

Heat Island Mitigation Effects of Various Ground Cover Materials in and around Yokohama Campus, Tokyo City University

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ABSTRACT

Yokohama Campus of Tokyo City University (TCU-YC) is located inland of Yokohama, yet it is endowed with various kinds of greenery. People can enjoy nature even in this urban area. It has a water reservoir (a biotope, in this case, aquatic habitat) and we can find groups of trees and shrubs everywhere on the campus. The surface temperature of various materials covering the ground was measured using infrared thermal images and the heat island mitigation effect (HIME) was estimated in terms of the heat island potential (HIP) in summer. We found that, even though TCU-YC is located in an urban area, the HIME there is high thanks to the forest as well as the biotope.

Key Words: Urban surface, Ground cover material, Surface temperature, Heat island potential, Field measurement, Diurnal variation, Heat island mitigation, Thermal design

1. Introduction

The rate of temperature rise due to global warming is about 0.7 °C/100 years, while the rate due to heat island effect in Japanese cities can be as high as ~ 2.2 °C/100 years⁽¹⁾. Heat island effect (HIE) has become serious in recent years due to the increased thermal capacity of artificial materials on one hand, and on the other hand, to decrease in land cover by greenery (vegetation) and wetlands. In the summer of 2016 in Japan, 21,383 people were struck down by heat stroke and among them, 59 people died⁽²⁾. A nuclear accident associated with the great earthquake in Japan in 2011, made clear the importance of energy saving. In order to suppress HIE and promote energy saving, cool roof materials were found effective and very important in urban areas⁽³⁾.

Symbiosis with nature is indispensable. In a well-planned 'environmental city', the quality of life must be guaranteed even after exhaustion of active cooling resources. The effect of solar shading by leaves and the transpiration of plants should be considered. Moreover, forests and wetlands are important for the preservation of biodiversity⁽⁴⁾. The ratio of green land cover (in Tsuzuki-ku, Yokohama) decreased from 38.1% to 31.8% during the 13 years from 2001 to 2014. For wild creatures to survive there, it is essential to maintain at least the current balance. We

should keep 'Satoyama'⁽⁴⁾.

We find that TCU-YC is a good subject for this experiment and that it is desirable to improve it to the level of Satoyama. Endangered species can be found on TCU-YC, and the campus has both a sizable aquatic biotope and a forest. Our students are in charge of them; the faculty teach the their management and then students use them in educational activities for children.

In this research, we conducted a study of the thermal environment, taking advantage of the aquatic biotope and forest at TCU-YC. We calculated thermal conditions quantitatively using Heat Island Potential (HIP)⁽⁵⁾, which is a good index of the heat island mitigation effect (HIME). HIME is evaluated by the decrease of sensible heat flux and is expressed by HIP. We used high-resolution thermography, and analyzed the data. By this procedure, we unveiled differences in the HIME provided by various kinds of plant cover (greenery) and artificial materials. From the viewpoint of the HIME, we evaluated the present condition of thermal environment in TCU-YC by using HIP. On the basis of the results, we estimated the future condition with the change of land coverage. The evaluation of HIME was carried out in the height of summer.

2. Measurement location and method

We measured the temperature of various surfaces on the university campus (such as a parking lot, RC, grass, shrubs, and the biotope) and those in the surrounding residential area. Figure 1 shows the various land cover surfaces on TCU-YC. The letters A–E indicate areas where we took infrared thermal images; the star symbol ★ indicates a weather monitoring station. The infrared images were captured from the fifth floor (approximately 15 m high) of a building sandwiched between E area and D area. The measurement was carried out every two hours until 10 a.m. on August 11 from noon of August 10, 2016. It took approximately 15 min in each series of measurements. We also performed continuous measurements of underground, ground, and water temperature (every 10 min). The measurement points were almost the same points as in the thermal images. The measurement sensors were water-proof thermistors. The depth of underground and water measurements was less than 5 cm from the surface. When the ground temperature was measured, the sensor was fixed with aluminum tape. We also used meteorological data from a local meteorological observatory close to the sea in Yokohama, and data from an observatory in Midori-ku (in Yokohama City) of the residential area, excluding TCU-YC.

