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Comparison of Thermal Effects of Different School Ground Surface Materials* - A Case of Yooljeon Elementary School-

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학교운동장 피복물질 간의 온열효과 비교* - 율전초등학교를 대상으로 -

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ABSTRACT

Granite soil has been used traditionally as a school playground surface. Natural turf has also been used in some schools. Recently artificial turf has come into common use instead of granite soil or natural turf. Artificial turf playgrounds are used at 174 schools in Seoul, Korea. More than 3,500 artificial turf fields are installed in the United States. Because of the increase of artificial turf usage, there are many studies about the estimation of artificial turf effects to environment. Compared with artificial turf material effects such as characterization of substances released from material, and recognition of volatility of heavy metal into the surrounding environment - air or the percolating rainwater -, less studies for thermal effects of artificial turf playground have been done. Especially, the corresponding studies in Korea are few. Thus, the purpose of this research is to compare the thermal effects of artificial turf on school playground between natural turf and granite soil. In this study, air temperature and Predicted Mean Vote (PMV) were compared in three scenarios by Computational Fluid Dynamics (CFD) model. Additionally, the results were validated through a field measurement. Air temperature decreasing effects by natural turf are greater than those by artificial turf and granite soil at 14:30 on 20th, July 2011. It shows the same decreasing effects at 23:30. However, the difference is less than that of daytime. PMV differences between natural turf and the other two surface covers are large at daytime while those are much less at nighttime.

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Consequently, air temperature and PMV of artificial turf are the highest among three school playground surface pavements.

KEYWORDS : Thermal Comfort, CFD, Artificial Turf, Air Temperature, PMV

요 약

마사토가 학교 운동장 피복재료로 많이 사용되어 왔고 일부에서는 천연잔디를 사용해 왔으나 최근에는 인조잔디가 많이 사용되기 시작하고 있으며 서울의 경우 174개교의 운동장에 인조잔디가 설치되었고, 미국에서는 인조잔디를 시공한 곳이 운동장뿐 아니라 공원에 이르기까지 3,500곳 이상이 된다. 이러한 인조잔디 사용의 증가로 인해 인조잔디가 주변 환경에 미치는 영향은 많이 연구된 것에 비해 인조잔디가 주변 미기후에 미치는 영향은 한국에서는 많이 연구되지 않고 있다. 그러므로 본 연구의 목적은 학교 운동장에 시공되는 세가지 포장재료가 – 인조잔디, 천연 잔디 및 마사토 – 각각 주변에 미치는 기온저감 및 열환경 영향을 조사하여 학교운동장 계획에 유용한 정보를 제공하는 데에 있다. 본 연구에서는 전산유체역학기법(Computational Fluid Dynamics, CFD) 시뮬레이션을 이용하여 세 가지 포장재료에서의 기온 및 열쾌적지수(Predicted Mean Vote, PMV) 시뮬레이션 결과를 도출하여 현장 관측 기온 값과 비교하였다. 2011년 7월 20일 14시 30분 주간의 기온 저감효과는 천연잔디가 인조잔디와 마사토포장과 비교하여 가장 높게 나타났다. 야간에도 23시 30분에 기온 저감 효과가 나타났지만 주간보다는 크지 않았다. PMV효과도 역시 천연잔디가 인조잔디와 마사토포장보다 주간보다 크게 나타났으나 야간에는 별 차이가 없었다. 본 연구결과 인조잔디가 기온 저감효과 및 열쾌적성 효과가 가장 낮게 나타나 학교운동장 계획 시 이와 같은 열환경 효과를 고려할 필요가 있다고 판단되었다.

주요어 : 열쾌적성, 전산유체역학, 인조잔디, 기온, PMV

INTRODUCTION

In campus or school playground planning, the selection of appropriate surface cover materials of the playground is an important element of landscape planning. Granite soil has been used traditionally as school playground surface. Natural turf has also been used in some schools. Recently artificial turf has come into common use instead of granite soil or natural turf at school playground as a substitute of natural turf or granite soil. Ford Foundation and Monsanto Industries introduced the first generation artificial turf made by short-pile plastic fivers in 1964 for young people, especially in cities where outdoor play areas were limited. Since then, second, third and new generation artificial turf have been introduced with improving in safety, playability, appearance, durability, lower annual operating costs and maintenance requirements. It adapted not only athletic fields but also residential lawns and landscaping. In these days, more than 3,500 fields were covered by artificial turf in the United States(Cheng *et al.*, 2014; Little, 2008). In Korea, 174 school playgrounds in Seoul are covered by artificial turf in 2012(Seoul Metropolitan

Office of Education, 2012).

