COOL AIR SEEPING FROM AN URBAN GREEN SPACE, IMPERIAL PALACE, IN CENTRAL TOKYO

Ken-ichi Narita*[1], Hirofumi Sugawara*[2], Hitoshi Yokoyama*[3], Ikusei Misaka*[4] and Dai Matsushima*[5]
*[1]Nippon Institute Technology, Saitama, Japan; *[2]National Defense Academy, Kanagawa, Japan
*[3] Tokyo Metropolitan Research Institute for Environmental Protection, Tokyo, Japan
[4] R&D Institute, Takenaka Corporation, Chiba, Japan;[5] Chiba Institute of Technology, Chiba, Japan

Abstract
In this paper, results are shown from micro-climatological observations performed in and around a largest green space in central Tokyo, "Imperial Palace", during summer. Air temperature was measured at 1-minute intervals between the boundary of the green space and the Tokyo Station. In order to catch the phenomena of cool air seeping-out in calm conditions, several sonic anemometers were set along the green space boundary. In a clear calm night, flow-out wind directions from green spaces to surrounding built-up areas were discerned at all measuring points. The obvious shift of wind direction appeared at the beginning of the flow-out with a sharp temperature fall of 1 or 2 degrees.

Key words: radiative cooling, cold air drainage, urban park

1. INTRODUCTION

The mitigation effect of green space in urban area has been expected to be comparable to that of water surfaces. In Japan, its cooling effect in hot and humid summer is especially important and it is considered as an important method available for city planning. In a clear calm night, ground inversion layer is formed in a green space by radiative cooling, and some accumulated cool air near green surface flows out gravitationally into surrounding city area. Such "cold air seeping" was firstly observed in "Shinjyuku-Gyoen Park" in Tokyo (Narita *et al.* 2002, Honjyo *et al.* 2003 and Narita *et al.* 2004). Different from the daytime advection by prevailing wind, the turbulent mixing is very weak in nighttime seeping phenomena because of the stable atmospheric condition. Therefore, the cooling effect for ambient air, that is the negative sensible heat flux, was very small, but the flow-out air was kept cool as far as the seeping front, 80-90 m from the boundary in that case.

In this paper, results are shown from micro-climatological observations performed in and around a largest green space in central Tokyo, "Imperial Palace", during summer. It was once the Edo-Castle, then surrounded by a moat. Its area is 230*ha*, and it located adjacent to one of the main CBD, "Maru-no-uchi", which includes Tokyo Station. The topography around the Imperial Palace is inclined toward east; the elevation of west side is 25 m higher than east side. Then, the east side water surface in the moat is only few meters lower than ground level, but the depth of west side moat is more than 20 m. The core area of the Imperial Place is covered by dense forest.

2. OBSERVATION METHODS

The observations were performed during summer in 2007 and 2008. The main purpose in 2008 was to make clear the effect of topography on the cool air seeping, and that in 2007 was to grasp the seeping front in east side CBD area. Air temperature was measured at 1-minute intervals at totally 27 points in and around the Imperial Palace including west side moat slope in 2008 (Fig. 1), and at totally 50 points between the east side boundary of the green space and the Tokyo Station in 2007. In order to catch the cool air seeping-out in calm conditions, several sonic anemometers were set along the green space boundary in 2008, and also in adjacent built up area in 2007. Measuring height was 2.5m above the ground and sampling frequency 1Hz. In addition, the vertical air temperature profile was measured using a lift car in 2007 to reveal the depth of seeping-out cool air.

Fig.1 Observation points around Imperial Palace.

Corresponding author address; Ken-ichi Narita, Department of Architecture, Nippon Institute of Technology, Gakuen-dai, 4-1, Miyashiro, Saitama, Japan; e-mail: narita@nit.ac.jp