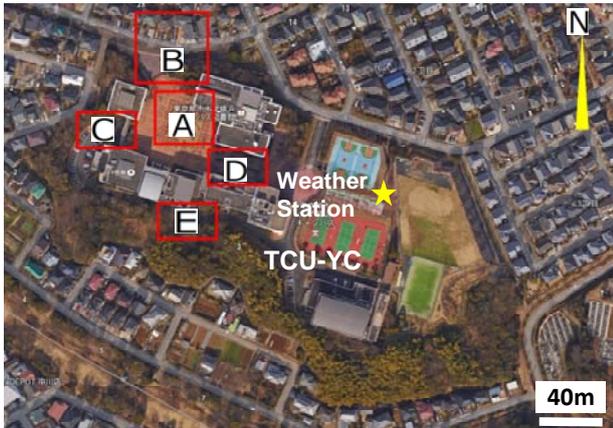


Fig. 1 Measurement site and capture areas of infrared thermal images (retrieved from Google Maps)

3. Measurement results and discussion

3.1 Meteorological data

We compared the air temperature data from three sources: the university campus, the Yokohama local meteorological observatory, and the elementary school in Midori-ku. Figure 2 shows these data for eight days. Data are included for several days before the date of the thermal imaging. The result is remarkably clear: TCU-YC > Midori-ku Elementary School > Yokohama. We note that the temperature difference is sizable in the daytime but almost negligible in the evening. We also calculated the absolute humidity using the air temperature and

the relative humidity data. The results show Yokohama > Midori-ku Elementary School > TCU-YC, in Fig. 3. There was no rainfall during this period. Hot, clear days occurred before the

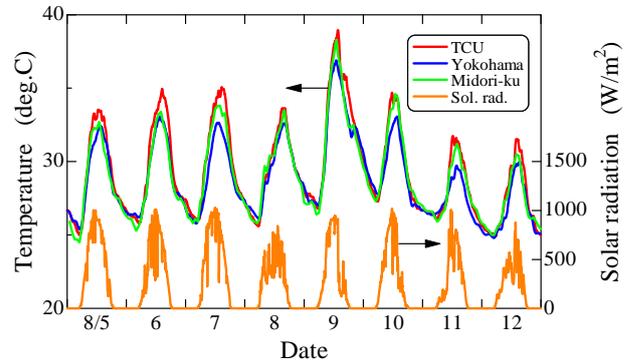


Fig. 2 Daily variation of air temperature and solar irradiation in Yokohama area

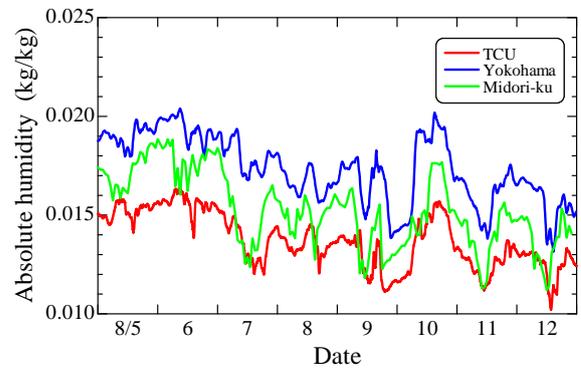
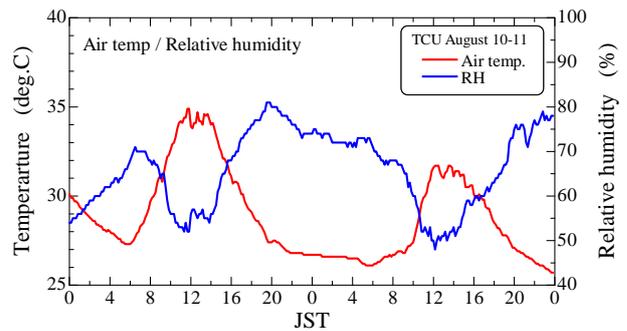
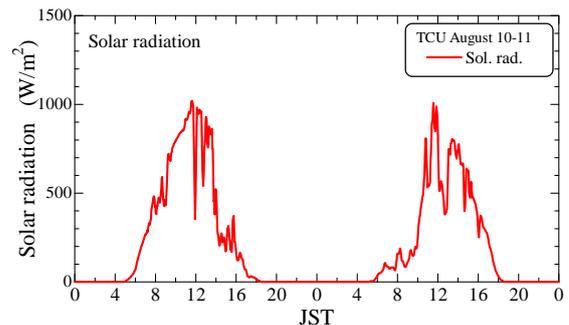


