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LETTER

Urban heat mitigation by roof surface materials during the East Asian summer monsoon

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Abstract

Roof surface materials, such as green and white roofs, have attracted attention in their role in urban heat mitigation, and various studies have assessed the cooling performance of roof surface materials during hot and sunny summer seasons. However, summers in the East Asian monsoon climate region are characterized by significant fluctuations in weather events, such as dry periods, heatwaves, and rainy and cloudy days. This study investigated the efficacy of different roof surface materials for heat mitigation, considering the temperatures both at and beneath the surface of the roof covering materials during a summer monsoon in Seoul, Korea. We performed continuous observations of temperature at and beneath the surface of the roof covering materials, and manual observation of albedo and the normalized difference vegetation index for a white roof, two green roofs (grass (*Poa pratensis*) and sedum (*Sedum sarmentosum*)), and a reference surface. Overall, the surface temperature of the white roof was significantly lower than that of the grass and sedum roofs (1.1 °C and 1.3 °C), whereas the temperature beneath the surface of the white roof did not differ significantly from that of the grass and sedum roofs during the summer. The degree of cloudiness significantly modified the surface temperature of the white roof compared with that of the grass and sedum roofs, which depended on plant metabolisms. It was difficult for the grass to maintain its cooling ability without adequate watering management. After considering the cooling performance and maintenance efforts for different environmental conditions, we concluded that white roof performed better in urban heat mitigation than grass and sedum during the East Asian summer monsoon. Our findings will be useful in urban heat mitigation in the region.

1. Introduction

The urban heat island effect exists in urban regions worldwide that are home to more than half of the global population (Oke 1973, Karl *et al* 1988, Kalnay and Cai 2003, Grimm *et al* 2008). Given the space restrictions that characterize urban environments, roofs provide optimal spaces that can be secured easily and account for a large proportion of urban surface that can be used to mitigate urban heat through the installation of white roofs (cool or reflective roofs) or green roofs such as grass and sedum that can endure hot and dry conditions in summer (Ban-Weiss *et al* 2015). Despite active research in recent years on roof surface materials and heat mitigation (Santamouris 2014), it remains unclear which roof surface types perform best in heat mitigation under frequently cloudy conditions, dry periods, and heatwaves that characterize summer monsoon climates (Hoag 2015).

To assess the heat mitigation effects by roof surface materials, it is essential to consider the temperatures both at the surface and beneath the roof covering materials as the former influences air temperature and urban microclimate and the latter the temperature inside the building (Virk *et al* 2015). A white-painted thin coating (i.e., a white roof) can be applied to the roof surface. The difference between the temperature at the surface and underneath the coating on white

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roofs is expected to be marginal. In contrast, grass and sedum roofs form thick layers composed of planter material, vegetation, and soil layers, which can insulate the transfer of heat from the vegetation surface to the roof surface. Thus, there could be significant differences in the temperatures at the surface and underneath the layers on grass and sedum roofs (Jaffal *et al* 2012).

Most previous studies on roof surface materials have focused on either the surface temperature or the temperature beneath the surface, and have not considered both temperatures simultaneously. In general, studies at the building scale have focused on temperature reduction beneath the surface to cool the building interior in summer (Sailor *et al* 2011, Kolokotsa *et al* 2013). Most studies at the city scale have focused on the surface temperature in roof surface materials that directly influence air temperature and the urban heat island (Susca *et al* 2011, Li *et al* 2014).

The performance of roof surface materials in heat mitigation under cloudy summer conditions remains unknown. A number of studies on roof surfaces and urban heat mitigation have been carried out in Mediterranean climate regions in the dry season (Akbari *et al* 2001, Zinzi and Agnoli 2012). Most experimental studies have focused on specific short periods during the hottest sunny days in summer (Takebayashi and Moriyama 2007, Coutts *et al* 2013). A modeling study by Georgescu *et al* (2014) showed that the effectiveness of green and white roofs in urban heat mitigation decreased in humid regions such as Florida in summer. Cloudy and rainy days account for a significant proportion of summer in the East Asian Monsoon climate region and can therefore influence the heat mitigation effects of roof surface materials.

Minimizing the maintenance efforts of roof surface materials is essential for sustainable roof surface management. Vegetation requires water; thus, previous studies assessed the effects of irrigation and dry periods on the cooling performance of green roofs (Nagase and Dunnett 2010, Sun *et al* 2014). East Asian monsoon summers typically have both heatwaves as well as rainfall, and it is unclear whether vegetation, such as grass and sedum, can survive on roofs and provide cooling effects without watering during summer.