There are some questions about safety of materials to human health and environment. According to Li *et al.* (2010), various substances from the crumb rubber material in artificial turf are released to the environment. It affected living organisms in the near to the artificial turf ground. Also, artificial turf can bring out potential risk to human health and the environment, from the contaminants released by the crumb rubber material(Cheng *et al.*, 2014). Compared with many researches about the effects of artificial turf to human health, thermal comfort of artificial turf are less. Yaghoobian *et al.*(2010) estimated the effects of artificial turf on the energy balance of nearby buildings and the temperature of urban areas using three-dimensional heat transfer model of the urban canopy. They found out that artificial turf ground emit 2.3kW h m^{-2} day^{-1} of heat to the atmosphere, which could result in urban air temperature increases of up to 4℃. However, they did not estimate thermal comfort of artificial turf ground. Lee and Ryu(2010) investigated the influence of landscape pavements on the condition of no wind and direct solar beam exposition in Korea. The Wet-Bulb Globe Temperature(WBGT) results were abnormally high on every pavement. Thus, they concluded that the windy condition is important for thermal comfort.

Thermal comfort is an important factor in open space design. People want to feel the warm sun rays and fresh air, while they are having outdoor activity(Nikolopoulou *et al.*, 2001). Many study groups have studied outdoor thermal comfort, and methods to improve thermal environment with landscape and urban planning (Bonan, 2000; Eliasson, 2000; Nikolopoulou *et al.*, 2001; Alcoforado *et al.*, 2009; Shashua-Bar *et al.*, 2009; Bae and Kim, 2012; Moon and Jang, 2012; Chen and Ng, 2012; Cheng *et al.*, 2012; Park *et al.*, 2012; Park, 2012, 2013; Lim *et al.*, 2013; Song *et al.*, 2014; Yoon *et al.*, 2014; Taleghani *et al.*, 2015). Thermal comfort can affect positive or negative effect to the children who play on the ground during the daytime. According to Johns and Ha(1999), children are normally more engaged in physical activity than inactive activities. Moreover, Zask *et al.*(2001) found that for a school of median size(200 students), 51.4% of boys and 41.6% of girls were engaged in moderate to vigorous physical activity while 14.7% of boys and 9.4% of girls were engaged in vigorous physical activity. In terms of time spent in playground boys and girls spent 78% and 63% of their recess time engaged in physical activity, respectively (Beighle *et al.*, 2006). However, thermal comfort of artificial playground has not been studied much in Korea. Thus the purpose of this research is to compare the thermal effects of artificial turf on school playground between natural turf and granite soil. In this study, air temperature and Predicted Mean Vote(PMV) were compared in three scenarios by Computational Fluid Dynamics(CFD) model, then the results were compared with field observation and discussed and conclusions are derived finally. Ultimately, it aims to provide thermal environment information for planning and designing more comfortable school playground.

MATERIALS AND METHOD

1. Study site

The study site is Yooljeon Elementary School(37° 17'59.2"N 126° 58'07.8"E) which is located at Suwon, Republic of Korea. Suwon is one of large cities in Korea whose population is 1,147,955 (Statistics Korea, 2012). The climate of Suwon is the temperate continental climate with hot and humid summer and dry and cold winter. The average air temperature is 12.0℃, the warmest month air temperature is 25.6℃ in August, the coldest month air temperature is −2.9℃ in January. The average annual precipitation is 1312.3mm and the amount of three summer months is 780. 1mm from June to August and it occupies 59.4% of annual precipitation(http://www.kma.go.kr/weather/climate/average_regional.jsp#a1). In terms of land use, school is surrounded by the apartment and houses on three sides. There is a four lane drive road on north side of school(FIGURE 1). Green space is not much on the study area so school is an important open space. Trees are planted along the school boundary, but not densely planted.

2. Field observation

Onset HOBO Pro RH and Temperature data Logger was installed 2m high above the ground to observe air temperature and relative humidity data from 2009 to 2014. The data logger was protected by a white radiation shield to reduce the radiation effect. Observation data on July 20th, 2011 were used to input parameter for simulation and validation of simulation results. The highest air temperature was recorded on that date during summer in 2011. It was a free convection day and the cloudiness was less than 1(10%). The prevailing wind in 10m was 1.7m/s and wind direction was 180 degree (Korea Meteorological Administration, 2011a). The maximum temperature was 31.5℃, and average temperature was 27.8℃.

3. Urban microclimate simulation

To investigate the thermal effects of playground cover materials three scenarios of different playground cover were studied

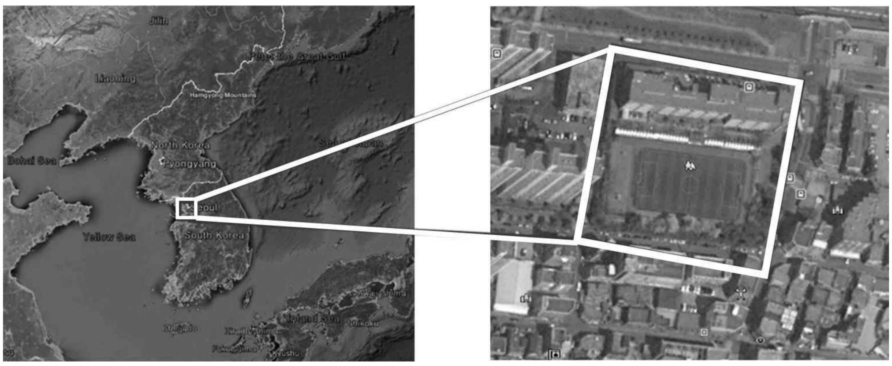

FIGURE 1. Study site location(Source: http://earth.google.com)

