

Operation and Management of a Large Rooftop Garden on a Commercial Building in an Urban Area and Multicomponent Evaluation of Environmental Performance of the Garden

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Abstract: *Namba Parks is a large commercial building with 11,500 m² of terraced rooftop gardens located in central Osaka. This large area of vegetation provides an attractive landscape and is aimed at increasing both the economic and environmental value of the property, conserving biodiversity, mitigating the heat islands associated with urban climate, and improves CO₂ absorption. A multicomponent evaluation of the urban vegetation was performed to assess the thermal environment, including both mitigation of heat islands and thermal comfort for visitors, the diversity of avifauna and insect species, and the amount of CO₂ absorbed by trees. These data will be valuable for designing future vegetated buildings to contribute to sustainable urban areas.*

Rooftop vegetation, Operation and maintenance, Biota, Thermal environment, CO₂ absorption

1. Introduction

Urban vegetation is essential for human health and safety, and provides spaces where people and wildlife can co-exist. Vegetated buildings in Japan were first promoted with the enforcement of the rooftop vegetation law by the Tokyo metropolitan government in 2001. This law was established mainly to mitigate the heat island phenomenon in Tokyo and initially recommended any type of rooftop vegetation. As a result, most building owners selected thin, lightweight, low-cost, and low-maintenance flora such as turf or sedum, which were found to be rather unattractive and provided few ecological services. More recently, taller trees and various forms of vegetation have begun to be used on rooftops along with green walls, providing both greater quantity and quality of vegetation.

Namba Parks, one of the largest rooftop gardens in Japan, consists of a 31-story office tower and a 10-story commercial complex located in the central district of Osaka. This commercial complex has an 11,500 m² rooftop garden, which includes approximately 5,300 m² of vegetation. Photos 1 and 2 show distant and closer views of the building taken in 2013. The garden is distributed across a terraced rooftop from the second to the tenth floor, facing north, and has an average slope of 16.3%. The regional ecosystem was factored in for its design. Various water features and mixed forested areas were arranged to support a network of bird habitats and an environment for insects such as dragonflies and butterflies. This complex is successfully operated in a unique manner that increases the number of customers visiting the complex.

We performed a multicomponent evaluation of the rooftop vegetation, demonstrating the enhanced value that the rooftop garden provides from a variety of perspectives.



Photo 1. Perspective of Namba Parks



Photo 2. Vegetation on a gentle slope

2. Operation and management of the rooftop garden

The management and maintenance methods used for this garden can be characterized as “open” and “agrochemical-free.” Maintenance of most rooftop gardens is generally performed during times other than business hours. In contrast, open maintenance allows for communication with visitors and the local community. Just under 10 exclusive gardeners prune, replant flowers, and engage in all gardening work during business hours. Visitors are able to talk with them and learn useful and interesting information about the vegetation. Gardening classes and allotment gardens are also operated for local residents. Such efforts maintain people’s awareness of the garden and ensure they become more frequent customers of the commercial facilities.

Agrochemical-free maintenance is also an uncommon method of managing rooftop vegetation, as simple and inexpensive operation and maintenance is generally preferred. However, here it is considered necessary to preserve the ecosystem and the safety of visitors. Undesirable insects consequently increase to some extent as a result of this approach, but all of the tenants including the restaurants are aware of this and are understanding. The gardeners work to remove such insects by hand and using traps, but some survive such as butterflies, which visitors enjoy. Furthermore, many citrus trees have been planted for swallowtail butterflies. All these maintenance methods keep the garden healthy and add to the value of the vegetation.

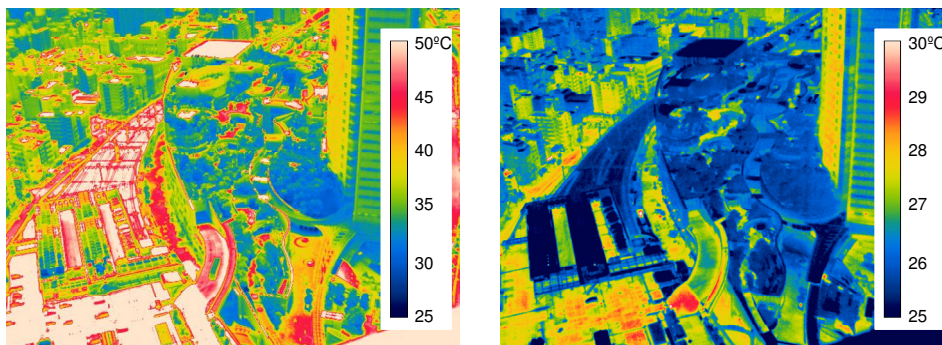
3. Microclimate

Investigation of the thermal environment was performed considering several metrics, including the urban climate, garden microclimate, and human comfort. Large areas of vegetation play an important role in mitigating the heat island phenomenon, because of their potential for reducing the air temperature through evapotranspiration. Cool air derived from the vegetation also flows into the city at night. These effects are particularly important in this area, since Osaka has a lower percentage of green space than most large Japanese cities, resulting in hot night-time conditions in summer.

