effect was noted when three ounces of water were used.

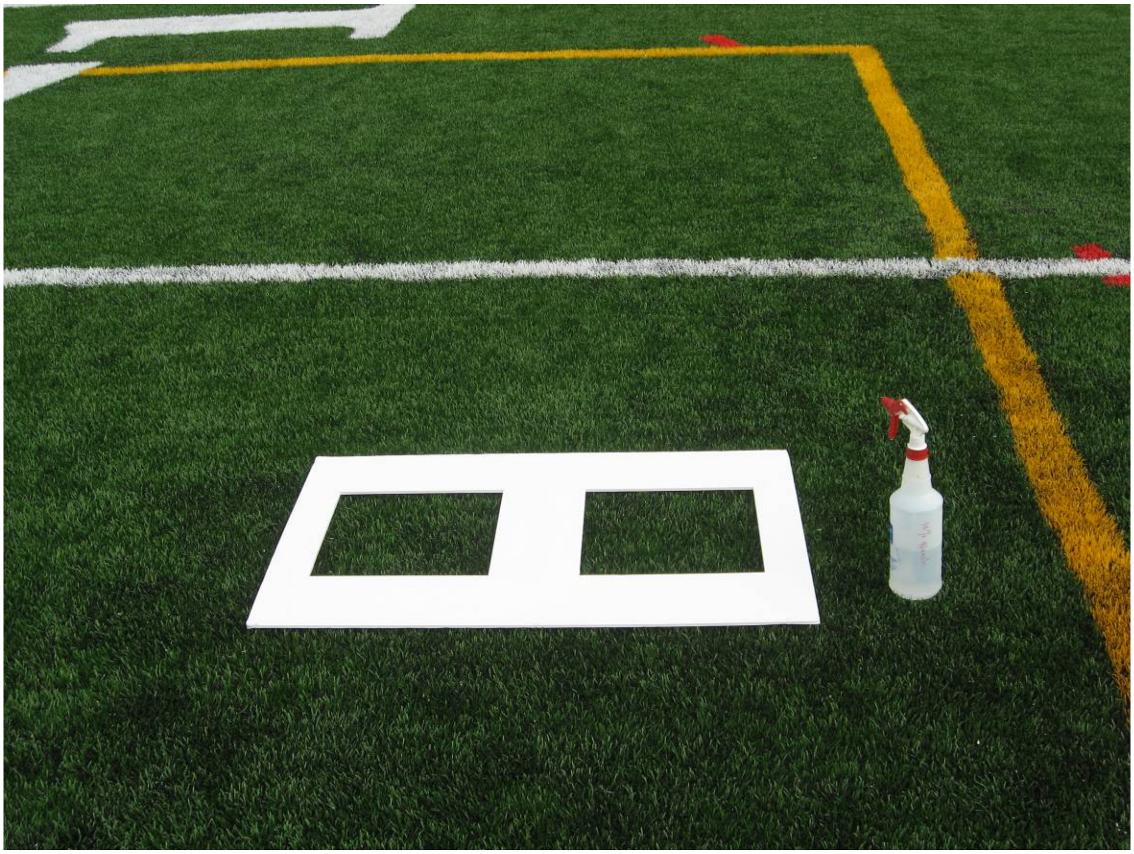


Figure 20

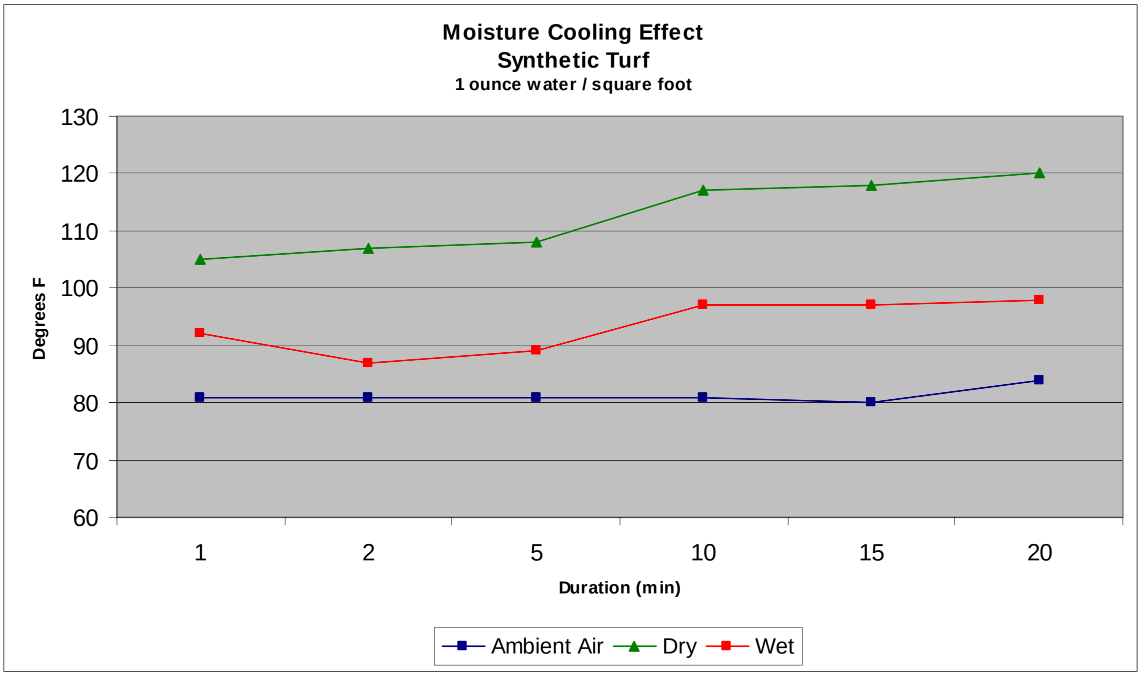


Figure 21

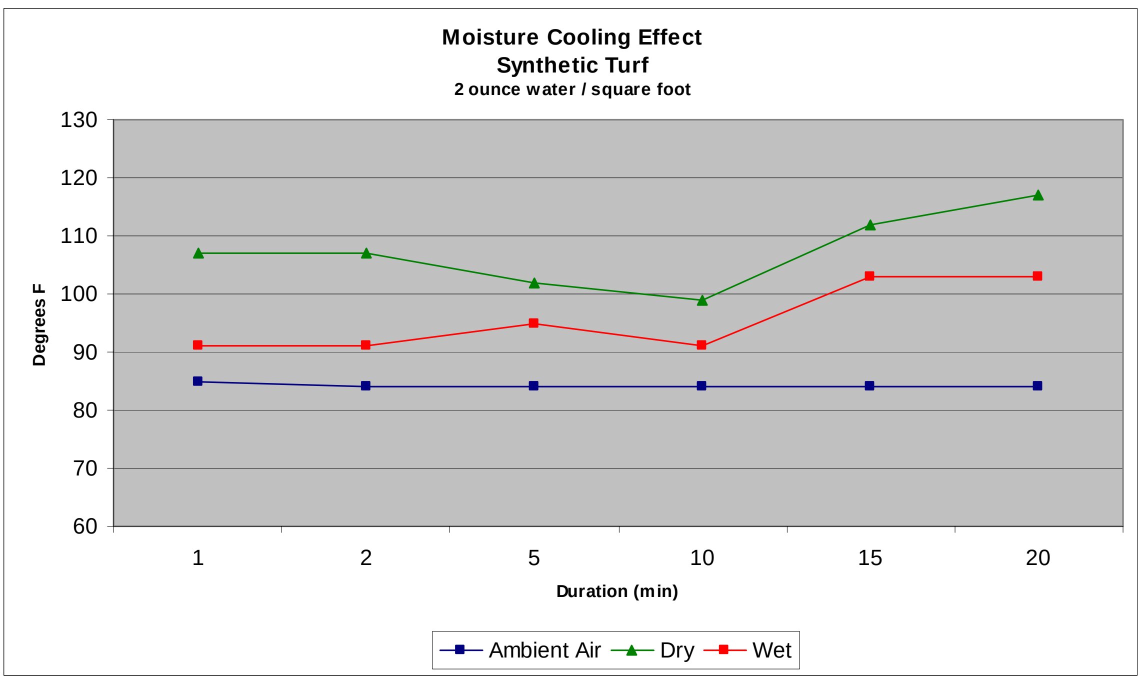


Figure 22

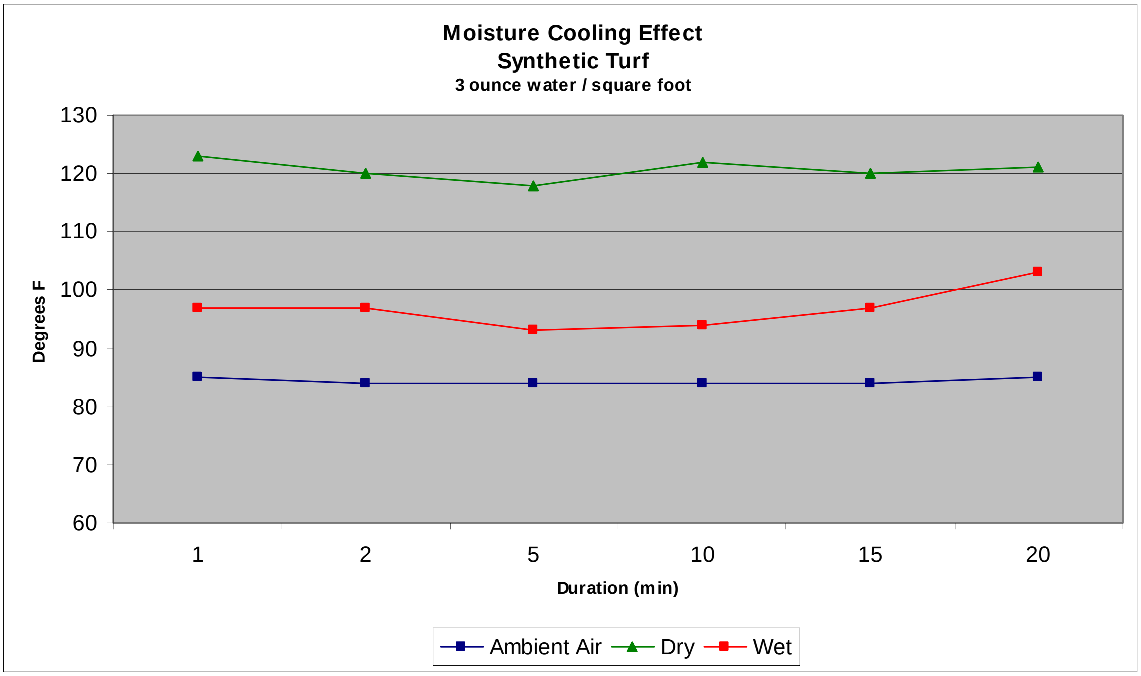


Figure 23

Summary

The results of the temperature measurements obtained from the fields studied in Connecticut indicate that solar heating of the materials used in the construction of synthetic turf playing surfaces does occur and is most pronounced in the polyethylene and polypropylene fibers used to replicate natural grass. Maximum temperatures of approximately 156° F were noted when the fields were exposed to direct sunlight for a prolonged period of time. Rapid cooling of the fibers was noted if the sunlight was interrupted or filtered by clouds. Significant cooling was also noted if water was applied to the synthetic fibers in quantities as low as one ounce per square foot. The elevated temperatures noted for the fibers generally resulted in an air temperature increase of less than five degrees even during periods of calm to low winds.

The rise in temperature of the synthetic fibers was significantly greater than the rise in temperature noted for the crumb rubber. Although a maximum temperature of 156° F was noted for the fibers, a maximum temperature of only 101° F, or approximately 16 degrees greater than the observed ambient air temperature, was noted for the crumb rubber.

Evaluation of Benzothiazole, 4-(tert-octyl) Phenol and Volatile Nitrosamines in Air at Synthetic Turf Athletic Fields

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The growing popularity of crumb rubber in-filled synthetic turf playing surfaces has resulted in questions concerning the potential resulting human health effects from the inhalation of volatile chemicals by users of those fields. A limited number of studies have attempted to identify and quantify these chemicals. One such study, conducted in 2007 by the Connecticut Agricultural Experiment Station[1] identified benzothiazole, butylated hydroxyanisole, n-hexadecane, and 4-(tert-octyl) phenol as potential chemicals of concerns. This study, however, was laboratory based and did not include collection and analysis of samples from installed fields. Another study, conducted by the Norwegian Institute for Air Research[2], evaluated the air quality at three different indoor fields.

A study was designed and conducted to specifically evaluate the possible presence of benzothiazole, 4-(tert-octyl)phenol, and volatile nitrosamines in air above recently installed outdoor, crumb rubber in-filled synthetic turf playing surfaces in Connecticut.

Field G

Methodology