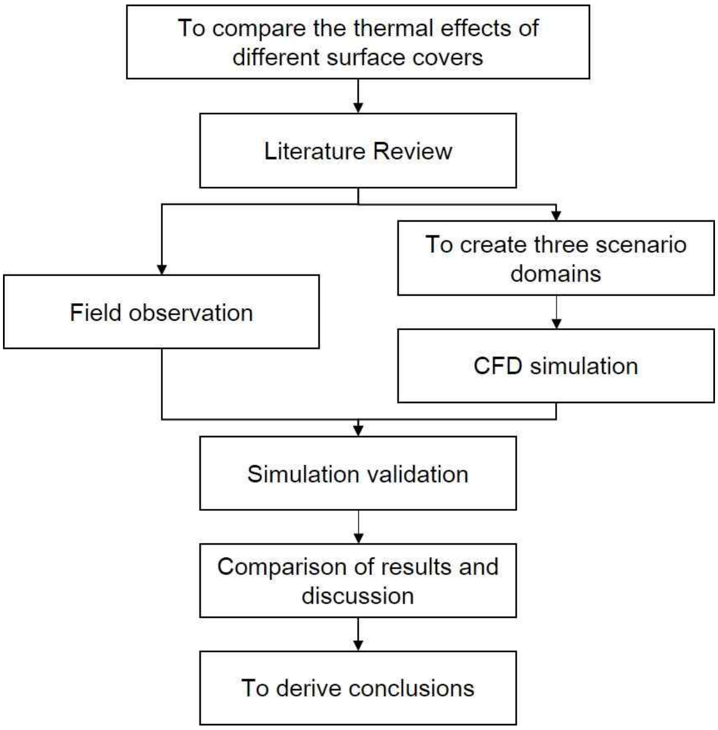

FIGURE 2. Study procedure

in this study(FIGURE 2). One scenario is the existing – playground covered with artificial turf – situation. Second scenario is natural turf playground. Last scenario is playground covered with granite soil which has been widely used for playground in Korea and mainly consists of weathered granite soil. These three scenario microclimates were simulated by CFD and tested. The urban microclimate simulation by CFD can be used to investigate the thermal environment and energy fluxes in the area concerned for different urban landscape planning. It gives the possibility to predict the thermal conditions in high spatial and temporal resolution. In addition, it makes it possible to investigate an infinite number of spots of the studied area whereas micrometeorological measurements only provide data for a limited number of spots(Yahia and Johansson, 2014). For urban microclimate simulation, ENVI–met 3.1(Bruse and Fleer, 1998) was used to simulate interactions between surface–plant–air in urban environment.

Taleghani *et al.*(2014b) studied a validated and calibrated parametric study of heat mitigation strategies for urban courtyards in Netherlands. They investigated three urban heat mitigation strategies that moderate the microclimate of the courtyards using ENVI–met. Taleghani *et al.*(2014a) studied thermal assessment of heat mitigation strategies. They simulated three scenarios – courtyard vegetation, high albedo surfaces, and courtyard ponds – to investigate potential heat mitigation strategies in a university campus environment. Song *et al.* (2014) validated ENVI−met model with in situ measurements such as net radiation, air temperature, surface temperature and wind speed. Furthermore, thermal effects of urban environment has been studied by many research groups(Song and Park, 2012; Carnielo and Zinzi, 2013; Peng and Jim, 2013; Shen *et al.*, 2013; Taleb and Abu−Hijleh, 2013; Yang *et al.*, 2012, 2013).

In addition, ENVI−met provide PMV Model to investigate thermal comfort. PMV is measured on a nine−point scale(+4= extremely hot, +3=hot, +2=warm, +1= slightly warm, 0=comfort, −1=slightly cool, −2=cool, −3=cold, −4=extremely cold). The PMV model predicts the thermal sensation as a function of activity, clothing and the four classical thermal environmental parameters such as air temperature, mean radiant temperature, air velocity and humidity. PMV model is flexible to include all the major variables influencing thermal sensation(Ole Fanger and Toftum, 2002). Originally, PMV was used for assessing moderate indoor thermal environment, however, outdoor thermal environment was studied by many study groups using PMV model(Berkovic *et al.*, 2012; Chow and Brazel, 2012; Égerházi *et al.*, 2013; Fahmy and Sharples, 2009; Lim *et al.*, 2013; Perini and Magliocco, 2014). So PMV was selected for thermal comfort estimation in this study. To calculate PMV values, input parameters were set as walking speed of 0.83m/s and resistance clothing resistance as 0.5 for hot summer(TABLE 1).