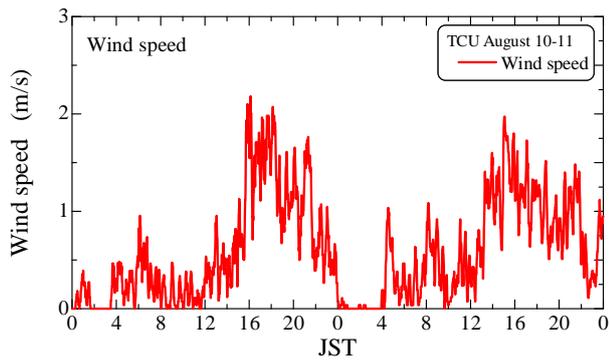
Fig. 3 Daily variation of absolute humidity in Yokohama area



(a) Air temperature and relative humidity



(b) Horizontal solar irradiation



(c) Wind speed

Fig. 4 Meteorological data of measurement date in Yokohama campus of Tokyo City University

measurement date. The meteorological data are shown in Fig. 4 (a)–(c) for the capture measurement of infrared thermal image in TCU-YC. The hot clear days are typical of summer weather.

3.2 Thermography and ground temperature data comparing artificial and natural ground cover

Figures 5–7 indicate thermal images captured at noon and just after midnight in area A, B, and D. There is a biotope in the central part of area D, and the water is always drained. It was found that the range of the surface temperature was remarkable in the daytime, but was not outstanding at night. The surface temperatures of artificial materials such as asphalt, concrete and brick were much higher than those of the natural materials such as plant and water surfaces in the daytime. The temperature of the tiled roof of the single house was the highest, and exceeded 50 °C at noon. At night, the temperature difference became small in comparison with the daytime, but the surface temperatures of the artificial materials were clearly higher than the natural surfaces. The cause appears to be the significant thermal capacity of the artificial surface materials⁽⁶⁾. Tiled roof in area B and wood deck built over the biotope in area D became the high temperature in the daytime, but, the temperature difference with the nature surface was dissolved at night.

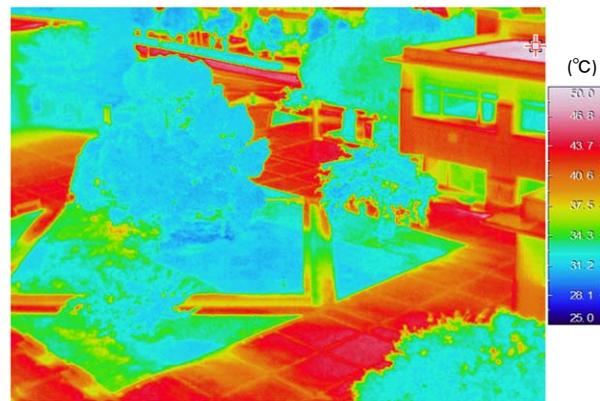
The surface materials which represented this campus were chosen among the thermal images as shown in Table 1. The forest was composed of cherry and camphor tree. The species of shrub was Boxwood (*Buxus sempervirens*). The species of undergrowth was *Ophiopogon japonicas*. The latter was planted around the roots of trees and had good exposure to sunlight. The number of pixels used was decided according to the area of each of the surface materials. The total pixels of the detector were 320 × 240. The spatial resolution was 1.78 mrad. The smallest temperature indication was 0.06 °C. The minimum number of pixels was > 300, and the maximum number was < 5000 (according to the area). The standard deviation for each material at each measurement was small enough, and the significance of

the average temperature of the chosen pixels became clear.

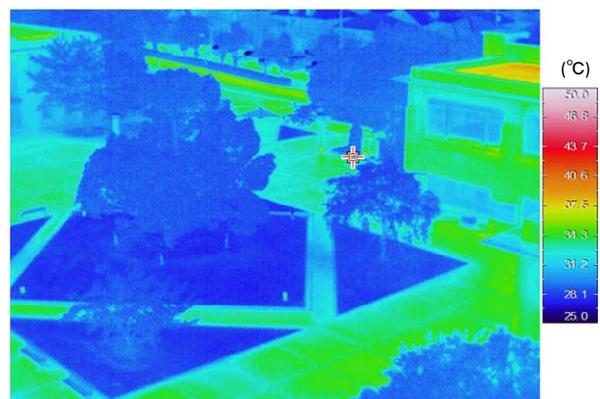
Figure 8 shows the diurnal variation of the surface temperature of the various materials shown in Table 1. Except for the tiled roof, the surface temperatures of artificial materials were higher all day than those of natural materials. The state that the artificial surface temperatures were higher than the air temperature was maintained even at night. The surface temperature of the tiled roof became the highest in the daytime, but was about the same as the natural surfaces by night. The water temperature was the