Two fields in Connecticut were selected for this study. Both fields were constructed in 2007 by FieldTurf using polyethylene fiber with cryogenically produced rubber and silica sand infill. One field, identified as Field F, is located in the northern portion of the state, while Field G is located in the southern portion of the state. Selection of the fields was based upon the ability to obtain permission to perform the testing and not based upon manufacturer or geographic location. Both fields are multipurpose fields used for sports such as football, soccer, field hockey, and/or lacrosse among others and are encircled by synthetic running track surfaces. These two fields were previously the subject of a separate study by the authors entitled "Thermal Effects Associated with Crumb Rubber In-filled Synthetic Turf Athletic Fields." The air sampling activities were conducted on August 15, 2008, at Field F and on August 18, 2008, at Field G.

Five sample locations were selected at each of the sampled fields. One location at each field was directly over the center portion of the playing surface, while the remaining four were located off the playing surface at either end or sides of the fields. These later locations were selected to provide "background" results to account for potential transport of vapors by wind and to evaluate the possible volatilization of target compounds from the running track surfaces.

A Davis Vantage Pro2 automated meteorological station was utilized to measure temperature, relative humidity, wind speed, and wind direction at the fields throughout the sampling period. The station was erected near the sampling location in the center portion of the field (Figure 1). The temperature sensor portion of the instrument was located approximately five feet above the synthetic turf surface.

Figure 1 - Meteorological Station

Additional measurements were made of the air temperature at heights of one foot and four feet above the synthetic turf surface using six-inch Enviro-Safe, Easy Read Armor Case thermometers with a protective plastic jacket. These thermometers have a working temperature range of 0 degrees Fahrenheit (° F) to 220° F with two-degree graduations and are National Institute of Standards and Technology (NIST) certified. The thermometers were suspended within Styrofoam insulating cylinders. The inside dimensions of the cylinders were approximately $3^{3}/_{8}$ inches diameter by 7¼ inches tall. Outside dimensions were approximately 4¼ inches diameter by 7¾ inches tall. Twelve one-half inch holes were drilled into four sides of the cylinders to allow for airflow through the cylinder while still providing protection from the heating effect of the sunlight (Figure 2).