For the basic setting ENVI−met simulation starting time was 05:30 AM. July 20th in 2011. Total simulation time was 48 hours for increasing simulation accuracy and the first 24 hours results were discarded in analysis because ENVI−met needs spin−up time for simulation(Middel *et al.*, 2014). Each state results was saved at 60 minute interval. Roughness length was 1.4(Oke, 1987). Three scenario playground states were set in the input file. Three spatial domains were set up using digital map and aerial photo image from Daum map(http://map.daum.net). There are four land use types on spatial domain − Buildings, roads, green

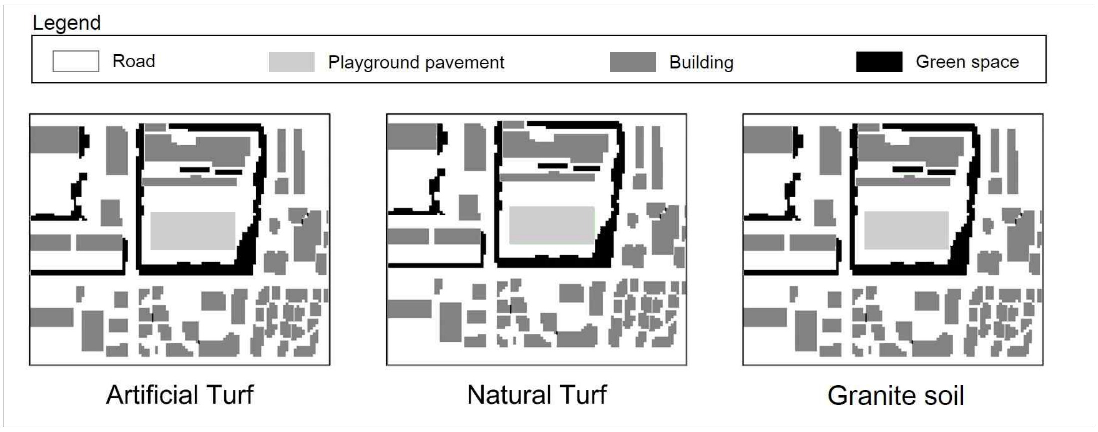

FIGURE 3. Three scenario spatial domain

TABLE 1. Input parameters

Main Data	
Start simulation at day [DD. MM. YYYY]	20.07.2011
Start simulation at time [HH:MM:SS]	05:30:00
Total simulation time in hours	48.00
Save model state each interval [min]	60
Wind speed in 10 m ab. ground [m/s]	1.7
Wind direction [0:N, 90:E, 180:S, 270:W]	180
Roughness length Z0 at reference point	1.4
Initial temperature atmosphere [K]	298.71
Specific humidity in 2500 m [g Water/kg air]	7
Relative humidity in 2m [%]	58
PMV	
Walking Speed [m/s]	0.83
Energy-Exchange [Col.2 M/A]	116
Mech. Factor	0.0
Heat transfer resistance cloths	0.5

space, and playground pavement(FIGURE 3). Granite soil parameters were added on Envi-met database file because these parameters do not exist in ENVI-met 3.1. 'Receptors' can be set to record the simulated data on specified points in the spatial domain. Two receptors were set on the domain. Receptor_O was set at the same location with observation station for simulation validation, and Receptor_S was set at the middle of the playground for comparing overall results of the playground. Both receptor data were extracted from 1.5m high above the ground.

4. Simulation validation

In order to validate simulation with field data, simulation results were compared with observed air temperature data. FIGURE 4 shows data comparison between observation data and simulation data. Generally, simulation data had lower air temperature than the observation data and daily maximum air temperature was recorded an hour early. This is a pattern of ENVI-met result because of the inadequate computation of heat storage (Middel *et al.*, 2014).

The maximum air temperature difference between observation and simulation was 1.32℃ at 07:30. The observed maximum temperature was 31.52℃ and it continued for 3 hours from 13:30 to 16:30 because the data logger was installed under the tree canopy on the playground, then cooling effects of trees lowered the maximum air temperature. According to monthly weather report (Korea Meteorological Administration, 2011b), the maximum air temperature of Suwon was 32.8℃. Considering this situation, the temperature variation graphs show similar change tendency. Regression analysis was tested to validate the simulation results. It was used to get the information about the goodness of fit of a model for validating simulation results(Fahmy and Sharples, 2009; Ng *et al.*, 2012; Chow and Brazel, 2012; Chen and Ng, 2013; Müller *et al.*,