The goal of this study was to investigate which roof surface materials provide the most effective cooling by considering the temperatures at and beneath the surface of the roof covering during the summer monsoon in Seoul. We took field measurements of the temperatures at and beneath the surface for white, sedum, grass, and reference roof surface materials during three months in the summer monsoon. The questions we wished to address included: (1) how does cloudiness affect surface temperature for the three roof surface materials, and (2) which roof surface material minimizes maintenance efforts to sustain the cooling performance throughout summer?

2. Materials and methods

2.1. Experimental site and period

The experimental site was located on the rooftop of the College of Agriculture and Life Sciences building of Seoul National University, Seoul, South Korea (37.457297°N, 126.948263°E). Data were collected from 20 May to 14 September (day of year (DOY): 140–257) in 2015. Summer is defined as the period from June to August (DOY 152–243).

2.2. Roof surface materials

We investigated three roof surface materials; Kentucky bluegrass (*Poa pratensis*; hereinafter called grass), *Sedum sarmentosum* (hereinafter called sedum), and a white-painted surface. The reference roof surface was an existing rooftop of the building that was painted green. On the rooftop, we measured the surface temperature of the reference roof in a 0.5 × 0.5 m plot. The other materials were laid horizontally on the reference roof. We planted grass in a 1.8 × 1.8 × 0.4 m planter that had been filled with a 0.15 m layer of organic soil on top of a 0.1 m layer of pearlite (artificial soil). This soil mix is commonly used in roof gardens (Sun *et al* 2014). We planted sedum in a 1.0 × 1.0 × 0.1 m planter, filled with a 0.05 m layer of organic soil on top of a 0.05 m layer of pearlite. High-albedo paint (ESU–100, NOROO Paint and Coatings Co.) was painted onto the surface of a 1.8 × 1.2 × 0.01 m aluminum panel.

2.3. Data collection and processing

A hyperspectroradiometer (FieldSpec 4 Wide-Res, ASD, Inc.) was used to measure albedo for four roof surface materials (white, grass, sedum, and reference) on DOY 173 and 257. The same instrument was used to measure the normalized difference vegetation index (NDVI) for grass and sedum on DOY 140, 181, and 223. For each of the four roof surface materials, spectrum measurements were performed through a reference panel (Spectralon, Labsphere) above the target surface and then again immediately after removing the panel; the two spectra were compared to calculate the albedo and reflectance of the surface. NDVI was calculated from the red reflectance (630–690 nm) and near-infrared reflectance (750–800 nm) (Tucker 1979). Type E thermocouples (CS220, Campbell Scientific) were attached underneath the surfaces of the white, grass, and sedum materials to measure the temperature beneath the surface of each roof surface material during DOY 174–243. Three infrared radiometers (SI–121, Apogee Instrument, Inc.) were installed at 0.8 m above the sedum roof, 0.9 m above the white roof, and 0.5 m above the grass roof to measure surface temperature during DOY 140–243.

There were heatwave alerts (days when a peak daily temperature exceeding 33 °C occurred on more than