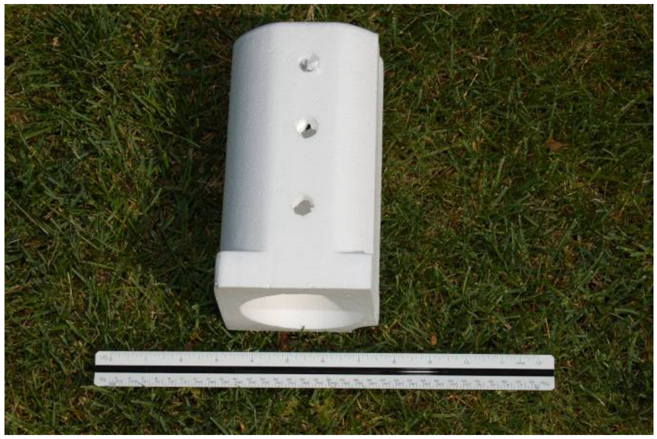

Figure 2 - Styrofoam cylinders used for temperature measurements

The Styrofoam cylinders were then mounted to the metal pole supporting the weather station. The mounted cylinders can be seen in Figure 1.

The temperature of crumb rubber in-fill material was measured using a digital pen thermometer with a stated sensing range of -58° F to 536° F in 0.1 degree divisions with accuracy of one degree. The sensing probe measured eight inches long and was constructed of stainless steel.

Air samples were collected through dedicated adsorbent media with the intakes set at approximately four feet above ground surface (Figures 2 through 5). The samples to be analyzed for benzothiazole and 4-(tert-octyl) phenol were collected using XAD-2 adsorbent media (Catalog #226-30, lot 4501, expiration date April 2012) produced by SKC Inc. of Eighty Four, Pennsylvania. A minimum of 480 liters of air was pumped through the adsorbent media at an approximate rate of two liters per minute using an SKC Airlite sampling pump. A 37 mm, 2 micron PTFE filter was placed inline before the adsorbent media tube.

Figure 3 - Field Sample Location

Figure 4 - "Background" Sample Location

Figure 5 - Sampling Pumps. ThermoSorb N module on left; XAD-2 and filter on right

The samples to be analyzed for volatile nitrosamines were collected using ThermoSorb N adsorbent media produced by Advanced Chromatography Systems of Johns Island, South Carolina. A minimum of 75 liters of air was pumped through the adsorbent media at an approximate rate of one liter per minute using an SKC Universal Pump 224-PCXR8 sampling pump.

Both models of sampling pumps have a manufacturer's stated flow rate accuracy of +/- 5%.

The intakes for all samples were set at approximately four feet above either the playing surface or the grass surface surrounding the playing field. The sampling media was connected to the sampling pumps using approximately six inches of ¼ I.D. x 3/8 OD poly tubing. The pump was calibrated prior to sampling utilizing a BIOS DryCal DC-Lite air pump calibrator. A sacrificial media tube and poly tubing was used during the pump calibration.

All samples were delivered to the Wisconsin Occupational Health Laboratory at the University of Wisconsin via overnight courier service for analysis. The analytical methods employed for benzothiazole and 4-(tert-octyl) phenol analysis were based upon NIOSH Method 2550. The samples were desorbed with 10 minutes of sonication performed three times with three milliliters (mL) of methanol. The combined methanol fractions were then evaporated to approximately 0.5 mL with nitrogen and brought to a final volume of 1.0 mL with methanol. The extracts were then analyzed by reversed phase high-performance liquid chromatography employing a 0.1 percent formic acid:methanol linear gradient program. Detection was achieved by triple quadruple mass spectrometry using multiple reaction monitoring. A reporting limit of 100 nanograms was established for the analytes based upon statistical data analysis.

The analytical methods employed for the nitrosamine analysis were based upon OSHA Method 27. The samples were with approximately three mL of methylene chloride:methanol (75:25 v/v). Extracts were analyzed by reversed phase high-performance liquid chromatography employing a 0.1 percent formic acid:methanol linear gradient program. Detection was achieved by turbo ion spray triple quadruple mass spectrometry using multiple reaction monitoring in positive ionization mode. A reporting limit of 100 nanograms was established for the analytes based upon statistical data analysis; however, any discernable peak for n-nitrosodimethylamine was reported with appropriate comment.

Results

Field F

Air sampling activities were conducted at Field F on August 15, 2008. Five discrete sample locations were chosen. One location (SF-1) was near the center to the playing surface while the remaining four locations (SF-2, SF-3, SF-4, and SF-5) were around the perimeter of the synthetic running track. The sample locations are graphically presented in Figure 6. Sampling activities were initiated at 11:40 and were completed at 16:07.

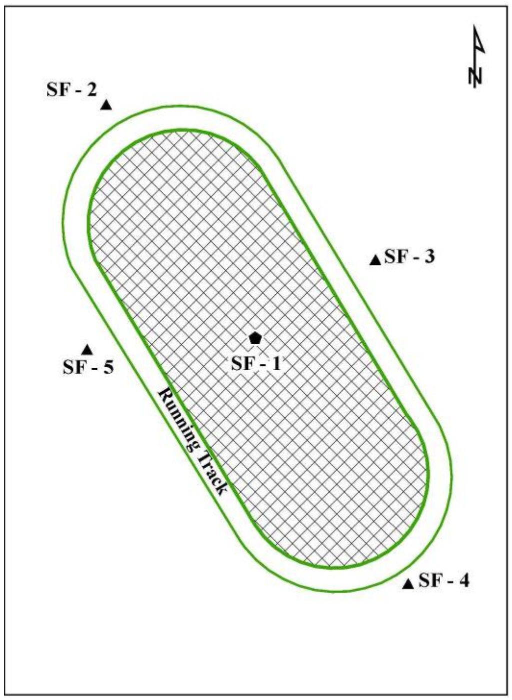

Figure 6 – Sample Locations Field F

Weather conditions on August 15, 2008, at the sample site were generally a mix of clear and partly cloudy skies with ambient air temperatures between 75° F and 80° F. Winds were generally light to calm. The late morning and early afternoon winds were measured

