Effect of Solar Illuminance and Albedo on Surface Temperature of Outdoor Sport Surfaces

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Abstract

The solar illuminance intensity and the surface temperature of five outdoor sport surfaces, namely, artificial turf, natural turf, artificial track, clay track, and tennis court (artificial turf infilled with sand), were measured from February 2004 to January 2005. On August 11, 2004 at 11:00 in the summer, the surface temperatures of the artificial and natural turfs, the artificial and clay tracks, and the tennis court were 67.0, 42.2, 63.9, 45.1 and 59.3 °C, respectively. On January 20, 2005 at 11:00 in the winter, the surface temperatures of the same fields were 19.6, 11.5, 21.8, 10.8, and 11.8 °C, respectively. The maximum surface temperatures were in descending order as follows; artificial turf > artificial track > tennis court > clay track > natural turf. The surface temperatures of all the sport surfaces increased with the solar illuminance intensity to around 110 kLx. The illuminance intensity began to level off around 110 kLx. The albedos of the sport surfaces seem to have a qualitative relationship to the surface temperatures rather than the effect of illuminance intensity. If the materials and the vertical structure of surfaces remain the same, it is possible to comparatively estimate the surface temperature by using the albedo.

Keywords ; surface temperature, outdoor sport surface, solar illuminance, albedo.

Introduction

The tremendous growth in the use of polymeric surfaces for an increasingly wide range of sports has made us aware of the serious lack of objective technical information on the nature and behaviour of these systems. The number of reports (Tipp and Watson,1982; Andreasson et al., 1986; Valiant, 1990) relating to the performance of a range of plastics and rubbers in these situations to their physical and chemical characteristics have been increasing with year. Unfortunately, limited work has been carried out on the issue of high surface temperatures of polymeric surfaces for outdoor sports. Under the condition of high surface temperature, sports people may be endangered in extremes of heat and at risk of hyperthermia.

Buskirk et al. (1971) reported that the surface temperature of the artificial turf peaked at 60°C on September 11 and 15, 1970 at 14:00. At the same time, on September 11, the surface temperature of the natural turf was 35°C. Subsequently, a comparison of the surface temperatures of natural turf and artificial turf measured for 21days from late September to early October was reported by Kandelin et al.(1976). The maximum surface temperature of the artificial turf reached 59°C while that of natural turf reached 45°C. These readings were taken on the respective surfaces at the same time. Aoki et al.(2005) reported the change in the surface temperatures of the artificial turf on the outdoor futsal field and the natural turf from September to December 2003. The surface temperatures of the artificial and natural turfs on September 18, were 58.5 °C and 42.1 °C, respectively. The difference of the surface temperatures between both the turfs decreased from 16.4 °C on September 18 to 4.5 °C on December 25. Thus far, comparisons of the surface temperatures of other polymeric surfaces for outdoor sports have not been considered with the exception of the paper by Aoki (2005a).
Prior to this, relationship between the surface temperatures and the absorption of solar radiation has not been systematically studied. Hartmann (1994) reported that the solar radiation that is adsorbed and emitted, largely

affects the surface temperature over land. Some fraction of the sunlight is reflected without being adsorbed. This reflectivity is termed as the albedo, which is derived from the Latin word for "whiteness". The surface albedo (Bonfils et al.,2001) is highly variable, depending on the type and condition of the surface material. Therefore, the surface albedos seem to directly affect the surface temperatures of materials.

Studies involving the measurement of the outdoor sports surfaces by using solar energy and albedo, were not reported until recently. In this paper, the relationship between the surface temperatures of outdoor sport surfaces and the solar illuminance intensity measured over nearly one year, is presented. In addition, the surface temperatures are discussed from the perspective of surface albedo .