(a) Photograph



(b) Infrared thermal image at noon

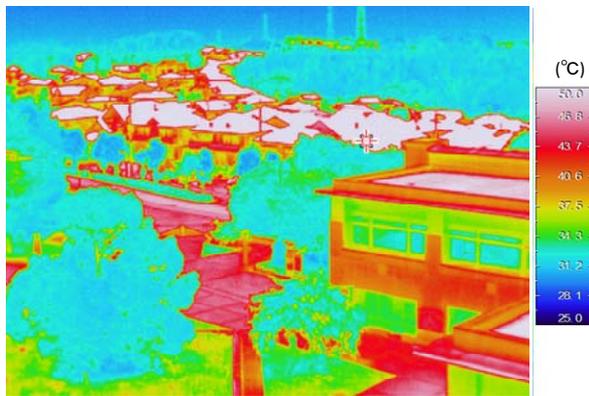


(c) Infrared thermal image just after midnight

Fig. 5 Scenery and infrared thermal image in area A



(a) Photograph



(b) Infrared thermal image at noon

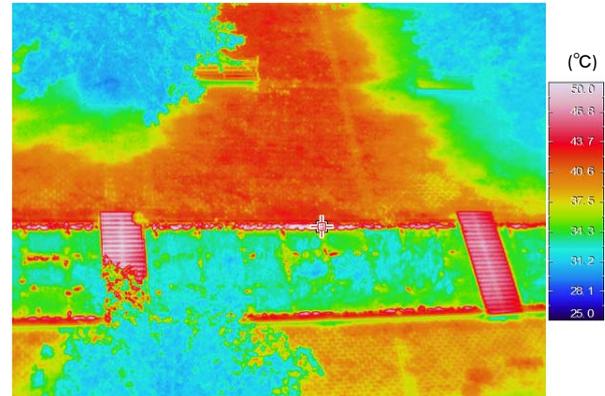


(c) Infrared thermal image just after midnight

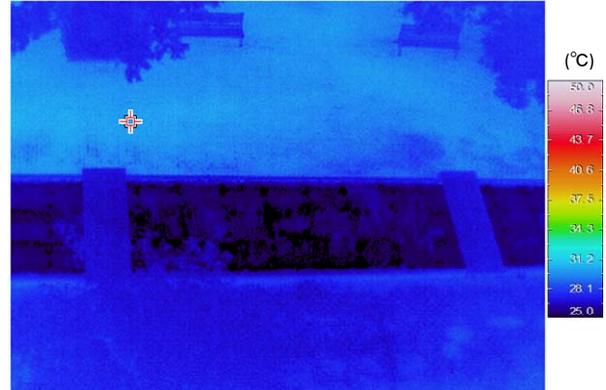
Fig. 6 Scenery and infrared thermal image in area B



(a) Photograph



(b) Infrared thermal image at noon



(c) Infrared thermal image just after midnight

Fig. 7 Scenery and infrared thermal image in area D

lowest (usually) all day long. Figure 9 shows the diurnal variation of the surface temperature of various plants. The standard error of the average surface temperature from the image was nicely small thanks to the many pixels used for analysis of the surface temperatures. This made it possible for us to distinguish the HIME between various plants using Welch's t-test. The level of significance was $p < 0.1\%$. The difference in surface temperature between trees and grass was significant. Our

analysis indicated a high HIME for the biotope. It contained running water, so the temperature remained low. In the grassy area, the surface temperature in the daytime was notably high. In contrast we found that the temperature was nicely suppressed in the other natural areas (shrubs, forest, and biotope). Figure 10 shows the diurnal variation of the underground, ground, and water temperatures of various materials shown in Table 2, as measured by contact thermometers using thermister

Table 1 Surface materials and the areas from which infrared thermal images were extracted

Surface material	Area	Surface material	Area
Asphalt	C	Forest	E
Brick	A	Grass	A
RC roof	B	Biotope	D
Tile roof	B	Shrub	B
		Undergrowth	C