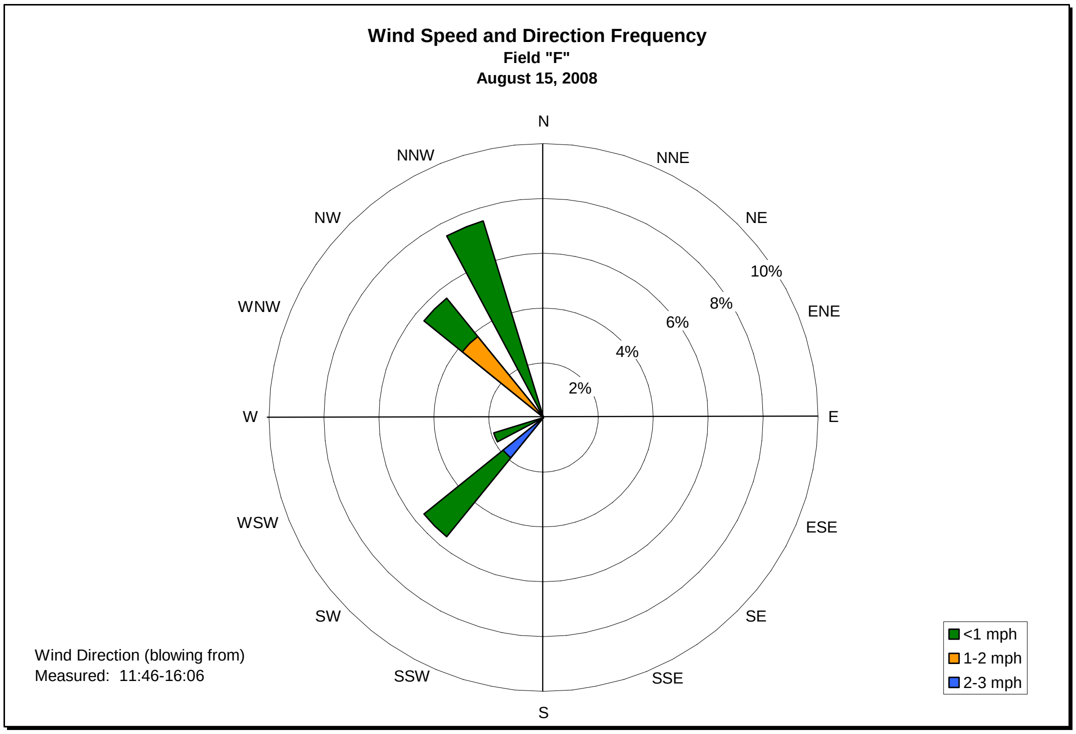

Figure 7 - Wind Speed and Direction

to be less than two miles per hour and were from the north and northwest. At approximately 15:30, the winds shifted to the southwest and increased to a maximum of three miles per hour. Figure 7 depicts the wind speed, direction, and frequency noted during the testing period. A brief rain shower occurred at approximately 14:45.

The air temperature was measured at three different heights (one foot, four feet, and five feet) directly over the playing surface near sample location SF-1. In addition, the temperature of the crumb rubber in-fill material was measured at a depth of approximately one inch. The measured temperatures are shown in Figure 8. The air temperature was noted to increase with decreasing height above the playing surface. The average air temperature measured at a height of five feet was 76.6° F, while the average temperatures at one foot and four feet were 85.7° F and 81.7° F, respectively. The average temperature of the crumb rubber was 91.7° F. Significant cooling of the crumb rubber and the air column at one foot and four feet above the surface was noted following the brief rain shower that occurred at 14:45.

Periodic measurements of the surface temperature of the synthetic "grass" fibers were measured using an infrared thermometer manufactured by EXTECH Instruments (EXTECH Pocket IR thermometer). A maximum temperature of 127° F was noted at 12:00.

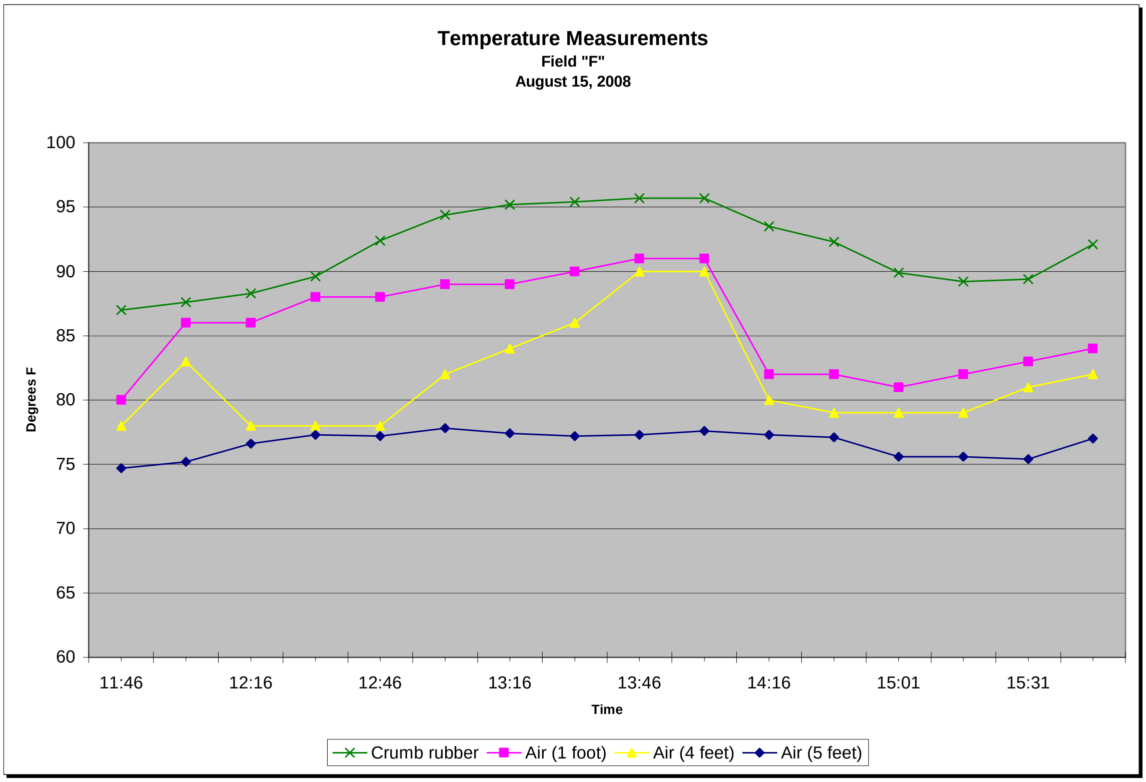

Figure 8 – Temperature Measurements Field F

All air sampling pumps were activated between 11:40 and 11:49. The pumps connected to the ThermoSorb N media were allowed to run at a flow rate of approximately one liter per minute for approximately 75 minutes. At the conclusion of the appropriate time interval, the SKC Universal Pump 224-PCXR8 was deactivated and the ThermoSorb N module was removed and sealed using the supplied caps. After approximately four hours, the SKC Airlite sampling pumps were also deactivated and the XAD-2 adsorbent tubes were removed and sealed using the supplied caps. The PTFE filters were capped and placed into plastic zip bags.

Table 1
Sampled Air Volumes - Field F
August 15, 2008

	ThermoSorb N Module			XAD-2 Module		
Sample ID	Start Time	End Time	Air Volume (L)	Start Time	End Time	Air Volume (L)
SF-1	11:49	13:04	76.13	11:49	16:08	519.04
SF-2	11:42	12:57	75.90	11:42	15:57	512.04
SF-3	11:45	13:00	75.98	11:45	16:04	519.55
SF-4	11:47	13:03	77.82	11:47	16:07	521.30
SF-5	11:40	12:55	78.75	11:40	15:46	493.23

The samples were packaged for delivery to the Wisconsin Occupational Health Laboratory at the University of Wisconsin. The analytical methods employed are described in the "Methodology" section above.

The volatile nitrosamine analysis indicated that there were no detectable concentrations of nitrosamines in the air directly above the synthetic turf playing surface (Table 2). The results also indicate that the air upwind and downwind of the playing surface lacked detectable concentrations of nitrosamines.

Table 2
Volatile Nitrosamines Results – Field F

	SF-1		SF-2		SF-3		SF-4		SF-5	
	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv
Nitrosodibutylamine (n-)	<1.1	< 0.18	<1.1	< 0.17	<1.4	< 0.22	<1.1	< 0.17	<1.0	< 0.16
Nitrosodiethylamine (n-)	<1.1	< 0.27	<1.1	< 0.26	<1.4	< 0.34	<1.1	< 0.27	<1.0	< 0.24
Nitrosodimethylamine (n-)	<1.1	< 0.38	<1.1	< 0.36	<1.4	< 0.46	<1.1	< 0.37	<1.0	< 0.34
Nitrosodipropylamine (n-)	<1.1	< 0.21	<1.1	< 0.20	<1.4	< 0.26	<1.1	< 0.20	<1.0	< 0.19
Nitrosomorpholine (n-)	<1.1	< 0.24	<1.1	< 0.23	<1.4	< 0.30	<1.1	< 0.23	<1.0	< 0.21
Nitrosopiperidine (n-)	<1.1	< 0.24	<1.1	< 0.24	<1.4	< 0.30	<1.1	< 0.24	<1.0	< 0.22
Nitrosopyrrolidine (n-)	<1.1	< 0.28	<1.1	< 0.27	<1.4	< 0.34	<1.1	< 0.27	<1.0	< 0.25

µg/m^3 = mircograms per cubic meter
ppbv = parts per billion per volume

The laboratory analysis of the air directly above the synthetic turf playing surface also lacked detectable concentrations of benzothiazole and 4-(tert-octyl) phenol (Table 3). The upwind and downwind samples yielded similar results. No detectable concentrations of either compound were noted upon extraction of the two micron PTFE filters.