Methods

Test Fields

Lake Biwa, the largest lake in Japan, is located near the centre of the main Japanese island of Honshu. Biwako Seikei Sport College (N35°13'39", E135°56'49") is located on the west side of Lake Biwa. Five practice fields are located on the campus as shown in Figure 1. An artificial turf (**A**: SRI Hybrid Co.,Japan, model LP-65C, green colour , made from polyethylene) was installed in February 2003 ; this turf has a longer fibre (65 mm in length) than that of the first and second generation of the artificial turf. The bottom layer was composed of silica sand, and a layer of rubber granules was laid over that. The remaining 25 mm of the fibre was left loose. In the adjacent practice field (**B** in Figure 1), common Bermuda grass was used as the natural turf. The subsurface of the natural turf practice field consisted of soil (150 mm in thickness) on top of packed small stones. The artificial track (**C**: Oku en-tout-cas Co.,Japan, model TOP ACE-CB) (400 m, 6 lanes) was installed in February 2003. The upper layer of polyurethane (3 mm in thickness), which has subsurface consisting of rubber grains (9 mm in thickness) over asphalt grains was covered with polyurethane (1 mm in thickness). The clay track (D) was in close proximity to the artificial track. The upper layer of soil (100 mm in thickness) consisted of a subsurface of a packed small-stone layer (100 mm in thickness) was covered with sand (3 mm in thickness). Tennis courts (E: Oku en-tout-cas Co.,Japan, model D120, installed in February 2003) were composed of artificial turf (19 mm in thickness, green colour , made from polypropylene) infilled with sand (17 mm in thickness) that covered asphalt (50 mm in thickness).

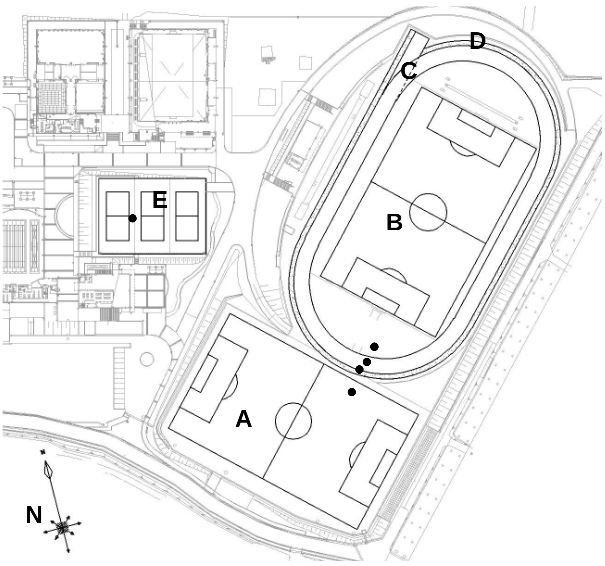


Fig. 1. Schematic diagram of outdoor sport fields in Biwako Seikei Sport College.
A: Artificial turf, B: Natural turf, C: Artificial track, D: Clay track, E: Tennis court.
• : measurement sites.

Measurements

The surface temperatures were measured with an infrared thermometer (Horiba Co., Japan, model UT-02F).The illuminance intensity on the sport surfaces from the sun was measured with a photo recorder (T & D Co., Japan, model PHR-51). The albedo of the sport surfaces was measured with an albedometer (Climatec Co., Japan , model CPR-PCR-01) prepared by Aoki (2005b).

The measurements of temperature and solar illuminance were conducted only on sunny days from February 2004 to January 2005 at 2 hour intervals from 9:00 to 17:00. Measurements, completed within 15 minutes, commenced at 9:00, 11:00, 13:00, 15:00, and 17:00. The measurements of albedo were conducted on August 24 and 25, 2006.

Results and discussion

Repetition of measurement for surface temperature

The values of repetition measurements (n=6) for the surface temperature at the measurement site of each outdoor sport surface are shown in Table 1. The relative standard deviations (RSD) were 1.3% (artificial turf), 2.4% (natural turf), 0.5% (artificial track), 0.6% (clay track), and 1.3% (tennis court), respectively. The larger RSD for the natural turf was possibly caused by roughness of the field. However, it was highly accurate that the RSDs of repetition measurement for each outdoor sport surface were less than 3%.

Table 1 Repetition of measurement for surface temperature for each outdoor sport surface.

	art. turf	natural turf	art. track	clay track	art. tennis court
	43.0	31.0	37.7	24.5	38.2
	44.1	32.7	37.9	24.8	37.5
	43.1	32.4	38.0	24.5	37.0
	42.6	32.6	38.0	24.7	37.2
	42.8	33.0	38.0	24.8	36.8
	42.6	31.6	38.3	24.8	37.2
mean	43.0	32.2	38.0	24.7	37.3
STD	0.56	0.76	0.19	0.15	0.49
RSD,%	1.3	2.4	0.5	0.6	1.3

Note : This measurement was conducted on April 18, 2004 - a sunny day (14:00-14:15)
STD : standard deviation.
RSD : Relative standard deviation.
art. : abbreviation of artificial.