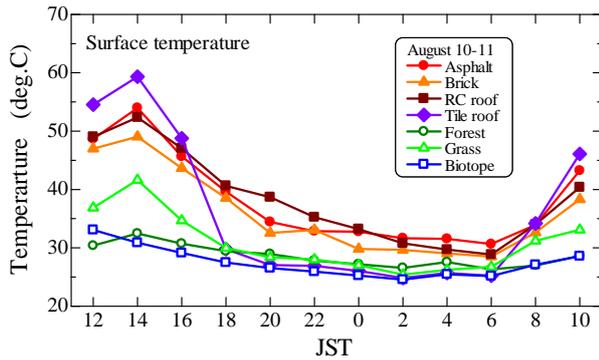


Fig. 8 Diurnal variation of surface temperature of various materials

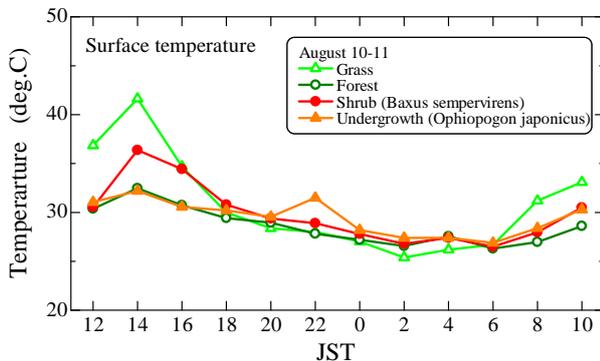


Fig. 9 Diurnal variation of surface temperature of various plants

sensors. Here, Grass, Shrub, and Forest mean the soil temperature under them. Biotope (sunny) and (shady) mean the water temperature in sunny and shady spots. The other data indicates the surface temperature. The temperatures of shrubs, forest, and biotope (shady) were the lowest throughout the day, and the daily changes were small. The temperature of the sunny biotope was slightly higher in the daytime owing to the influence of the sunlight, but was the same as biotope (shady) at night. The temperatures of the wood deck⁽⁶⁾ and grass became high in the daytime, but decreased rapidly at night. The time at which they showed their maximum values in the daytime was earlier than for the other materials. The surface temperatures of asphalt, brick, and the RC roof were high at night.

Table 2 Surface materials and the areas in which temperature sensors were set up

Surface material	Area	Surface material	Area
Asphalt	C	Grass	A
Brick	A	Shrub	B
Wood deck	D	Forest	E
RC roof	B	Biotope (sunny)	D
		Biotope (shady)	D

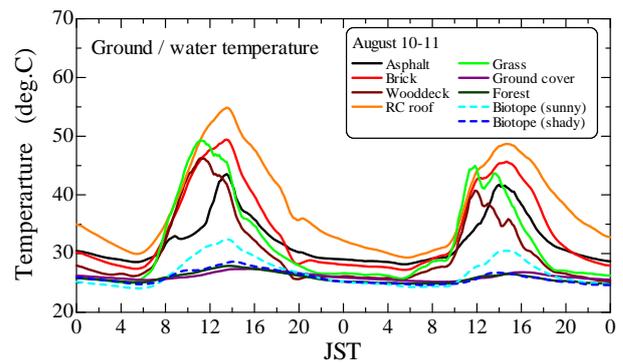


Fig. 10 Diurnal variation of underground, ground, and water temperature of various materials

4. Evaluation of heat island potential (HIP)

HIP expresses the sensible heat budget added from all surfaces of the target area to the atmosphere and is indicated with a temperature unit. It is defined by the following equation.

$$HIP = \frac{\int_{All\ surfaces} (T_{si} - T_a) ds_i}{A} \quad (1)$$

where T_{si} , T_a , ds_i and A indicate each constituent surface temperature, air temperature, each constituent surface area and total horizontally projected surface area, respectively. In other words, under the condition that the air temperature and the wind speed are uniformly in the area, it means a surface integrated difference between the each constituent surface temperature and the air temperature as a horizontally projected plane in consideration of the uneven profile.

The current land use of the campus (TCU-YC) and the neighboring residential area is shown in the upper part of Fig. 11 and is based on aerial photographs. Three future development plans were assumed for the current TCU-YC.

- (1) Commercial area plan: RC building is enlarged, and all the remaining land is changed to an asphalt parking lot.