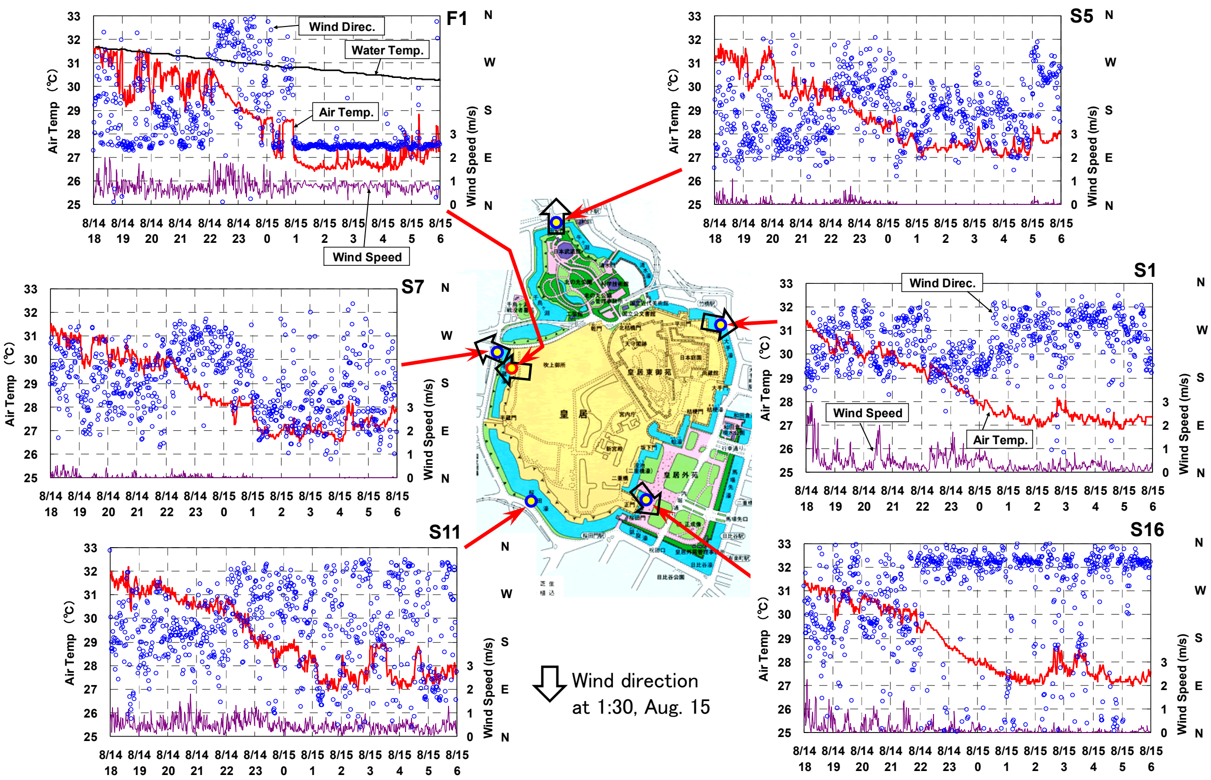

Fig.2 Seeping-out phenomena of cool air in calm night－1-minute average time variations of air temperature, wind speed and direction at boundary points.

3. RESULTS

Observation period in 2008 was totally 65 days from July 27 to September 29. The weather condition of this period was rather anomalous, the number of no rainfall day amounts only 19. Figure 2 shows the example of seeping-out phenomena of cool air in calm clear night around Imperial Palace. At east-side point (S16), wind direction is almost fixed in north-west after 22:00 on Aug. 14. At the west-side inner point (F1), obvious shift of wind direction appeared at 1:00 on Aug. 15 with a sharp temperature fall of 2 degrees. Before this event, time variation of temperature and wind direction is similar to that of the east-side. These imply the westerly wind after 22:00 was synoptic scale phenomena and it resulted in rather rapid temperature drop at all measuring points. Then, three hours later (at 1:00), this westerly wind became weak and cool air drainage from the Imperial Palace was started even in the west side. The wind directions at 1:30 at each sonic point show the cool air flows out to the surrounding city area for all direction (illustrated by arrows in Figure 2). While there was no traffic near the points (F1) and (S16), the other four sonic anemometers were clung to the roadside light poles and probably affected by traffic disturbance. That is the reason why the wind direction was fluctuated and the sharp temperature drop was not so clear at these points.

In order to examine the topographic effect of the deep moat, we focused the difference between inner side point (F1) and outer side point (S7) of the west side moat. In the outer side, the magnitude of sharp temperature drop became smaller than that of the inner side, but there can be seen no significant time lag in both side temperature time-variations. This suggested that the cool air from the Imperial Place flows across the deep moat at once; it dose not constitute the barriers against the cool air seeping.