Surface temperatures with time

The variations in the surface temperatures of sport surfaces with season and time are shown in Figure 2. All of the surface temperatures investigated in this study showed monthly increases from February 24, 2004(winter) to August 11, 2004(summer). The surface temperatures of the artificial turf, the natural turf, the artificial track, the clay track, and the tennis court at 11:00 on August 11, 2004 were 67.0, 42.2, 63.9, 45.1 and 59.3 °C, respectively. The difference in the surface temperatures between both the turfs was 24.8 °C, and that between the two tracks was 18.8 °C. Buskirk et al.(1971) reported that the surface temperature of the artificial turf peaked at 60°C on September 11 and 15, 1970 at 14:00. At the same time, on September 11, the surface temperature of the natural turf was 35°C. In their case, the difference in the surface temperatures between both the turfs was 25 °C similar to my result. On January 20, 2005 at 11:00 in the winter, the surface temperatures of the same fields were 19.6, 11.5, 21.8, 10.8, and 11.8 °C, respectively. The difference in the surface temperatures between the two turfs in the winter was 8.1°C, which was lower than 24.8 °C in the summer. With regard to the two tracks, the difference in the winter was 11.0°C, which was lower than 18.8 °C in the summer.

Solar illuminance affects the increase in the surface temperature of material. The variation in the solar illuminance intensity on the surfaces according to month and time is shown in Figure 3. The strongest illuminence intensity during the measurement term in 2004 was 106 kLx at 11:00 on June 16.

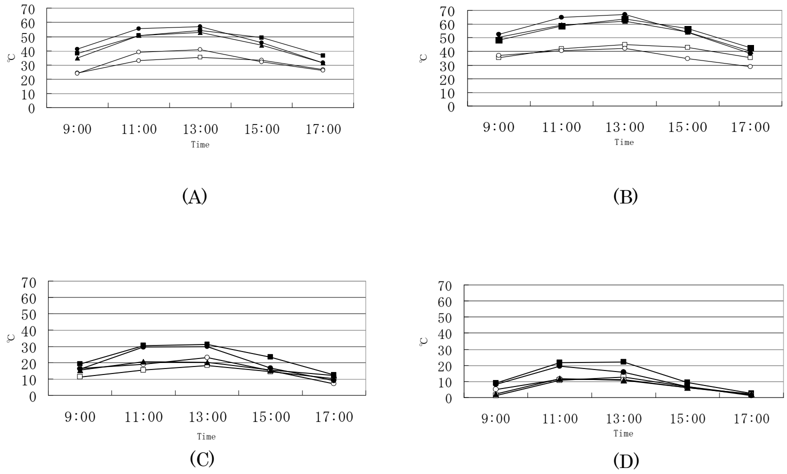


Fig. 2 Change in surface temperature (℃) of outdoor sport surfaces with season and time
A: May 25,2004, B: Aug.11,2004, C: Nov.17,2004, D: Jan.20,2005.

□: clay track,■: artificial track, ○: natural turf, ●: artificial turf,
▲: artificial tennis court.

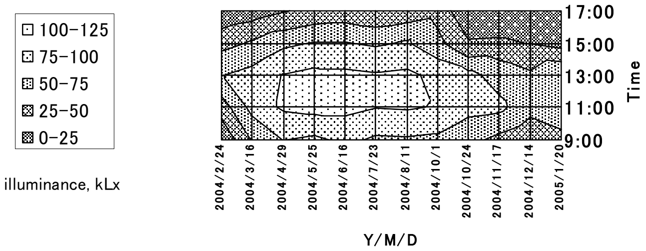


Fig. 3 Variation in solar illuminance according to month and time during 2004-2005.