The rooftop garden provides a relaxing environment for local residents, and guaranteeing their thermal safety is one of the most important responsibilities of the facility managers, since people can be exposed to strong solar radiation on building rooftops. Investigations using a thermal index for human comfort and thermal safety were carried out to evaluate the design and effects of the vegetation.

3.1 Urban heat island mitigation

Figure 1 shows thermal images of Namba Parks taken on 3 August 2011 from the top of an adjacent high-rise building in the daytime and at night. The surface temperatures of the vegetation in the garden, colored concrete pavement in an open space, and an asphalt parking lot (Photo 1) were approximately 30, 45, and 55 °C in the daytime, respectively. The temperature difference between the vegetation and pavement types ranged from 15 to 25 °C and resulted in large differences in sensible heat flux to/from urban air. The vegetation surface was cooler than the air by 3.4 °C, thus absorbing heat from the atmosphere. These differences were derived from the evapotranspiration of the plants as well as differences in the solar reflectance and heat capacity of the materials. Thus, large vegetated areas in a dense city contribute to reducing the heat load and help break up urban heat islands.



(1) 12:00 pm on 3 August 2011

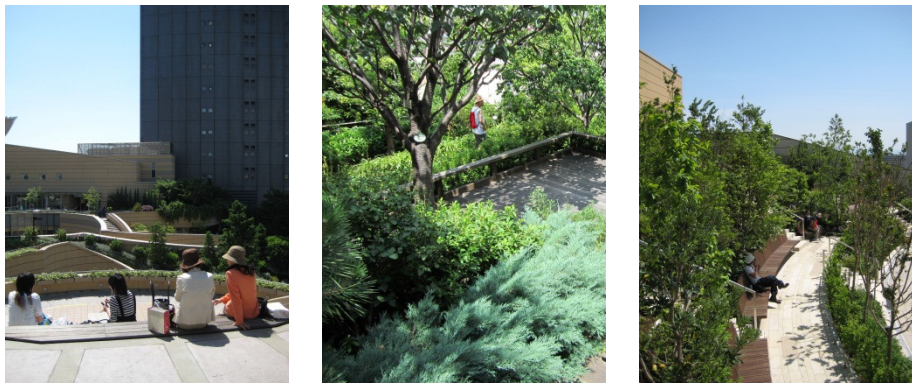
(2) 3:00 am on 3 August 2011

Figure 1. Thermal images of Namba Parks and its surrounding area

3.2 Thermal comfort

There are several rest areas in the garden with various forms of vegetation. Photos 3a–c correspond to an open space (open), a densely vegetated area (dense), and a sparsely vegetated area (sparse), respectively. Meteorological elements including air temperature, relative humidity, wind speed, and black globe temperature were measured at 1 point in the “open”, 3 points in the “dense”, and 4 points in the “sparse” areas. Measurements were carried out during 26–31 July 2010 and the standard new effective temperature¹⁾ (SET*) was derived from the measured parameters. SET* is a thermal index defined as the equivalent dry bulb temperature in an isothermal environment at 50% relative humidity in which a subject, while wearing clothing standardized for the activity concerned, has the same heat stress (skin temperature) and thermoregulatory strain (skin wettedness) as in the actual environment²⁾. It is now widely used as a suitable index for evaluating outdoor thermal comfort and is also used for the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), although it was originally developed as an index of indoor thermal comfort.

SET* is considered appropriate for comparing the comfort levels among a few selected locations, as in this case. Clothing assumed for calculating the SET* was 0.5 clo (a short-sleeved undershirt and long pants) and the metabolic rate was 1.2 met (approximately 84 W/m², standing). The measurement height was 1.0 m. The sampling interval was 1 min and the averaging time was 10 min.



(1) Open (2) Dense (3) Sparse
 Photo 3. Rest spaces with various forms of vegetation

Figure 2 shows changes in the mean SET* with time in each area on 27 July 2010. Both the maximum and minimum values of SET* obtained from multiple points are shown, averaged over 1 h, since visitors are free to move to their favorite resting places within each area.