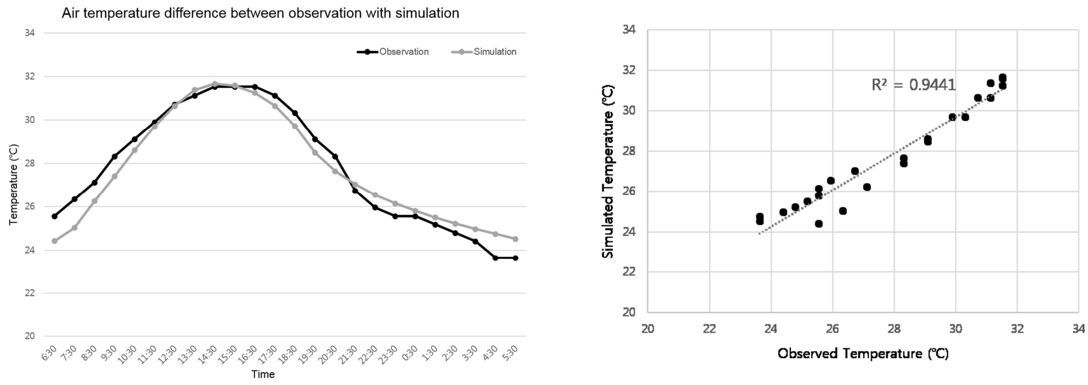

FIGURE 4. Simulation data validate with observed data

2014). R^2 value of 0.9527 in this simulation shows high consistency between observation data and simulation data.

RESULTS AND DISCUSSION

1. Air temperature

After confirming simulation validation, air temperature and PMV values of each scenario were compared and discussed. FIGURE 5 shows simulated air temperature of three receptors at the same point on three scenarios from 06:30 Jul. 20 to 05:30 Jul. 21. For the whole simulation period, air temperatures of artificial turf show the highest values while natural turf shows the lowest air temperature. At the daytime, the differences among artificial turf and other two scenarios are relatively high while the temperature differences between granite soil and natural turf are a little, almost same. Air temperature difference of each scenario at daytime (14:30) and nighttime(23:30) is shown in FIGURE 6. The maximum air temperatures of artificial turf playground, granite soil playground, and natural turf occurred at 14:30, which were 32.13℃, 31.47℃, and 31.28℃, respectively(TABLE 2). At this time, the air temperatures of artificial turf is higher than those of natural turf and granite soil by 0.85℃ and 0.66℃, respectively(TABLE 2). As we can see in FIGURE 6, air temperature of artificial turf playground is the highest while that of natural turf playground shows the lowest at the hottest time of the day. Solar radiation is an important factor to sensible heat, which varies according to surface material albedo. Albedo of natural turf is relatively high(0.26) while artificial turf albedo is 0.08. So it reflects more solar radiation(Yaghoobian *et al.*, 2010) and accumulates less heat with a lower specific heat capacity(Taleghani *et al.*, 2014a). The other reason that causes the difference among artificial turf, natural turf, and granite soil is latent heat of evapotranspiration. During evaporation, heat flux has a change in latent heat flux, which acts as a cooling effect. Natural turf absorbs water through their roots and emits it through leaves resulting in active transpiration, then evaporation occurs from natural turf(Lee *et al.*, 2009). The latent heat flux is the dominant means of heat