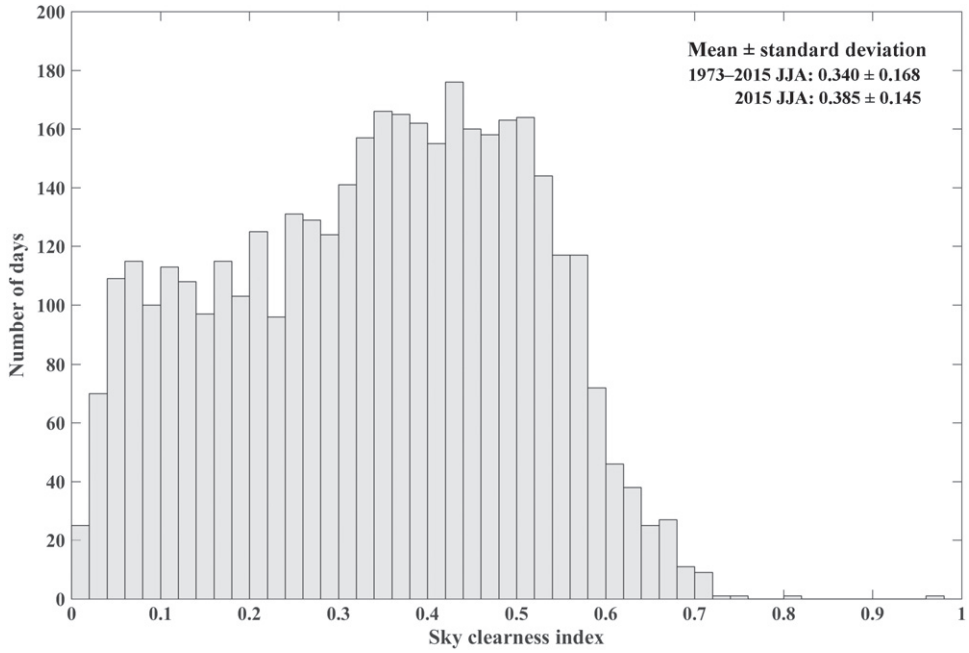


Figure 1. Distribution of daily sky clearness index from June to August (DOY 152–243) between 1973 and 2015. Mean and standard deviation of the sky clearness index for 1973–2015 and 2015.

two consecutive days) in Seoul on DOY 218–220 in 2015. To compare the degree of required management for the different roof surface materials, we specifically analyzed data for three periods that included an irrigated period before the heatwave (DOY 146–152), a non-irrigated period before the heatwave (DOY 182–188), and a non-irrigated period after the heatwave (DOY 221–227). We watered the grass with 30 l per day during the irrigated period.

The daily air temperature, relative humidity, precipitation (for 1953–2015), and solar radiation (from 1973 to August 2015) were obtained from an observatory of the Korea Meteorological Administration (Seoul 37.571406°N, 126.965708°E). To obtain the sky clearness index (the ratio of actual daily total solar radiation at the land surface, R_{sur}, to daily total potential solar radiation at the top of the atmosphere, R_{TOA}), R_{TOA} was calculated as follows:

$$R_{TOA} = \sum_{i=1}^{48} 60 \times 30 \times R_{TOA_i}, \quad (1)$$

where i is the half hour of the day. R_{TOA_i}, was calculated as follows (Liu and Jordan 1960); (Ryu *et al* 2012):

$$R_{TOA_i} = S_{sc} \times \left[1 + 0.033 \cos\left(\frac{2\pi t_d}{365}\right)\right] \times \cos\beta, \quad (2)$$

where S_{sc} is the solar constant (1360 Wm^{-2}; (Kopp and Lean 2011), t_d is the day of the year, and β is the solar zenith angle calculated from the latitude, longitude, and local time (Michalsky 1988). We calculated the daily sky clearness index by dividing R_{sur} recorded at the weather station by R_{TOA} (equation (3)):

$$\text{Sky clearness index} = \frac{R_{sur}}{R_{TOA}}. \quad (3)$$

The distribution of the sky clearness indices for 43 years of summers (1973–2015) is shown in figure 1.

2.4. Statistical analyses

Statistical analyses were performed using SigmaPlot 12.0 software (Systat Software Inc., Chicago, IL, USA). We utilized one-way analysis of variance followed by Tukey's post-hoc test to compare the mean daytime surface temperature of each of the four roof surface materials for the three periods. All results are presented as mean ± 95% CI unless otherwise specified. A p-value of <0.05 was considered to be statistically significant.

3. Results

3.1. Albedos of the roof surface materials

The albedos of the roof surface materials varied significantly (table 1). The white roof had the highest mean albedo, followed by the reference, grass, and sedum roofs. The albedo of the white roof decreased significantly between DOY 173 (0.819) and 257 (0.748) ($p < 0.05$). The grass and sedum roofs had similar albedos (~0.18) on DOY 173, but the albedo of the sedum roof decreased significantly on DOY 257 ($p < 0.05$). The reference surface maintained an albedo (~0.3) higher than that of the grass and sedum roofs from DOY 173 to 257.

Table 1. Albedos of four roof surface materials. Albedos of white, grass, sedum, and reference roofs (mean ± 95%).