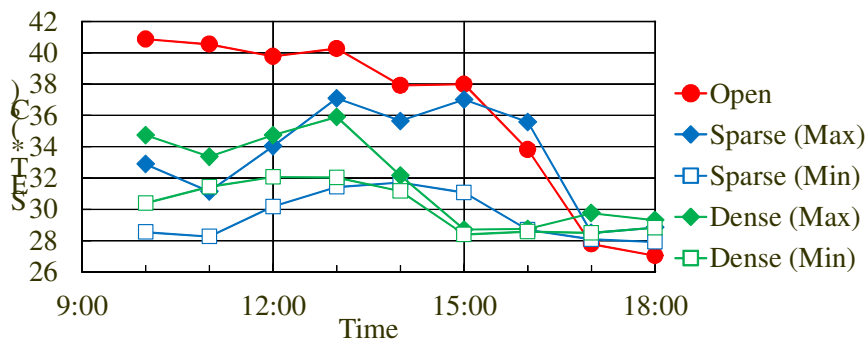


Figure 2. Diurnal variations in the maximum and minimum values of hourly averaged SET* in each area on 27 July 2010

The “open” area was a non-vegetated open space and the SET* was >38 °C until mid-afternoon. A previous study³⁾ on the relationship between SET* and thermal sensation in the outdoor environment indicated that an index range of 25–27 °C can be considered “neutral,” 27–30 °C “slightly warm,” 30–33 °C “warm,” and >33 °C “hot.” Therefore, the values for the “open” area indicated very hot conditions under direct sun and on the hot pavement. On the other hand, the “sparse” and “dense” vegetated areas had various thermal sensations ranging from “slightly warm” to “hot,” and people could choose more comfortable benches or places to rest in each area. Minimum values of the SET* varied from 28 to 32 °C throughout the day, corresponding to “slightly warm” to “warm,” providing thermally safe places and encouraging visitors to stay and enjoy the garden for many hours. Visitors tended to prefer

“sparse” areas to “dense” areas, because the former had gentle breezes and low relative humidity. These conditions provide greater comfort in an outdoor environment and were often impeded by the “dense” vegetation.

3.3 Nocturnal cool air flow

Several studies have observed that the cool air produced by large green garden areas flowed into the surrounding districts on calm nights⁴). Three-dimensional wind vectors and air temperatures were measured in the sloped coppice located from the third to sixth floor using an 81000 3D ultrasonic wind sensor (Young) from 26 July to 31 August 2010. The measurement height was 1.5 m. The sampling interval was 1 min and the averaging time was 10 min. Land breeze was found to start around midnight and continue until around noon on fine days. During land-breeze periods, the wind was gentle and the vertical velocity was negative, i.e., weak downward airflow was generated in the coppice.

Figure 3 shows a decrease in air temperature after 18:00 on 28 July 2010. The values shown are differences from the temperature at 18:00 pm. “Rooftop” is the highest point of the building and is covered with a waterproofing sheet material. The air temperature gradually decreased at each vegetated area, with differences from the rooftop of up to -1.5 °C. This cool downward breeze has the potential to mitigate hot nighttime conditions in the surrounding city districts.

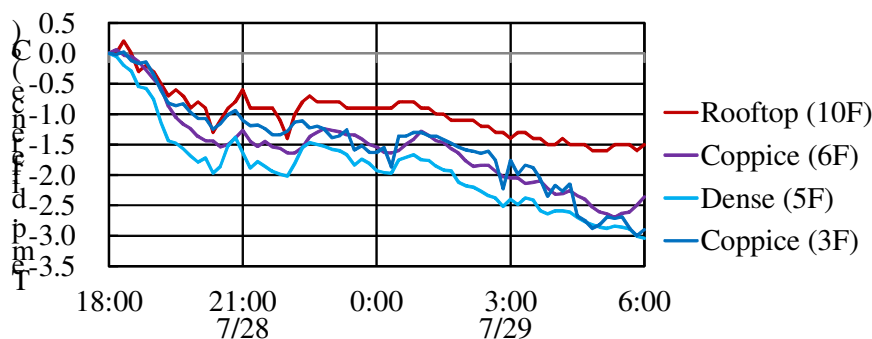


Figure 3. Decreases in the air temperature with time after 18:00 on 28 July 2010

4. Biota

Information on biota in the garden provides a better understanding of the urban ecosystem network. The vegetation in the garden has grown each year since completion of the development, in turn increasing the number and diversity of biota inhabiting the garden. Biological research has been conducted to identify the birds and insects in the garden since 2009. These data will be compiled and used for management and maintenance of the garden and to raise stakeholders’ awareness of the conservation of the ecosystem over the next few decades.