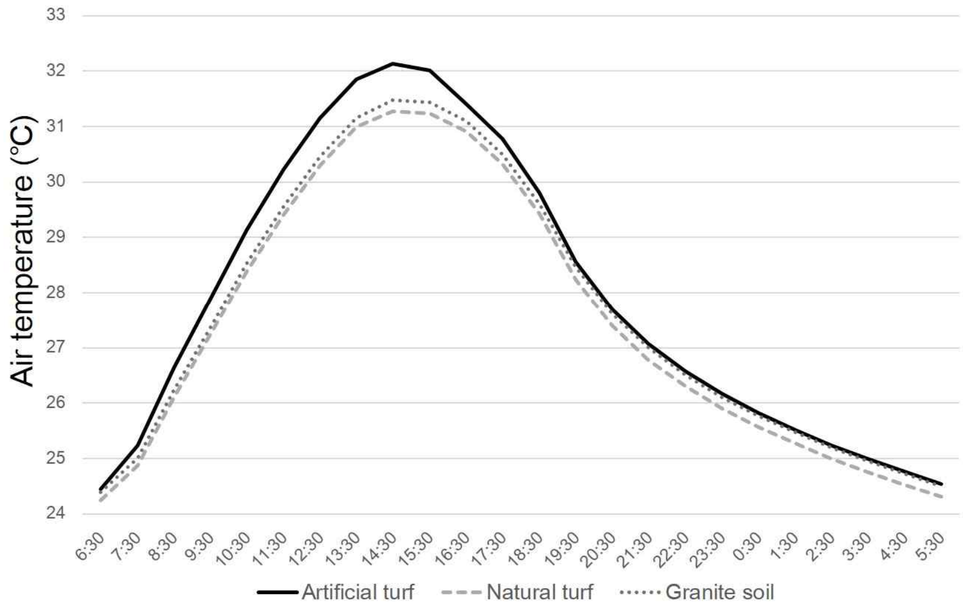

FIGURE 5. Air temperature difference between three scenarios

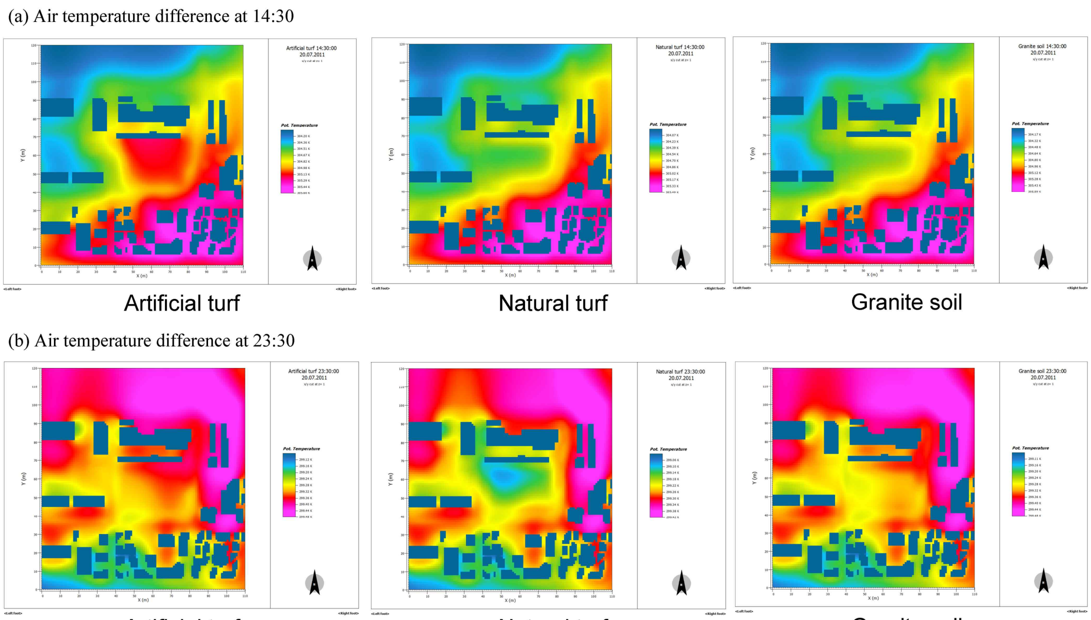

FIGURE 6. Air temperature map of each pavement materials at (a) 14:30 and (b) 23:30

removal from the grass surface by evaporation from the soil surface and transpiration by grass. This high latent heat in natural turf lowers the ambient air

TABLE 2. Maximum, minimum and average air temperature of each surface material

Air temperature	Artificial turf	Granite soil	Natural turf
MAX	32.13℃/14:30	31.47℃/14:30	31.28℃/14:30
MIN	24.44℃/6:30	24.39℃/6:30	24.24℃/6:30
Ave.	27.9℃	27.6℃	27.4℃

temperature and cools the environment more than artificial turf or granite soil. On the other hand, artificial turf cannot contain and transpire water from soil. Also, it evaporates less than natural turf or granite soil, which brings about higher air temperature during daytime.

After sunset, even though artificial turf scenario shows the highest air temperature and natural turf shows the lowest one, the difference between artificial turf and granite soil are small which are less than 0.1℃ until sunrise. Latent heat variation occurs during water phase changing by radiation in evaporation progress. Nighttime radiation is less than that at daytime because solar radiation does not exist but long wave radiation from earth emits at nighttime. For that reason, evaporation occurs less than daytime. That is why nighttime air temperature difference is less than daytime.

2. Thermal comfort by PMV

FIGURE 7 shows simulated PMV values of three scenarios. PMV values of artificial turf playground shows the highest one while that of natural turf playground shows the lowest one like the air temperature results. Maximum PMV value of artificial turf is 5.46 while those of natural turf and granite soil are 4.13 and 4.87 at 15:30, respectively(TABLE 3). FIGURE 8 shows PMV map of each pavement material at daytime(15:30) and nighttime(23:30). At daytime, students always play in the playground, yet the thermal conditions at artificial turf might be very hot for them. At 16:30, there is a sharp decrease of PMV values at all three scenarios because there are 19-story apartment buildings at western part of study site. As sun is located on western part of the sky at 16:30, apartment buildings block the sun light and provide shade. Consequently it brings about inordinately lower values in the study area (FIGURE 7, 8, 9a). During the daytime, PMV values at granite soil are slightly higher than that of natural turf. However, at night, the values of both are almost same(FIGURE 7).