	White roof	Grass roof	Sedum roof	Reference
DOY 173 (Early Summer)	0.819 ± 0.016	0.180 ± 0.016	0.174 ± 0.002	0.309 ± 0.002
DOY 257 (After summer)	0.748 ± 0.011	0.186 ± 0.009	0.141 ± 0.005	0.315 ± 0.008
Mean	0.782 ± 0.018	0.182 ± 0.010	0.160 ± 0.007	0.312 ± 0.004

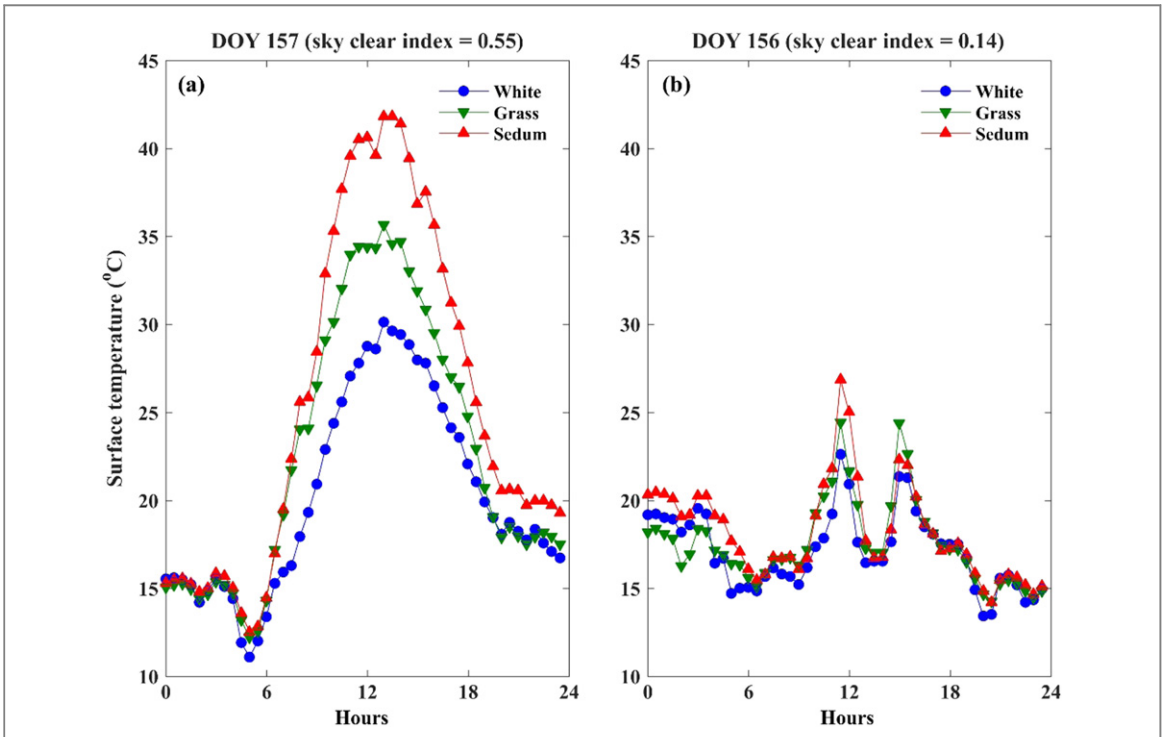


Figure 2. Diurnal patterns of surface temperature on clear and cloudy days. Diurnal patterns of (a) surface temperature on a clear day (DOY 157), and (b) surface temperature on a cloudy day (DOY 156), for a white, grass, and sedum roofs.

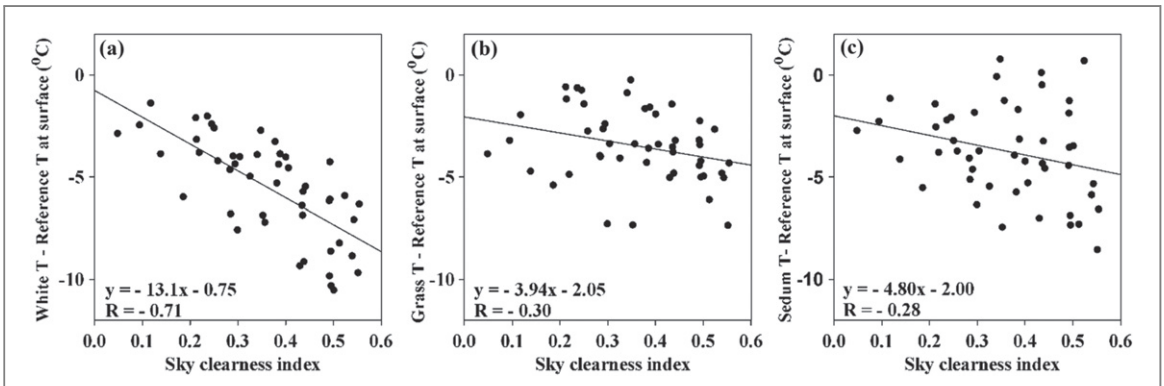


Figure 3. Relationships between sky clearness index and daytime surface temperature (*T*) differences between a reference and white, grass, and sedum roofs.