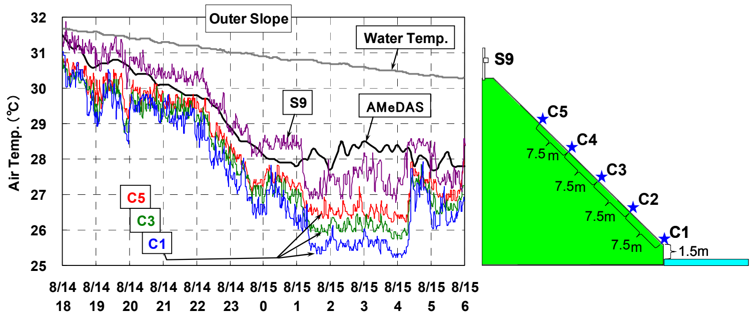

Fig.3 Time variation of air temperature along the moat slope.

Figure 3 shows the comparison of air temperature variation at the points along the outer slope. At road side point (S9), the sharp temperature drop appeared clearly just after 1:00. On the slope (C1～C5), the temperature decreased gradually from the time about one hour earlier than road side steep change. Notice the water temperature in Figure 3. This moat has no sufficient inflow, so natural rain is the only water supply. Consequently, water temperature was higher than air temperature during the night; exceeded 30 degrees Centigrade even early in the morning. Nevertheless, the air temperature was lowest in the bottom of slope, that is, the ground inversion layer was formed in the moat valley. The occurrence of cool air seeping phenomena is limited in calm night, so the turbulent heat exchange at the water surface is considered very weak.

Figure 4 is the result in 2007, focused on the seeping front in “Maru-no-uchi” CBD area. Three figures show the 1-minute average time variations of air temperature, wind speed and direction, as same manner as Figure 2. The upper graph is the result of point (S16) that is common to the observation in 2008. In this night, cool air seeping was started about at 0:50. At the point beyond the moat (middle graph), and at the edge of CBD beyond the Route 1 (lower graph), the start of temperature drop appeared later than point (S16). Figure 5 shows the temperature field during 3:00～4:00, when cool air expanded most broadly. The arrows in the figure express the wind directions at each sonic point.

To investigate the effect of the moat and wide-street on the seeping of cool air in detail, the isopleths between the Imperial Palace (Sakashita Gate) and the Tokyo Station were drawn in Figure 6. Here, the color means a temperature difference from the area-averaged temperature around Tokyo Station. Within the “Kokyo Gaien National Garden”, cool air spread out rapidly. However, the beginning of invasion of seeping front into CBD area was about two hours later. After that, the cool air front penetrated the CBD area and reached near the Tokyo Station. According to the sonic data of wind direction change, there was not so large time-lag until the front passed across the moat.　These results suggested that the wide street have a relatively large effect on cool air seeping than the moat even though water temperature was higher than ambient air temperature.

Figure 7 is the time-height isopleths drawn using vertical temperature profile collected by a lift car. Here, temperature was expressed as a difference from the upper layer air temperature at the height of 110 meters. This special observation was carried out for three days, and cool air seeping occurred only one night during these period. At the time of most strongly cooled period, air temperature was lower than reference upper layer up to the height of 14 m. Even the top height (25 m above the ground), the effect of cool air seeping was discernible clearly.

4. CONCLUSIONS

In a clear calm night, the cool air flows out from the Imperial Palace to the surrounding city area gravitationally.　In the west side, it flows over the valley of moat (20m depth) and spread out into the built-up area. In the east side, cool air front sometimes penetrate the adjacent CBD area and reached near the Tokyo Station.