Table 3
Benzothiazole and 4-(tert-octyl) Phenol Results – Field F

	SF-1	SF-2	SF-3	SF-4	SF-5
	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3
Benzothiazole	<0.19	<0.20	<0.19	<0.19	<0.20
4-(tert-octyl)phenol	<0.19	<0.20	<0.19	<0.19	<0.20

μg/m^3 = mircograms per cubic meter

Field G

Air sampling activities were conducted at Field G on August 18, 2008. The same procedures that were used in sampling at Field F were employed for the sampling at Field G. A potentially significant change in the sampling conditions was encountered during the activities at Field G. The owner of the field had groomed, or raked, the field three days prior to the air sampling activities. As a result of the grooming, the crumb rubber infill had not yet settled within the synthetic grass 'fibers" and was, therefore, more exposed at the surface.

As with the previous sampling, five discrete sample locations were chosen. The sample locations are graphically presented in Figure 9. Sampling activities were initiated at 11:17 and were completed at 15:33.

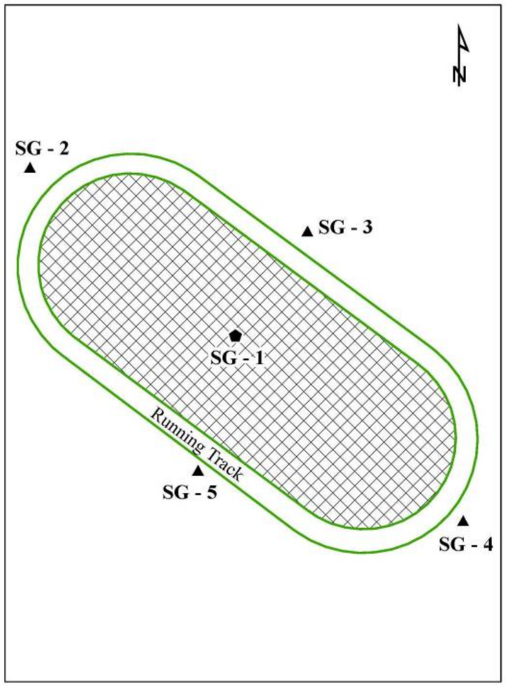

Figure 9 – Sample Locations Field G

Weather conditions on August 18, 2008, at the sample site were generally sunny with ambient air temperatures between 80° F and 85° F. Winds were generally light to calm and were variable in direction although were generally from a southerly direction. The maximum measured wind speed was three miles per hour. Figure 10 depicts the wind speed, direction, and frequency noted during the testing period.

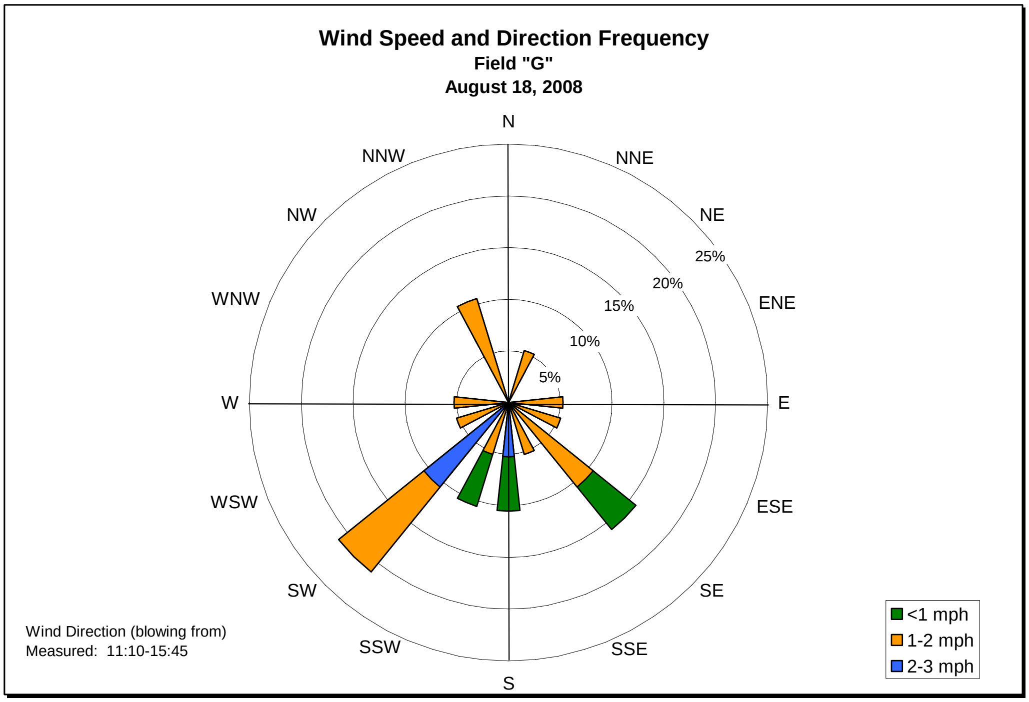

Figure 10 - Wind Speed and Direction

The air temperatures measured during the sampling at Field G are shown in Figure 11. As with Field F, the air temperature was noted to increase with decreasing height above the playing surface. The average air temperature measured at a height of five feet was 84.6° F while the average temperatures at one foot and four feet were 92.3° F and 88.4° F, respectively. The average temperature of the crumb rubber was 99.6° F. The surface temperature of the synthetic grass blades averaged 139° F.