Solar illuminance intensity is the main factor affecting the rise in the surface temperature of outdoor sport surfaces. The relationship between the surface temperature of each outdoor sport surface and the illuminance intensity at 11:00 on the days of measurement are shown in Figure 4. The surface temperature of each sport surface increased with the illuminance

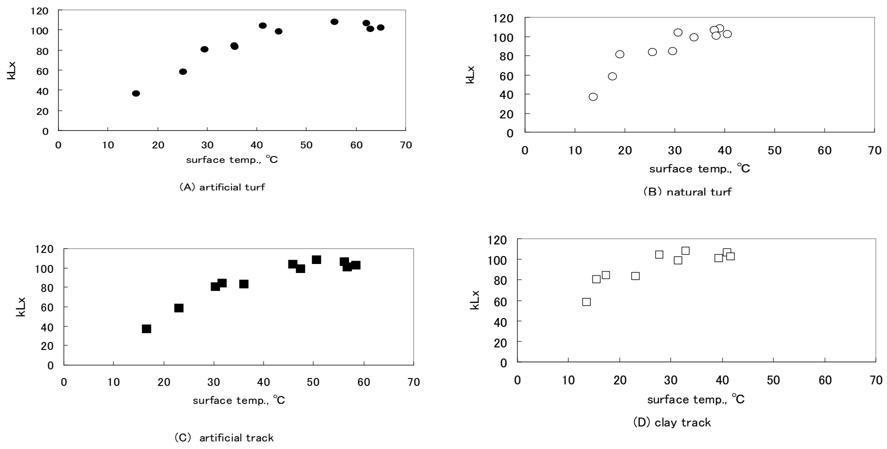
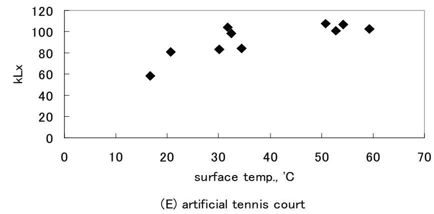


Fig. 4 Relationship between surface temperature (°C) of outdoor sport surfaces and solar illuminance (kLx) at 11:00 .



intensity to around 110 kLx. The illuminance intensity began to level off around 110 kLx. It is possible that this may be attributed to heat stored in the field in the summer, pushing the surface temperatures to a high level even after the solar illuminance has peaked.

As shown in Figure 4-A, C, and E, the surface temperatures of artificial surfaces increased up to around 60 °C in the summer. However, the surface temperatures of the natural turf (B) and the clay track (D) as shown in Figure 4 increased to only 40 °C. However, in the winter, the surface temperature difference was only a few degrees.

The reason for the lower surface temperature in the summer for the natural turf was due to the respiration of grass, which in turn lowers the temperature by evaporation of water. However, since the natural turf withered to respire very little in the winter, there is no wide gap in the surface temperatures of the two turfs.

The maximum surface temperatures were in descending order as follows; artificial turf > artificial track > tennis court > clay track > natural turf. The surface temperatures of the clay track, which is relatively low in the stated order, can be attributed to the large reflection of sunlight by the sand.

Papers which considered outdoor sports surfaces by using albedo, were not reported until recently with the exception (Honshik et al.,2007) which considered ambient UV exposure related to albedo in the field of alpine skiing. However, they did not study the surface temperature.

The relationship between albedos and surface temperatures of outdoor sports surfaces were taken into consideration by Aoki (2005b). These albedos are shown with the surface temperatures in Figure 5. According to these data, the artificial turf with the smallest albedo, had the highest surface temperature. However, the clay track covered with a thin layer of sand which had the largest albedo, had the lowest surface temperature. The tennis court which has a mixture of artificial turf and sand, had middle values of the albedo and the surface temperature. From these results, the albedo seems to be one of the main factors affecting the surface temperatures of outdoor sport surfaces.

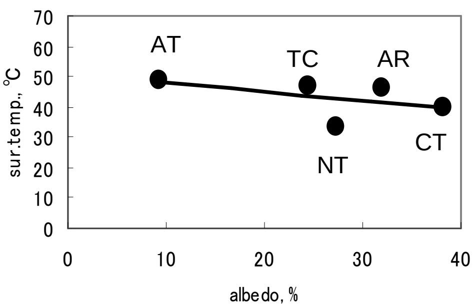


Fig. 5 Correlationship between albedos and surface temperatures of outdoor sport surfaces (Aug.24,2006).
AT: artificial turf, AR: artificial track, CT: clay track,
NT: natural turf, TC: tennis court.

