Thermal mitigation effects of hydroponic rooftop greening in urban areas

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DIGEST

1. INTRODUCTION

The urban heat island (UHI) effects are one of many phenomena caused by environmental degradation related to urbanization. The improvement of urban climate has become an increasingly important social issue. Previous studies have reported the heat flow of rooftops, but few studies have assessed the relationships between thermal mitigation and heat balance on green roofs. It is also important to consider the factors that are related to the mitigation effect on the urban greening area. This study aims to evaluate thermal mitigation effects of hydroponics rooftop greening in urban building during summer.

2. LITERATURE REVIEW

I summarize previous research on rooftop greening's effects. Section 2.2 summarizes monitoring and simulation studies of thermal mitigation effects. Section 2.3 summarizes monitoring and simulation studies of heat balance. Section 2.4 summarizes the collective research reviewed.

3. MATERIALS AND METHODS

This study was conducted on two rooftops (in Osaka and Kyoto) for two months (62 days: 1 July to 31 August) in two consecutive years (2013 and 2014). The study sites have different weather conditions. The hydroponic green system used in this study compromised a circulatory system with three open pools and two tanks, all made from polyethylene (Thickness 3 mm, specific heat capacity 2.3 J g^{-1} K^{-1}). Three hydroponic systems were installed in an area of approximately 25 m^2.

The installation locations of sensors and instruments are written as follows. I used a Campbell CR10X data logger (Campbell Scientific, Logan UT, USA) with a PHF-01 heat flux plate (Prede, Tokyo, Japan) and an array of thermocouples. Weather observation systems (Onset Computer Corporation, Bourne, MA, USA) were set up at study site.

In this study, I define mitigation indices, one each for air temperature, surface temperature, and conductive heat flux. Net radiation was estimated based on observation data. Latent heat flux on the green area was estimated using the Bowen ratio method. During analysis periods, the average difference of daily air temperature performed a simple t-test. Regression analysis was used to analyze relationships between some factors and thermal mitigation indices. Statistical analyses were carried out using R ver.3.3.2.

4. RESULTS

The mitigation effects of the hydroponic urban greening system on the thermal environment were examined using daily and hourly observation data. I used the daily data from 1 July to 31 August for 2013 and 2014, and the hourly data during especially hot periods (EHP).

In weather conditions, air temperatures in the green roof and bare roof areas increased gradually until mid-August 2013. The total precipitation for the period 1 July to 31 August 2013 was 177.2 mm. The average air temperature for the two months was 28.5 ± 0.2 °C on the green roof area and 30.3 ± 0.3 °C on the bare roof area. The average difference in air temperature between the two was 1.8 °C ($p < 0.05$). During summer 2014, air temperatures in the green roof and bare roof areas increased gradually until the end of July, and in August lower temperatures and higher precipitation were recorded than in the previous year. In 2014, from 1 July to 31 August, total precipitation was 537.9 mm. Average air temperatures for the two months was 26.5 ± 0.2 °C on the green roof area, and 28.4 ± 0.4 °C on the bare roof area. The average difference in air temperatures was 1.9 °C ($p < 0.05$).

I performed regression analysis for the mitigation indices from meteorological elements observed at experimental site. Higher coefficients of determination were found in the regressions of the mitigation indices on ambient air temperature and solar radiation. Compared with the coefficients of determination for these two elements, those on the other elements were lower. A possible rationale for the low coefficients of determination of the other elements might results from indirect action of these elements on the thermal environment.

I also analyzed the thermal mitigation effects from heat balance elements based on the environment data. I showed the relationships between heat balance factor and thermal mitigation indices of the hydroponic urban green system. The coefficient of determination for the regression between latent heat flux and the mitigation index for air temperature was 0.59 in total. When latent heat flux increased, the ratio of decreasing air temperature also increased. The coefficient of determination for the regression between latent heat flux and the mitigation index for surface temperature was 0.71 in total. When latent heat flux increased, the ratio of decreasing surface temperature also increased.

5. DISCUSSION

In this study, the green roof area occupied by the hydroponic green system was always flooded with water, causing active evapotranspiration that I conjecture was directly responsible for evaporative cooling that decreased the air temperature. The coefficient of determination of 0.51 for the regression of the mitigation index for air temperature on daily ambient air temperature indicates a strong linear relationship between these variables. The coefficient of determination of 0.68 for the regression of the mitigation index for air temperature on daily integrated solar radiation indicates an even stronger relationship. Thus, solar radiation was the dominant factor that affected the mitigation of increasing air temperature, due to increases in the evapotranspiration from the hydroponic green system.

I found the coefficient of determination of 0.83 for regression of the mitigation effect on surface temperature on daily solar radiation. Solar radiation also affected the mitigation of increasing surface temperature due to evapotranspiration from the hydroponic green system and the interception of solar radiation by the hydroponic green system.

When only the latent heat flux was used to assess the thermal mitigation indices, it was difficult to provide a uniform evaluation method for 2013 and 2014. The difference in the heat balance between green roof and bare roof areas is related to factors such as latent heat flux, conductive heat flux, and water heat storage flux. In order to uniformly evaluate thermal mitigation on the different rooftops and to improve the accuracy of the regression model, I proposed assessment methods for thermal mitigation indices that included these three factors. I defined the thermal mitigation factor as the sum of the three heat balance factors (latent heat flux, conductive heat flux, and water heat storage flux).

Thermal mitigation effects on green rooftop varied according to weather conditions and differed from those of the bare roof surface. Findings concerning the thermal environment can be difficult to translate into an urban greening strategy. Consequently, the use of the proposed assessment model provides a simple method for evaluating how the green roof influences thermal mitigation.

6. CONCLUSIONS

I clarified the effect of a hydroponic green system on the thermal environment of an urban rooftop, including consideration of the influence of weather conditions. I also investigated the mechanism of cooling using a heat balance model that simulates the effect of a hydroponic green system on the thermal environment. The presence of water and plants in a hydroponic system might be expected not only to mitigate the thermal environment, but also to provide additional benefits. I will continue to study the mitigation effects, paying attention to the multiple roles of the urban rooftop.