3.2. Impact of cloudiness on surface temperature

Clouds strongly influenced the diurnal patterns of surface temperature among the roof surface materials (figure 2). The diurnal patterns of surface temperature of the white, grass, and sedum roofs differed between clear and cloudy days. The peak surface temperature of the white roof was significantly lower than that of the grass (by up to 5 °C) and sedum (by up to 13 °C) roofs on clear days (figure 2(a)). The surface temperature of the white, grass, and sedum roof materials had similar diurnal patterns and values on cloudy days (figure 2(b)).

The relationships between the sky clearness index and the temperature difference between the roof surface materials and the reference surface during daytime throughout summer differed between the white roof and grass/sedum roofs (figure 3). The sky clearness index and surface temperature difference of the

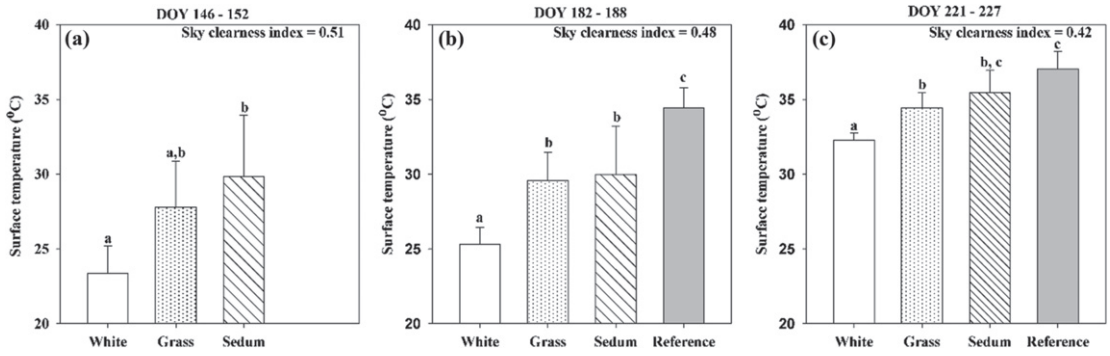


Figure 4. Mean daytime surface temperature of four roof surface materials. Mean daytime surface temperature of four roof surface materials for different periods in summer: (a) DOY 146–152 for irrigated grass roof, (b) DOY 182–188 before a heatwave without irrigation, (c) DOY 221–227 period after a heat wave without irrigation. Error bars indicate 95% CI, letters indicate significant difference among mean daytime surface temperature of the roof surface materials (Tukey test, $p < 0.05$).

Table 2. The normalized difference vegetation index (NDVI) of grass and sedum roofs. NDVI of grass and sedum for irrigated grass roof (DOY 140), before a heatwave (DOY 181), after a heatwave (DOY 223). Error bars indicate 95% CI.

NDVI	DOY 140	DOY 181	DOY 223
Grass	0.643 ± 0.001	0.554 ± 0.003	0.371 ± 0.055
Sedum	0.686 ± 0.006	0.671 ± 0.003	0.678 ± 0.007

white roof showed a marked negative correlation ($R = -0.71$). Compared with the white roof, the surface temperature difference between the green roofs and the reference showed weaker correlations with the sky clearness index ($R = -0.30$ for grass, and $R = -0.28$ for sedum).

3.3. Impacts of dry period on surface temperature and NDVI

The variations in mean daytime surface temperature and NDVI of the roof surface materials differed for the three summer periods. The mean daytime surface temperature of the white roof was lowest for all three periods regardless of watering (figure 4(a)) and heatwave occurrence (before heat wave: figure 4(b), after heat wave: figure 4(c)) ($p < 0.05$). There was no significant difference in the mean daytime surface temperature between the white and irrigated grass roofs ($p > 0.05$; figure 4(a)). While the NDVI of the sedum roof was similar in the three periods, the NDVI of the grass roof decreased significantly from 0.643 to 0.554 after the end of watering, and from 0.554 to 0.371 after the heatwave (table 2). However, there were no significant differences in mean daytime surface temperature between the grass and the sedum roofs in the three periods ($p > 0.05$).