The amount of increase in the surface temperature was related to the absorption of solar radiation. The surface temperatures and the albedos of the artificial track painted white, yellow, blue, and black were measured and are shown in Figure 6. The original color of the artificial track is orange. The white had the largest albedo, whereas the black had the smallest. The surface temperature of the artificial track painted white, was the lowest, whereas that of the artificial track painted black was the highest.

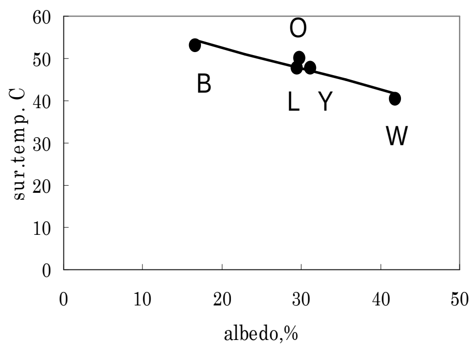


Fig. 6 Correlationship between albedos and surface temperatures on various colors of artificial track (Aug.25,2006).
B: black, O: orange, L: blue, Y: yellow, W: white.

Qualitatively, the correlation between the albedos and the surface temperatures shown in Figure 6, shows that the surface temperatures have an inverse relationship to the albedos. If the materials and the vertical structure of surfaces remain the same, we might comparatively estimate the surface temperature by using the albedo.

Summary

The solar illuminance and the surface temperature of outdoor sport surfaces from February 2004 to January 2005 were measured. On August 11, 2004 at 11:00 in the summer, the surface temperatures of the artificial turf, the natural turf, the artificial track, the clay track, and the tennis court were 67.0, 42.2, 63.9, 45.1 and 59.3 °C, respectively. On January 20, 2005 at 11:00 in the winter, the surface temperatures of the same fields were 19.6, 11.5, 21.8, 10.8, and 11.8 °C, respectively. The surface temperatures of all the sport surfaces increased with the solar illuminance intensity to around 110 kLx. The solar illuminance intensity began to level off around 110 kLx.

The albedos (reflectivity of sunlight) of the sport surfaces were related to the surface temperatures. The surface temperature where the artificial track was painted white, was the lowest and the albedo was the highest. On the contrary, the surface temperature where the track was painted black, was the highest and the albedo was the lowest. The surface temperature had a qualitative relationship to the albedo. If the materials and the vertical structure of surfaces remain the same, we might comparatively estimate the surface temperature by using the albedo.

The present studies focused on the relationship between surface temperatures and solar energy. Weather factors such as wind, probably affect the surface temperatures. In future studies, I would like to examine the effect of wind, and publish the results.

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屋外スポーツサーフェスの表面温度に与える太陽照度とアルベドの影響

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要旨

太陽照度と五つの屋外スポーツサーフェス(人工芝、天然芝、全天候型トラック、クレイトラック、砂入り人工芝テニスコート)の表面温度が 2004 年 2 月から 2005 年 1 月までの一年間にわたって測定された。2004 年夏季の 8 月 11 日 11 時の人工芝、天然芝、全天候型トラック、クレイトラック、およびテニスコートの表面温度は、それぞれ 67.0, 42.2, 63.9, 45.1, 59.3℃であった。また、2005 年冬季の 1 月 20 日 11 時の表面温度は、それぞれ 19.6, 11.5, 21.8, 10.8, 11.8℃であった。五つの屋外スポーツサーフェスの最高温度の順序は、おおむね人工芝>全天候型トラック>テニスコート>クレイトラック>天然芝となった。すべての屋外スポーツサーフェスの表面温度は太陽照度強度 110kL まで、ほぼ比例して増大し、頭打ちになった。各屋外スポーツサーフェスのアルベド(太陽光の反射率)を検討し、屋外スポーツサーフェスの表面温度とアルベドの間に、定性的に関係性を有することを見出した。また、全天候型トラック等の材質が同じで色が異なるだけであるならば、アルベドを計測することにより、それらの表面温度の違いを見積もる可能性が示唆された。

キーワード　；表面温度、屋外スポーツサーフェス、太陽照度、アルベド