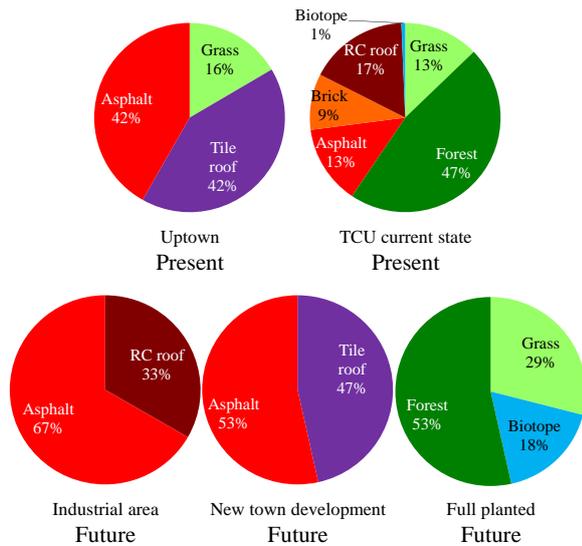


Fig. 11 Ratio of land coverage at present and simulated states

- (2) New town development plan: Housing land development is conducted without greening.
 - (3) Full planted plan: Roof greening is introduced, and greening or biotope is introduced on the grounds except for buildings
- The land use of these plans is shown in the lower part of Fig. 11. The heat island potential (HIP)⁽⁵⁾ can be calculated from the air temperature on the measurement date at TCU-YC, the surface temperature obtained from the captured infrared thermal images, and the land use ratio shown in Fig. 11.

Figure 12 shows the heat island potential (HIP) for the current land use of the campus (TCU-YC) and the neighboring residential area. HIP values remained positive throughout the day in both areas, because even on campus, artificial surfaces make up about 40% of the total. It was found that thermal emission from the surface toward the atmosphere occurs at night and that a fall in the air temperature at night is inhibited in this district. HIP values in the residential area were large in the daytime in particular, because tiled roofs accounted for more than 40% of the total surface area. This is expected to accelerate the rise of the air temperature in the daytime, and to leads to the substantial increase on extremely hot days (i.e., 35 °C or more). Figure 13 shows the HIP for the future development plans, and these values mean the difference from the present conditions. It becomes clear that if the whole TCU-YC becomes residential area, or if the RC buildings become commercial facilities surrounded by parking lots of asphalt, the HIP will be expected to increase more than 10 °C in the daytime, and several degrees even at night, compared with the current TCU-YC. When the planting area and biotope were substantially increased for the current TCU-YC, reduction of the HIP would occur at all times.

5. Summary

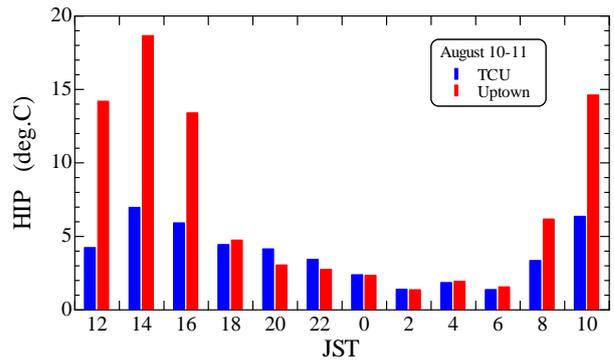


Fig. 12 Heat island potential (HIP) of uptown and campus (TCU-YC)

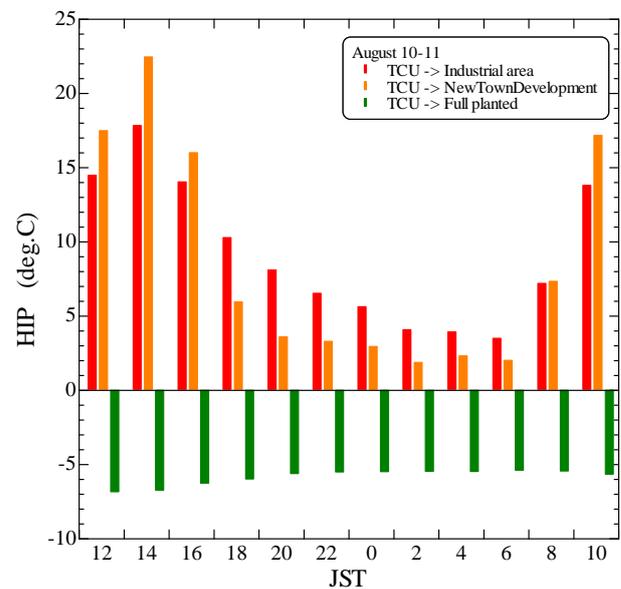


Fig. 13 Simulated heat island potential (HIP) for different development scenarios in the future

In urban areas where extreme development is proceeding, educational facilities such as university campuses where creation of large-scale green areas and water features is possible, are important for heat island effect mitigation. The heat island mitigation effect was evaluated using the heat island potential for the current Yokohama Campus of Tokyo City University. The current effect was verified, but was judged insufficient. Promotion of roof top greening and addition of a large-scale biotope are required. It was revealed that trees and shrubs were more effective than other kinds of plants. A cool roof technology is required by which to cool the city with water and greenery.

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