3.4. Temperature at and beneath the surface of the roof surface materials during summer

The mean of the white roof surface temperature was significantly lower than that of the other roofs (1.1 °C) over the entire summer period (table 3). The white, grass, and sedum roofs had lower surface temperatures than the reference during both the daytime and nighttime. The white roof had the lowest peak daytime surface temperature (figure 5; $p < 0.05$). The mean differences in the surface temperature between the white and green roofs at nighttime (0.1 and 0.8 °C for the grass and sedum roofs, respectively) were significantly smaller than the differences during daytime (1.9 °C and 1.7 °C for the grass and sedum roofs, respectively; table 3). The grass and sedum roofs had similar diurnal patterns in surface temperature.

The diurnal pattern and mean of the temperatures beneath the surface differed from those at the surface among the white, grass, and sedum roofs. The mean daytime temperature beneath the surface of the sedum roof was 0.26 °C and 0.8 °C lower than that of the white and grass roofs, respectively (table 3). The temperature beneath the surface of the white roof had a larger peak than that of the green roofs during daytime, but decreased rapidly at night (figure 5(b)). The mean temperature beneath the surface of the white roof was lowest at night, whereas that of the sedum roof was lowest during the day ($p < 0.05$). The timings of the peaks of the diurnal patterns of the temperature beneath the surface for the grass and sedum roofs were delayed compared with the white roof. The grass and sedum roofs had higher temperatures beneath the surface from 00:00 to 06:00.

4. Discussion

4.1. How does cloudiness affect surface temperature in the roof surface materials?

Our results indicate that the degree of cloudiness can significantly affect the surface temperature of white roofs during the East Asian summer monsoon. Daytime surface temperatures among the three roof surface materials differed significantly between clear and cloudy days. Under clear sky conditions, surface temperature in white roof was lower than that in grass and sedum up to 10 °C (e.g. figure 2(a)), which is

Table 3. Mean and 95% CI of the temperatures at and beneath the surface of white, grass, and sedum roofs during daytime, nighttime and all day (mean ± 95% CI).

Surface temperature	White roof	Grass roof	Sedum roof	Reference	Temperature beneath surface	White roof	Grass roof	Sedum roof
Daytime	28.8 ± 0.3	30.7 ± 0.3	30.5 ± 0.3	34.0 ± 0.3	**Daytime**	28.3 ± 0.2	28.0 ± 0.1	27.0 ± 0.1
Nighttime	25.2 ± 0.3	25.3 ± 0.3	26.0 ± 0.3	27.7 ± 0.2	**Nighttime**	26.1 ± 0.2	27.8 ± 0.1	27.3 ± 0.1
All day	27.3 ± 0.2	28.4 ± 0.3	28.6 ± 0.3	31.4 ± 0.3	**All day**	27.4 ± 0.1	27.9 ± 0.1	27.1 ± 0.1

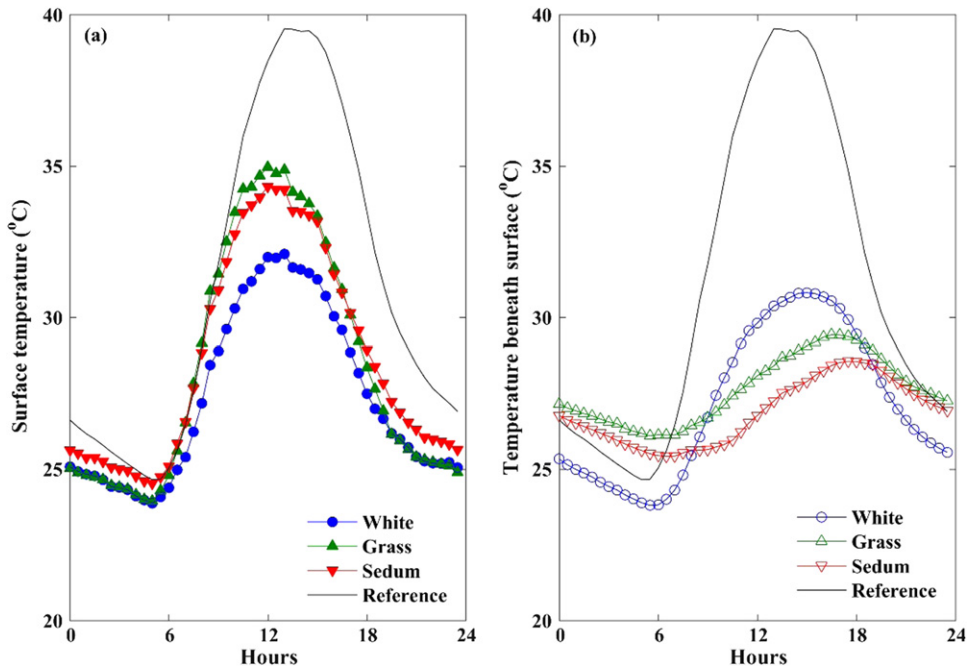


Figure 5. Diurnal patterns of the temperature at and beneath the surface of three roof materials. (a) Surface temperature of white roof, grass roof, sedum roof, and reference roof. (b) Temperature beneath the surface of the white roof, grass roof, and sedum roof. Surface temperature of reference roof is included.