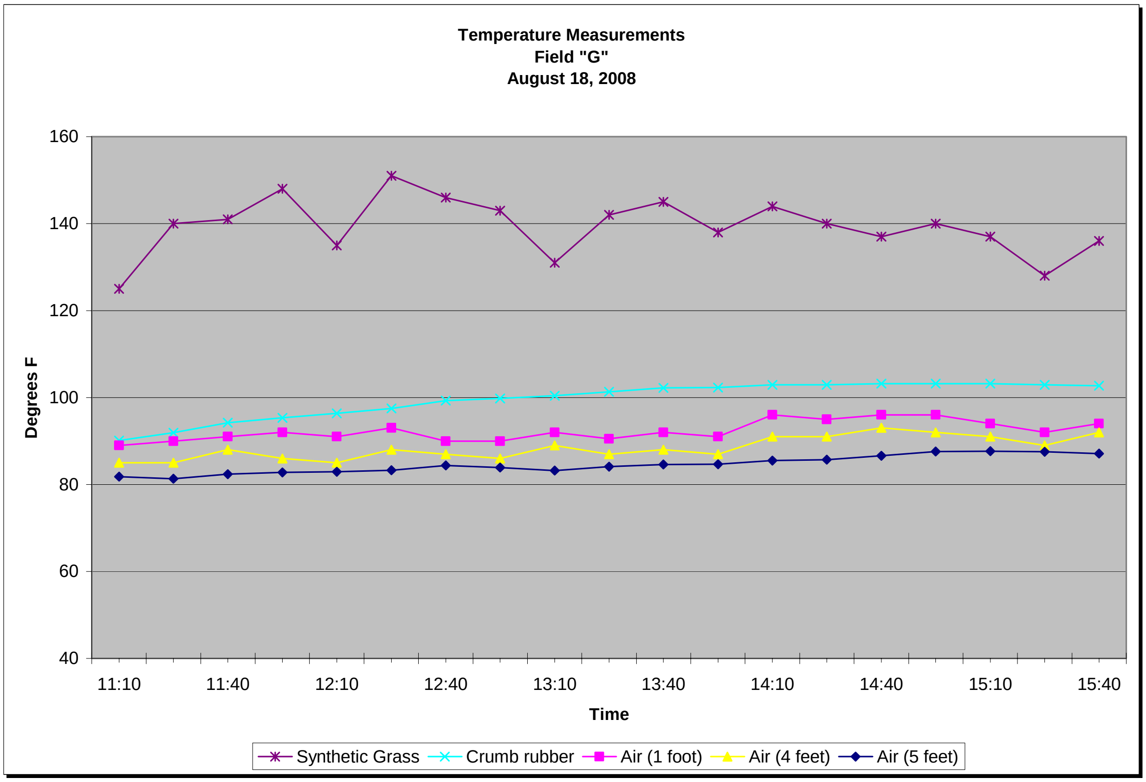

Figure 11 - Temperature Measurements Field G

All air sampling pumps were activated between 11:40 and 11:49. Table 4 details the start and stop times of the various sampling pumps and the volumes of air pumped during the sampling at Field G.

Table 4
Sampled Air Volumes - Field G
August 18, 2008

	ThermoSorb N Module			XAD-2 Module		
Sample ID	Start Time	End Time	Air Volume (L)	Start Time	End Time	Air Volume (L)
SG-1	11:22	12:37	75.75	11:22	15:23	480.96
SG-2	11:17	12:32	75.75	11:17	15:18	480.72
SG-3	11:25	12:40	75.15	11:25	15:25	481.44
SG-4	11:28	12:43	75.225	11:28	15:28	480.96
SG-5	11:33	12:48	75.525	11:33	15:33	481.20

The samples were packaged for delivery to the Wisconsin Occupational Health Laboratory at the University of Wisconsin. The analytical methods employed are described in the "Methodology" section above.

The volatile nitrosamine analysis indicated that there were no detectable concentrations of nitrosamines in the air directly above the synthetic turf playing surface (Table 5). The results also indicate that the air upwind and downwind of the playing surface lacked detectable concentrations of nitrosamines.

Table 5
Volatile Nitrosamines Results – Field G

	SG-1		SG-2		SG-3		SG-4		SG-5	
	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv	µg/m^3	ppbv
Nitrosodibutylamine (n-)	<1.3	< 0.20	<1.4	< 0.21	<1.4	< 0.21	<1.4	< 0.21	<1.4	< 0.21
Nitrosodiethylamine (n-)	<1.3	< 0.32	<1.4	< 0.33	<1.4	< 0.33	<1.4	< 0.33	<1.4	< 0.33
Nitrosodimethylamine (n-)	<1.3	< 0.44	<1.4	< 0.45	<1.4	< 0.45	<1.4	< 0.45	<1.4	< 0.45
Nitrosodipropylamine (n-)	<1.3	< 0.24	<1.4	< 0.25	<1.4	< 0.25	<1.4	< 0.25	<1.4	< 0.25
Nitrosomorpholine (n-)	<1.3	< 0.28	<1.4	< 0.29	<1.4	< 0.29	<1.4	< 0.29	<1.4	< 0.29
Nitrosopiperidine (n-)	<1.3	< 0.28	<1.4	< 0.29	<1.4	< 0.29	<1.4	< 0.29	<1.4	< 0.29
Nitrosopyrrolidine (n-)	<1.3	< 0.32	<1.4	< 0.33	<1.4	< 0.34	<1.4	< 0.34	<1.4	< 0.33

µg/m^3 = mircograms per cubic meter
ppbv = parts per billion per volume

The laboratory analysis of the air directly above the synthetic turf playing surface indicated a concentration of benzothiazole of 0.39 micrograms per cubic meter of air. No 4-(tert-octyl) phenol was detected (Table 6). The upwind and downwind samples yielded similar results. No detectable concentrations of either compound were noted upon extraction of the two micron PTFE filters.

Table 6
Benzothiazole and 4-(tert-octyl) Phenol Results – Field G

	SG-1	SG-2	SG-3	SG-4	SG-5
	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
Benzothiazole	0.39	<0.21	<0.21	<0.21	<0.21
4-(tert-octyl)phenol	<0.21	<0.21	<0.21	<0.21	<0.21

µg/m^3 = mircograms per cubic meter

Although the concentration of benzothiazole was quantified at 0.39 µg/m^3, the three trip spikes that were used as quality control recovered low for benzothiazole. The average recovery was 39% of the known spiked concentration, indicating that some degradation of the sample may have occurred prior to laboratory extraction. Assuming a similar degradation occurred for sample SG-1, the actual concentration of benzothiazole in the air directly above the synthetic playing surface may have been as high as 1.00 µg/m^3.

<u>Summary</u>

Twenty air samples were collected above and around two synthetic turf playing surfaces in Connecticut. Ten of the samples were analyzed for volatile nitrosamine content and 10 were analyzed for benzothiazole and 4-(tert-octyl) phenol content. The samples were collected on warm, late summer days during periods of light to calm winds. In one case, the synthetic turf surface had been groomed three days prior to the sampling. The sampling was conducted during periods when the temperature of the crumb rubber in-fill material was elevated due to exposure to the sun. The average temperatures of the crumb rubber were 91.7° F and 99.6° F. The surface temperature of the synthetic grass blades was noted to climb as high as 151° F. The combination of air temperatures, surface temperatures, wind speed and, in the case of Field G, the recent maintenance, are believed to be conditions favorable for generating maximum concentrations of the analytes in the air column above and around the playing surfaces.

This study determined that under favorable conditions for vapor generation, no detectable concentrations of volatile nitrosamines or 4-(tert-octyl) phenol existed in the air column at a height of four feet above the tested synthetic playing surfaces or in the air either upwind or downwind of the fields. The study did not evaluate if any of these two compounds were off-gassed from the fields, but simply that if they did, sufficient dilution within the air column existed to render them undetectable using methods based upon accepted OSHA and NIOSH procedures. The study also determined that benzothiazole, a common compound used in the manufacturing of rubber and plastics, was present at a very low concentration directly above one of the two fields sampled. This compound was not detected at the second of the two fields sampled nor was it detected in any of the upwind or downwind locations at either field. The field where benzothiazole was detected had recently been groomed, thereby bringing significant quantities of crumb rubber nearer to the surface of the field resulting in greater exposure to both the sunlight and air.

References

[1] Connecticut Agricultural Experiment Station (2007). Examination of Crumb Rubber Produced from Recycled Tires. AC005-8/07.

[2] Dye, C., Bjerke, A., Schmidbauer, N., and Mano, S. (2006). Measurement of Air Pollution in Indoor Artificial Turf Hall. Norwegian Institute for Air Research Report NILU OR 03/2006.