PMV difference at nighttime is much less than that at daytime(1.52). Minimum PMV value of artificial turf is −0.27 while those of natural turf and granite soil are −0.3 and −0.37 at 5:30, respectively (TABLE 3). PMV values of artificial turf, natural turf, and granite soil at 23:30 are also 0.2, 0.08, and 0.05, respectively. So PMV difference between three different surface covers is small and all PMV values of three scenarios are among thermal comfort range at nighttime. The difference of PMV at three surface covers was observed only on playground, yet there are not any significant thermal effects of different ground covers to their surrounding area.

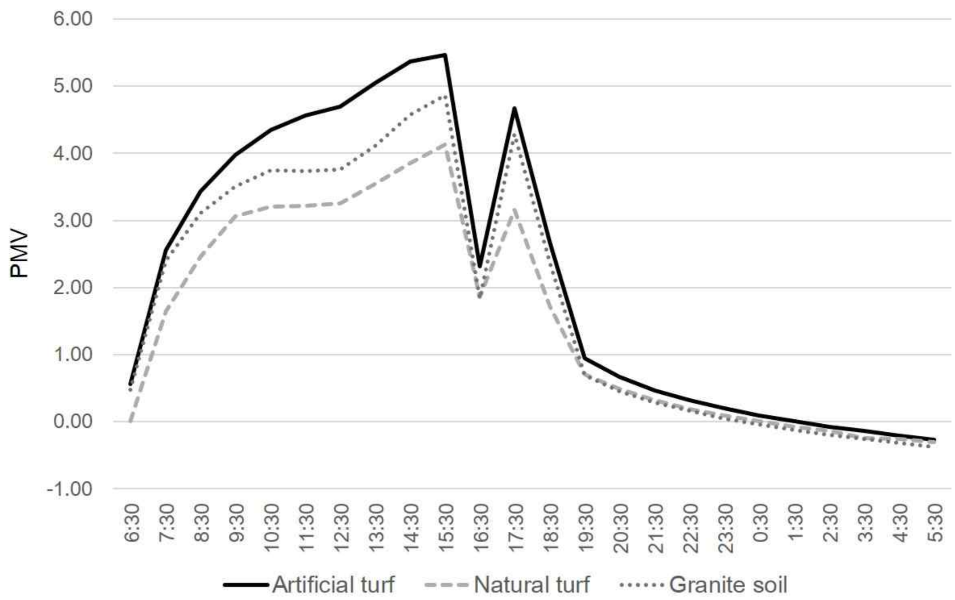

FIGURE 7. PMV difference graph

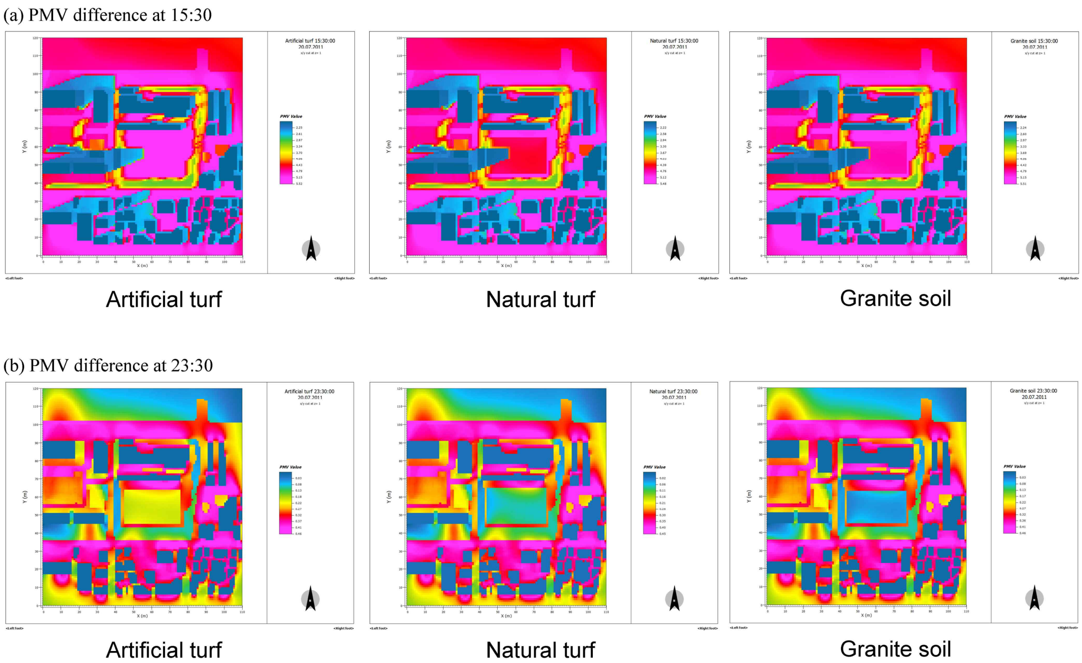

FIGURE 8. PMV map of each pavement material at (a) 15:30 and (b) 23:30

TABLE 3. Maximum, minimum and average PMV of each surface material

PMV	Artificial turf	Granite soil	Natural turf
MAX	5.46/15:30	4.87/15:30	4.13/15:30
MIN	−0.27/5:30	−0.37/5:30	−0.3/5:30
Ave.(09:30 to 16:30)	4.47	3.77	3.27