comparable to previous studies (Takebayashi and Moriyama 2007, Zinzi and Agnoli 2012). The lowest surface temperature on clear days appeared in the white roof mainly resulted from its high albedo, which reflected the greatest amount of solar radiation (figure 2(a)). It has been widely reported that white roofs of high albedo maintain a lower daytime surface temperature on clear-sky days (Akbari *et al* 1997, Takebayashi and Moriyama 2007, Synnefa *et al* 2012).

Under cloudy days, we observed that the differences in daytime surface temperature among the three roof surface materials were lower (figure 2(b)). This tendency is in agreement with a previous modeling study for London, which showed that the difference in the daytime air temperature between a white and green roof decreased on cloudy days (Virk *et al* 2015). The modeling study of Georgescu *et al* (2014) showed that the difference in the air temperature between white and green roofs in California will be greater than the difference in the air temperature among these roof materials in Florida and the Mid-Atlantic in 2100. Yang *et al* (2015) reported that cooling performance of white roof depends on meteorological and geographical conditions. Although the surface cooling performance by white roof was largely controlled by cloudiness, it showed the lowest mean surface temperature among the four surface materials over the whole summer period (table 3).

The difference in the surface temperature between the white roof and the reference surface showed a stronger negative correlation ($R = -0.71$) than that between the grass ($R = -0.30$) and sedum ($R = -0.28$) roofs and the reference surface. This result indicates that the surface temperature of green roofs was controlled by not only cloudiness but also physiological mechanisms such as stomata closure and transpiration (figure 3). Thus, the cooling performance of grass roofs for diverse sky conditions is highly variable given the extreme weather events such as dry period, heat spell and rainfall.

The white roofs showed consistently lower surface temperatures than the reference for the range of sky clearness index of the 40-year mean ± 1 S.D. (0.172–0.508; figure 3(a)). Thus, we expect that the installed white roof could be cooler than the reference during summer in Seoul for most sky conditions. The

annual mean surface solar radiation in Korea increased over the 15 year period from 1990 to 2005 (Wild *et al* 2009), and the sky clearness index in Seoul has also significantly increased over the 25 years from 1990 to 2014 (0.002 yr^{-1}, $p < 0.05$ from Seoul weather station). Thus, the cooling effects by white roof in this region are likely to increase in future.

4.2. Which roof surface material minimizes maintenance efforts to sustain cooling performance throughout summer?

The white roof required minimal maintenance to sustain cooling performance. The daytime surface temperature among the three roof surface materials differed for the three periods (watering, and before and after the heatwave). There were larger variations in surface temperature for the same sky clearness index for the green roofs (figure 3). This indicates that the green roofs were influenced by biological mechanisms, such as stomata conductance and transpiration. While there was no significant difference in the surface temperature between the transpiring grass roof and the white roof during the irrigated period (figure 4(a)), during the non-irrigated periods, the surface temperature of the grass roof was significantly higher than that of the white roof. The effect of the green roofs in mitigating heat is small without a thick soil layer and watering (Thuring *et al* 2010, Coutts *et al* 2013, Li *et al* 2014, Sun *et al* 2014), because grass has a shallow rooting depth; thus, its metabolic activity is highly sensitive to the level of soil moisture (Ryu *et al* 2008, 2010). Although there was little change in the NDVI of the sedum roof over the three periods, and a significant decrease in the NDVI of the grass roof between DOY 181 and 223, there was no significant difference in the surface temperature between the sedum and grass roofs on these dates (figure 4 and table 2). This indicates that the sedum tolerated the hot summer conditions well, which was reflected in the stable NDVI, but it did not decrease the daytime surface temperature effectively (Nagase and Dunnett 2010). A previous study showed that a sedum roof that received sufficient water could significantly reduce the sensible heat flux (Coutts *et al* 2013) thus surface temperature, which differed from the findings in our study. The 2015 summer monsoon brought 395.5 mm of rainfall between June and August (Seoul weather station, Korea Meteorological Administration), which was the lowest recorded summer rainfall since 1954. We found that this amount of rainfall was insufficient to support a covering of healthy grass, which rapidly reached senescence in early August, as shown by the decrease in the NDVI (table 2). Furthermore, the vapor pressure deficit, an indicator for plant water stress, in Seoul has increased over the last 61 years (1954–2014; 56.7 Pa $decade^{-1}$, $p < 0.05$ from Seoul weather station). Thus, we expect the management of green roofs in this region to become more difficult in the future.