1001-22-1-n2408-rpt

Evaluation of Stormwater Drainage Quality From Synthetic Turf Athletic Fields

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Each year, millions of scrap tires are generated in the United States. The Rubber Manufacturers Association estimates that in 2005 seven-eighths of the scrap tires generated were ultimately consumed or recycled in end-use markets.[1] Approximately 290 million new scrap tires are generated each year.[2] Beneficial reuses of scrap tires include use as tire-derived fuel, landfill leachate collection systems, septic system drain fields, various civil engineering applications related to roadway and bridge construction, various stamped and punched rubber products, and use in athletic field and other recreational applications. The potential environmental effects resulting from the reuse of scrap tires in civil engineering applications have been evaluated by Humphrey[3, 4] and Brophy[5], among others. While these studies have concluded that the use of tire chip has a negligible effect upon ground water quality, few, if any, studies have been conducted concerning the effect on water quality resulting from the installation of synthetic turf athletic fields containing cryogenically treated crumb rubber produced from scrap tires.

Figure 1 - Synthetic Turf with Crumb Rubber Infill

This paper presents the results of a study in which the stormwater drainage from crumb rubber and silica sand in-filled synthetic turf athletic fields was analyzed over a period of approximately one year.

Methodology

Three fields within Connecticut were selected for this study. Two of the fields are located in the northern portion of the state while the third is located in the southern portion of the state. Fields F and G were constructed by FieldTurf in 2007, and Field E was constructed in 2008. All fields are multipurpose fields used for sports such as football, soccer, field hockey, and lacrosse, among others, and are encircled by synthetic running track surfaces. In all cases, edge drains were present to capture the stormwater runoff from the running track surfaces (Figure 2).

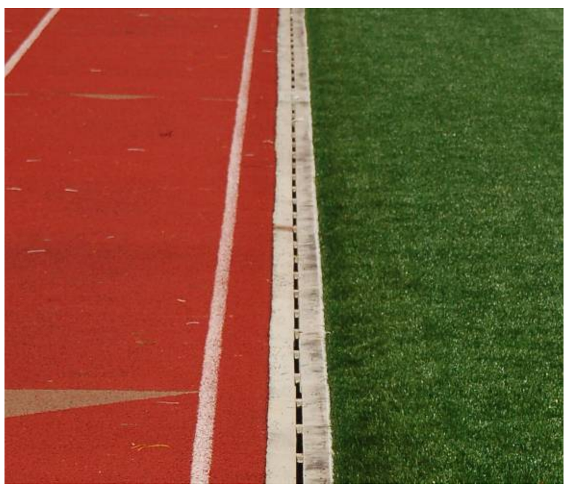

Figure 2 - Running Track Edge Drain

This allowed for sampling to be conducted of solely the stormwater that infiltrated the field surface and migrated downward through the in-fill material, through the polyethylene fiber backing, and into the underlying stone prior to entering the dedicated drainage piping. A typical cross section of a synthetic turf athletic field is shown in Figure 3.

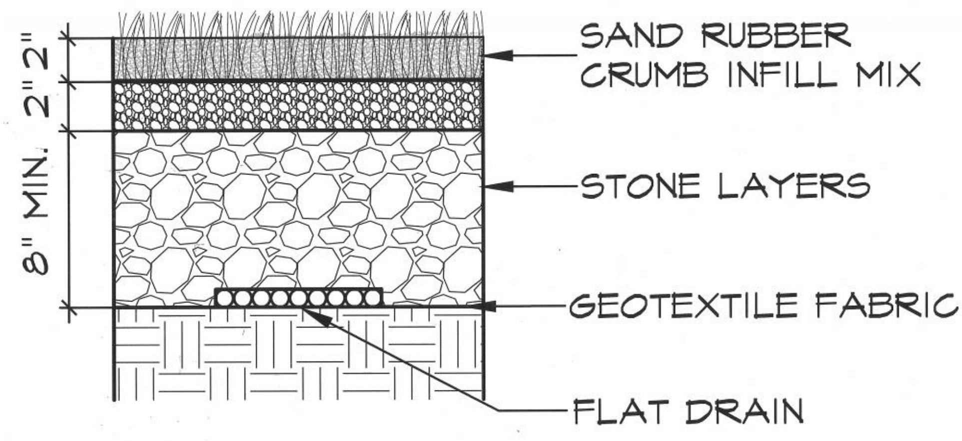

Figure 3 - Typical Field Cross Section

The use of the stone base and the flat drain systems is intended to drain stormwater out of and away from the playing surface as quickly as possible.

Each of the three sampled fields was constructed using nonmetallic underdrain systems that discharged directly to either a nearby catch basin or manhole. Grab samples of the discharge water were collected directly from the discharge pipe at the discharge location. Samples were generally collected on a calendar-quarter basis and were collected as soon as practical after the start of a rainfall event. The samples were collected using a high-density polyethylene dipper manufactured by Bel-Art and obtained from Forestry Suppliers, Inc. (catalog number 53915). The dipper was equipped with a six-foot polyethylene handle to allow for sampling without the need for entry into confined spaces. Tests performed included acute aquatic toxicity, dissolved metals (zinc, lead, selenium, and cadmium), and pH.

The aquatic toxicity monitoring was performed by GZA GeoEnvironmental, Inc. (GZA), of Bloomfield, Connecticut, in accordance with Method EPA-821-R-02-012. The water sample for this analysis was collected from Field F on October 12, 2007.

The analysis for dissolved metals content and pH was performed by Complete Environmental Testing (CET) of Stratford, Connecticut. The water samples for this analytical method were collected from Field F on October 12, 2007, October 20, 2007, November 6, 2007, February 5, 2008, April 28, 2008, and October 1, 2008. A single sampling event was conducted at Field G (April 29, 2008) and at Field E (July 24, 2008).

Subsequent to initiation of the study, the scope was expanded to include laboratory analysis of samples of the crumb rubber in-fill material. The laboratory analysis included the evaluation of metals content in an extract produced in accordance with EPA Method 1312. This methodology is referred to as the Synthetic Precipitation Leaching Procedure or SPLP. The purpose of the testing was to evaluate the potential to leach metals under acidic conditions in the controlled environment of a laboratory. The expectation was that the results would not be directly comparable to the actual in-place field conditions but would provide a useful check on the results of the drainage sampling. The analysis was performed by CET. Samples of the crumb rubber were collected from Field F on February 28, 2008, April 28, 2008, and October 1, 2008. A sample was collected from Field G on April 29, 2008, and from Field E on October 1, 2008. A sample of unused crumb rubber was also obtained from FieldTurf on October 23, 2007, and analyzed in accordance with the SPLP procedure.

Additional bench-scale testing was performed to evaluate the effect upon drainage water pH due to the stone layer that is installed under the synthetic surface materials. The tested fields were constructed using a stone layer consisting of broken basalt rock. A sample of basalt was obtained during the installation of Field E in order to perform the pH testing. The pH testing was conducted by first creating solutions of known pH. Five samples of stone, each having a mass of approximately 300 grams, were placed in separate glass jars. The known pH solution was then placed in contact with the stone samples, and the solution was monitored at five intervals up to 15 minutes. Separate control samples of tap water were prepared and served as quality control samples. Solutions of pH 4.2 and 5.2 were prepared for this evaluation.

Results

Aquatic Toxicity Evaluation

On October 12, 2007, a sample of stormwater was collected from the drainage system at Field F. The sample was placed into a container supplied by GZA and immediately delivered to GZA for an evaluation of the aquatic toxicity using *Daphnia pulex* as the test organism. The testing was conducted in accordance with EPA Method EPA-821-R-02-012. The results indicated >100% survival at both the 24- and 48-hour intervals at LC_{50} using copper nitrite as the reference toxicant.