In order to investigate the effect of mean radiant temperature on PMV, regression between PMV values of artificial turf(PMV_A) and mean radiant temperature of artificial turf(MRT_A) in simulation was tested. PMV equation is (ASHRAE, 2009; ISO-7730; Lim *et al.*, 2013):

$$PMV = [0.303e^{-0.036M} + 0.028]L \qquad (1)$$

Where,

L is the thermal load on the body(W/㎡),

defined as the difference between internal heat production and heat loss to the actual environment for a person hypothetically kept at comfort values of mean skin temperature and sweat rate at the actual activity level.

M is the metabolic rate(W/㎡) and L equation is:

$$L = (M - W) - 3.96 \times 10^{-8} f_{cl}[(t_{cl}+273)^4 - (t_r+273)^4] - f_{cl}h_c(t_{cl}-t_a) - 0.305 [5.73 - 0.007(M-W) - P_a] - 0.42 [(M-W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a) \qquad (2)$$

Where,

W is the physical work output(W/㎡)

f_{cl}: is the ratio of surface area of the body with clothes to the

surface area of the body without clothes

t_a: is the air temperature(℃)

t_r: is the mean radiant temperature(℃)

P_a: is the water vapor partial pressure (kPa)

h_c: is the convective heat transfer coefficient(W/㎡ · ℃)

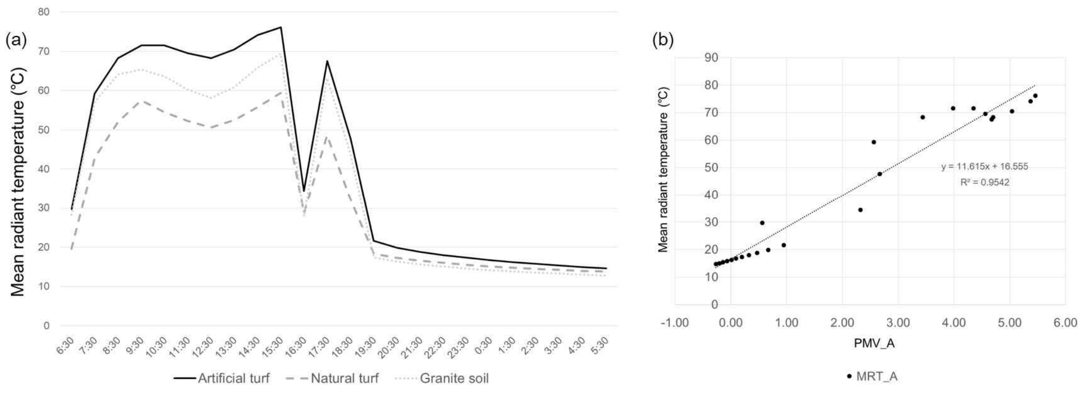

FIGURE 9. (a) Mean radiant temperature and (b) regression analysis between MRT_A and PMV_A

t_{cl}: is the clothing surface temperature (℃)

Radiation is an important factor on human thermal comfort such as PMV because radiation affects to t_r. Reflected solar short wave radiation and emitted ground long wave radiation affected considerable effect on thermal environment (Park, 2012). According to Lim *et al.* (2013), mean radiant temperature is a main factor of PMV difference in outdoor. It is mainly affected by solar radiation (Park, 2013), which affects sensible heat. Figure 9a shows simulated mean radiant temperature results at three scenarios. Mean radiant temperature of artificial turf is higher than natural turf and granite soil. FIGURE 9b shows regression plot between PMV_A and MRT_A whose R^2 is 0.9542, which means PMV_A is affected by MRT_A. Consequently, mean radiant temperature difference among three surface covers brings out the PMV difference.

CONCLUSIONS

Air temperature and thermal comfort value by PMV of three school playground surface materials were investigated by field measurement and CFD simulation at Yooljeon Elementary School at Suwon, Republic of Korea to provide information about more comfortable playground thermal environment for landscape planning.

Air temperature decreasing effects by natural turf is greater than that by artificial turf and granite soil at daytime. It also shows the same decreasing effects at nighttime, however, the difference is less than that of daytime. PMV differences between natural turf and the other two surface cover is large at daytime while those are much less at nighttime. Consequently, artificial turf playground showed the highest air temperature and PMV values among three surface materials. So it is not effective for cooling effect on playground. This should be considered for improving thermal environment in planning school playground.

One of limitations of this study is that only air temperature and relative humidity were observed in this study because of the limitation of observation equipment. More field observation data such as radiation and wind speed are needed for quality assurance of CFD simulation. This part needs to be done in further study. KAGIS

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