4.1 Avifauna

Figure 4 shows monthly numbers of identified species of birds from June 2009 to March 2013. The total number of identified species is currently 34, including 7 species listed in the Osaka

Municipal Red List. Many small migratory birds were found from autumn to winter and many resident birds bred in the garden. Raptors such as Peregrine Falcons and Grey-faced Buzzards flew over the garden and preyed on small birds. On the ground, Dusky Thrushes and Pale Thrushes fed on earthworms living in the soil. This suggests that the soil, which was originally artificial lightweight soil, has become fertile after about 10 y through mulching with leaves and pruned branches.

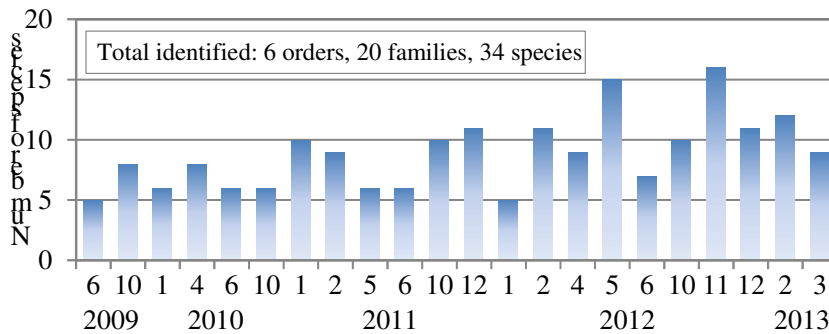


Figure 4. Monthly numbers of identified species of birds from June 2009 to March 2013

4.2 Insect species

Figure 5 shows the composition of insect orders found from June 2009 to May 2011. The total number of identified species was 152. This indicates that the garden has quite abundant insect fauna, even though the vegetation is located on an artificial structure in the center of the city. Bees, butterflies, and horse-flies were relatively abundant, because there are many flowerbeds and because a variety of flowers bloom in all seasons. On the other hand, relatively few forest insects such as beetles were found in the garden compared to popular city parks. Grasshoppers brought in with plants or soil during construction evidently were able to breed repeatedly in the garden, because they cannot fly away from it. Cicadas also emerged in the coppice and dragonflies bred in the water features.

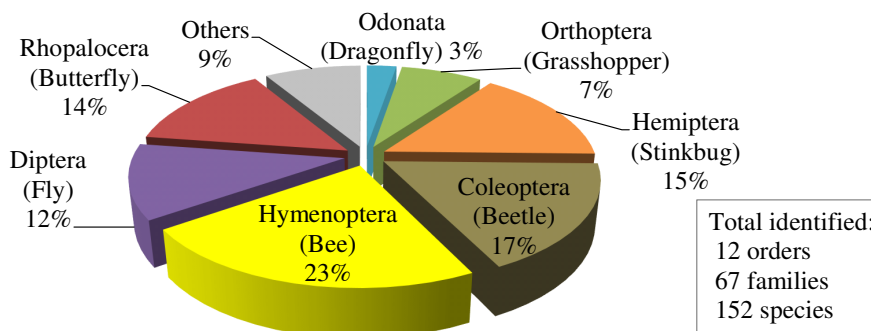


Figure 5. Composition of insect orders found from June 2009 to May 2011

5. Carbon fixation

Carbon dioxide (CO₂) in the atmosphere is absorbed by plants through respiration and assimilation. Urban vegetation plays an important, though a relatively small, role in mitigating global warming. Accurate unit absorption rates are essential for estimating the amount of CO₂ absorbed. However, rates derived from non-urban planted forests are



generally used in most cases because of the lack of urban data. Absorption rates for urban trees are expected to be smaller than those for non-urban trees because of building-induced strong winds, the limited amount of soil, and other factors.

The tree height, crown diameter, and chest-height diameter of all trees in the garden were measured in both March 2010 and March 2011 to estimate the amount of CO₂ absorbed by the garden. The total number of trees was 930 and the total amount of CO₂ absorption was 4.0 t CO₂/5,300 m² or 7.55 t CO₂/ha. This value is approximately a half of that for 20-y-old planted cedar forest. This result indicates that trees on artificial surfaces grow more slowly in practice. However, these data contribute to accurate estimation of urban carbon sinks.

6. Conclusions

Evaluations of the thermal environment, avifauna and insect species, and the amount of CO₂ absorption by trees were carried out for a large rooftop garden on a commercial building. The data confirmed that such a large area of vegetation mitigates the hot thermal environment in the city and provides a comfortable environment for visitors to the garden. It also expands and enhances the urban ecosystem, providing habitat for many bird and insect species.

Furthermore, it contributes to easing global warming by absorbing CO₂. These scientific studies will be continued and the data will be openly provided to promote development of such high-quality vegetated buildings.

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