Metals Content in Drainage Water

Samples of the stormwater were collected from Field F on October 12, 2007, October 20, 2007, November 6, 2007, February 5, 2008, April 28, 2008, and October 1, 2008. The samples were chilled and delivered to CET for analysis of the dissolved fraction of zinc, lead, selenium, and cadmium. The results were compared to the lowest aquatic life criterion for each element as established by the Connecticut Department of Environmental Protection. Table 1 summarizes the results of the laboratory analysis. The results of the laboratory analysis indicated that lead, selenium, and cadmium were not present in the drainage water. Zinc was determined to be present on four of the six sampling dates at a maximum concentration of 0.031 mg/L. The Water Quality Standard established by the Connecticut Department of Environmental Protection is 0.065 mg/L.

Table 1
Metals Content in Drainage Water - Field F

Constituent	Water Quality Standard[1]	Sample Date					
		10/12/2007	10/20/2007	11/6/2007	2/5/2008	4/28/2008	10/1/2008
metals (all units in mg/L)							
Zinc	0.065	<0.020	0.022	0.012	<0.002	0.019	0.031
Lead	0.0012	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium	0.005	<0.010	<0.005	<0.002	<0.002	<0.002	<0.002
Cadmium	0.00135	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
pH	--	7.30	7.41	7.34	7.48	7.85	7.83

[1] CT Department of Environmental Protection Standard for fresh water

A sample of stormwater was collected from the drainage system of Fields G and E on April 28, 2008, and July 24, 2008, respectively. The results, which are summarized in Tables 2 and 3, again indicated levels of dissolved zinc but at concentrations less than the applicable Water Quality Standard. Lead, selenium, and cadmium were not detected in the drainage from either Field E or Field G.

Table 2
Metals Content in Drainage Water - Field G

Constituent	Water Quality Standard[1]	Sample Date
		4/29/2008
metals analysis (all units in mg/L)		
Zinc	0.065	0.005
Lead	0.0012	<0.001
Selenium	0.005	<0.002
Cadmium	0.00135	<0.001
pH	--	8.7

[1]CT Department of Environmental Protection Standard for fresh water

Table 3
Metals Content in Drainage Water - Field E

Constituent	Water Quality Standard[1]	Sample Date
		7/24/2008
metals analysis (all units in mg/L)		
Zinc	0.065	0.036
Lead	0.0012	<0.001
Selenium	0.005	<0.002
Cadmium	0.00135	<0.001
pH	--	7.62

[1]CT Department of Environmental Protection Standard for fresh water

Laboratory Leaching Potential Evaluation

Samples of the crumb rubber and silica sand in-fill material were collected from Fields E, F, and G. The samples were collected on three different dates for Field F and on one occasion from Fields E and G. Approximately 150 grams of the in-fill material were collected on each date and delivered to CET for metals analysis in accordance with the SPLP extraction protocols. The results were compared to the criteria established by the Connecticut Department of Environmental Protection for the evaluation of the leaching potential of environmentally contaminated soil. The results, which are summarized in Table 4, demonstrate that the crumb rubber has the potential to leach metals but at concentrations less than the criteria established by the CT DEP for geographic areas that rely upon ground water as the source of potable water.

Table 4
Synthetic Precipitation Leaching Procedure - Crumb Rubber In-fill

		Date					
		10/23/2007	2/8/2008	4/28/2008	4/29/2008	10/1/2008	10/1/2008
		Raw Crumb Rubber	Field F	Field F	Field G	Field F	Field E
Constituent	Approximate "Age"	0 month	4 months	6 months	6 months	1 year	4 months
	Connecticut Pollutant Mobility Criteria	all units in mg/l					
Mercury	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Lead	0.015	<0.013	<0.013	0.006	0.004	<0.013	<0.013
Selenium	0.05	<0.01	<0.01	<0.002	<0.002	<0.01	<0.01
Cadmium	0.005	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005
Chromium	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Arsenic	0.05	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Barium	1.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silver	0.036	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	1.3	<0.04	<0.04	<0.04	<0.04	na	na
Nickel	0.1	<0.05	<0.05	<0.05	<0.05	na	na
Zinc	5	1.6	0.91	1.9	1.1	2.4	4.7

na: not analyzed

Bench-Scale pH Analysis

The measurements obtained as part of the sampling of the drainage water discharge indicated a pH that was higher than anticipated. Measurements obtained of the pH of rainfall in the town of Cheshire, Connecticut during the study period indicated a pH of rainfall that was generally between five and six units. It was theorized that the basaltic stone base used in the construction of the athletic fields had a neutralizing effect on the infiltrated rainfall at the field locations. A limited bench-scale test was developed and performed to evaluate the effect of the stone on the pH level of various prepared solutions. The stone used for the performance of these tests was obtained during the construction of Field E.

In the first test, approximately 300 grams of crushed basaltic stone were place in each of five nine-ounce glass jars. The glass jars were then filled with tap water, and the pH was measured as a function of time by sequentially pouring the water out of each sample jar and into a separate clean glass jar for evaluation. A parallel set of jars was used containing just tap water as a set of control samples. The crushed stone was determined to have minimal effect on the tap water.

Table 5
pH Evaluation - Tap Water

Jar #	Weight of Stone (g)	Duration (min.)	pH	Water	Duration (min.)	pH
1	318	1:00	7.2	Control	1:55	7.4
2	272	2:00	7.7		2:05	7.8
3	304	5:00	8		6:00	7.8
4	312	10:00	7.9		11:00	7.9
5	322	15:00	7.9		16:30	8

The test was then repeated using a solution with a pH of 5.2 units. This test determined that the stone tended to raise the pH of the slightly acidic solution by nearly one full unit within the first minute of the test and then by approximately one-half unit at the conclusion of the test.

Table 6
pH Evaluation - Prepared Solution of pH 5.2

Jar #	Weight of Stone (g)	Duration (min.)	pH	Water	Duration (min.)	pH
1	306	1:00	6.3	Control	3:00	5.4
2	326	2:00	6.4		6:00	5.6
3	308	5:00	6.2		13:00	5.8
4	286	10:00	6.4		18:00	5.8
5	286	15:00	6.4		22:00	5.9

The test was repeated once again using a solution with a pH of 4.2 units. The stone was once again determined to have a neutralizing effect on the pH of the solution. A rise of over two units was noted immediately. The final pH was similar to the end point of the test that was conducted using a starting solution of pH 5.2.

Table 7
pH Evaluation - Prepared Solution of pH 4.2

Jar #	Weight of Stone (g)	Duration (min.)	pH	Water	Duration (min.)	pH
1	312	1:00	6.6	Control	3:00	4.2
2	290	2:00	5.9		6:00	4.2
3	304	5:00	6.2		13:00	4.8
4	304	10:00	6.2		18:00	4.8
5	304	15:00	6.5		22:00	4.4

Summary

The evaluation of the stormwater drainage quality from synthetic turf athletic fields included the collection and analysis of eight water samples over a period of approximately one year from three different fields, the collection and analysis of samples of crumb rubber in-fill from the same three fields plus a sample of raw crumb rubber obtained from the manufacturer, and the evaluation of the effect of the stone base material on the pH of the drainage water. The results of the study indicate that the actual stormwater drainage from the fields allows for the complete survival of the test species *Daphnia pulex*. An analysis of the concentration of metals in the actual drainage water indicates that metals do not leach in amounts that would be considered a risk to aquatic life as compared to existing water quality standards. Analysis of the laboratory-based leaching potential of metals in accordance with acceptable EPA methods indicates that metals will leach from the crumb rubber but in concentrations that are within ranges that could be expected to leach from native soil. Lastly, it can be concluded that the use of crushed basaltic stone as a base material in the construction of the athletic fields has a neutralizing effect on precipitation.

References

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