The accumulated dust on the white roof surface slightly decreased the albedo. A previous study reported that accumulated dust on a white roof surface reduced the surface albedo, which resulted in the decrease in the surface temperature (Gaffin *et al* 2012). We measured the albedo of the white roof on DOY 173 and 257 and found a significant decrease (from 0.819 to 0.748) during this period (table 1). To maintain consistent cooling performance of white roofs in the megacity Seoul, which experiences significant air pollution, periodic cleaning of the white roof surface would be required, which is likely easier and more cost-effective than the watering required by green roofs.

4.3. Which roof surface material is the most effective in reducing the temperature at and beneath the surface?

The white roof showed the most effective surface cooling for both daytime and nighttime throughout the summer. Our results suggest that the performance of the roof surface materials depends on the characteristics of the weather. Although the difference in the surface temperature between the green roofs and the white roof was small on cloudy days, the surface temperature of the white roof was clearly lowest on clear days (figure 2). The white roof had the lowest daytime surface temperature, which is consistent with previous studies (Takebayashi and Moriyama 2007, Coutts *et al* 2013, Georgescu *et al* 2014). The white roof exhibited the lowest mean surface temperature among the roof surfaces throughout the entire summer period (table 3).

The peak daytime temperature beneath the surface among the three roof surface materials differed from the peak daytime surface temperature (figure 5). The white roof had the highest daytime temperature beneath the surface (figure 5 and table 3). The heat capacity of the surface materials plays an important role in the variations in the temperature beneath the surface. Because the white roof consisted of a single aluminum panel that had been painted, the temperature difference between the surface and beneath the surface was smaller (0.7 °C ± 0.5 °C) than that of the green roofs (2.7 °C ± 0.8 °C and 3.5 °C ± 1 °C for the grass and sedum roofs, respectively), which were composed of soil layers. The soil layers created an insulating effect during the daytime and released their stored heat at night (Jim 2015). This caused the temperature beneath the surface of the green roofs to be higher than that of the white and reference roofs at night. These diurnal patterns in the temperature beneath the surface were also observed for white and sedum roofs in a previous study (Coutts *et al* 2013).

Overall, white roof is the most effective strategy for urban heat mitigation during the East Asian monsoon

summer. Although the daytime temperature beneath the surface of the white roof was higher than that of the sedum roof (table 3), the mean difference in the surface temperature between the white and sedum roofs (1.3 °C ± 0.4 °C) was greater than the mean difference in the temperature beneath the surface between the white and sedum roofs (0.3 °C ± 0.3 °C) on all days. Previous studies in southern Europe where low-rise buildings dominate tended to focus on reducing the temperature beneath the roof surface to decrease the energy use of the top floor of the building (Synnefa *et al* 2012, Romeo and Zinzi 2013). In the case of Seoul, a large proportion of the city is composed of high-rise buildings and apartments. Thus, reducing the roof surface temperature is likely more effective for urban heat mitigation than reducing the heat transfer from beneath the roof surface to the top floor of the building.

5. Conclusion

As the size and number of cities continue to increase, the urban heat island effect will increase accordingly, and the demand for roofs with cooling properties is likely to rise. Although the East Asian region accounts for approximately 20% of the world's population, there have been few studies assessing roof types that mitigate urban heat in a monsoon climate region. We found that white roof showed the lowest mean surface temperature (27.3 °C) over the whole summer compared to grass (28.4 °C), sedum (28.6 °C) and reference (31.4 °C) roofs although cloudiness strongly regulated surface temperature in white roof. White roof also required less effort to maintain its cooling performance than the green roofs, which required adequate watering. Thus, we suggest that white roof is more effective in heat mitigation than grass, and sedum during summer in Seoul. The findings of this study could contribute to the development of effective strategies for mitigating urban heat and provide information for city planners and policy makers in selecting more effective roof surfaces for cooling.

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