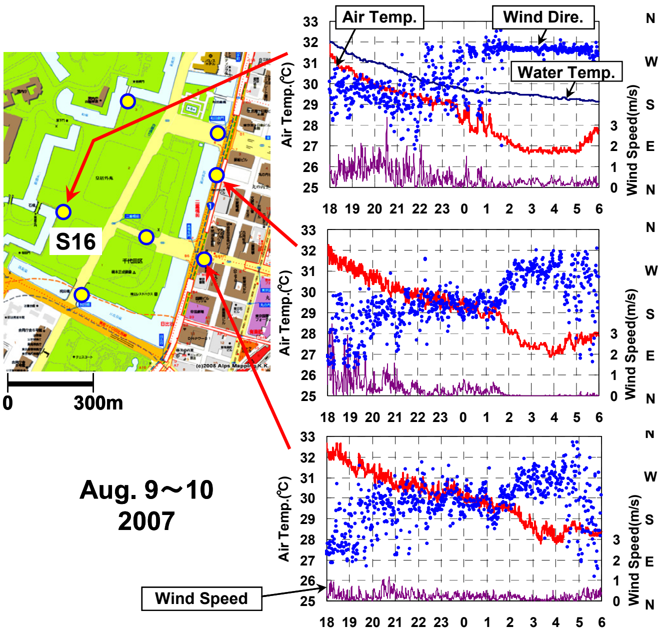

Fig.4 Seeping-out phenomena of cool air in the east side of Imperial Palace.　(same manner as Figure 2)

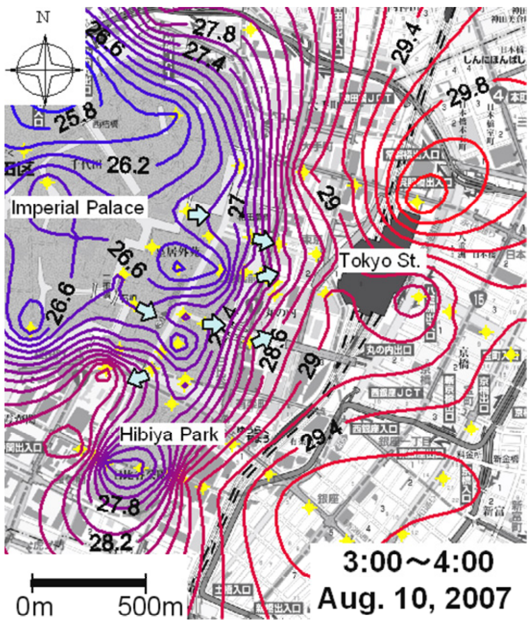

Fig.5 Temperature field and wind direction when seeping-out phenomena appeared.

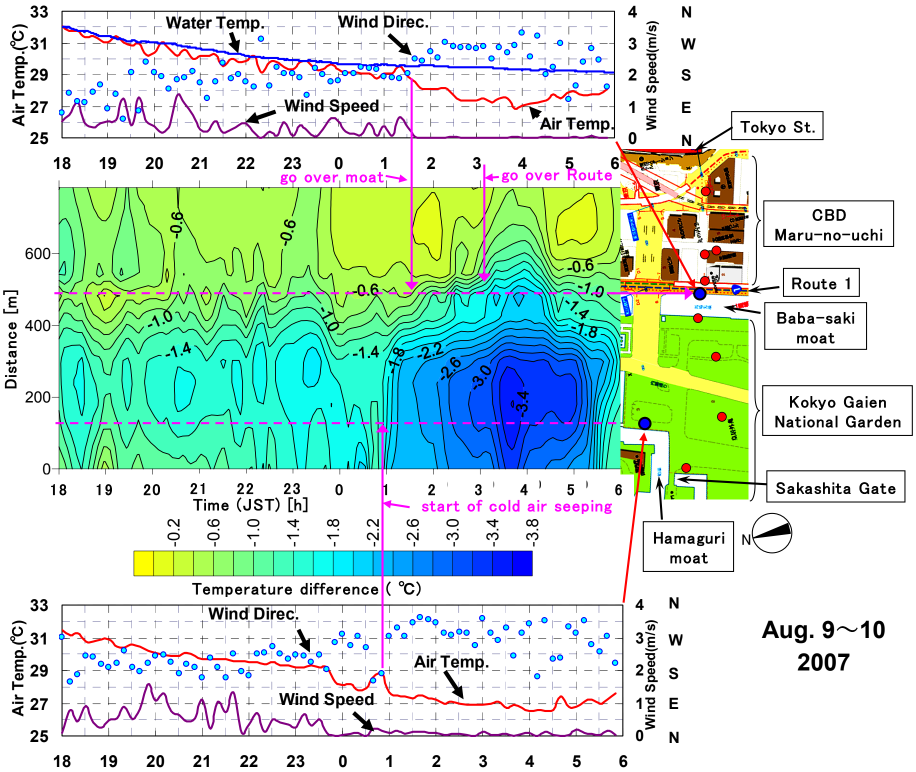

Fig.6 Air temperature difference isopleths between Imperial Palace and Tokyo Station.

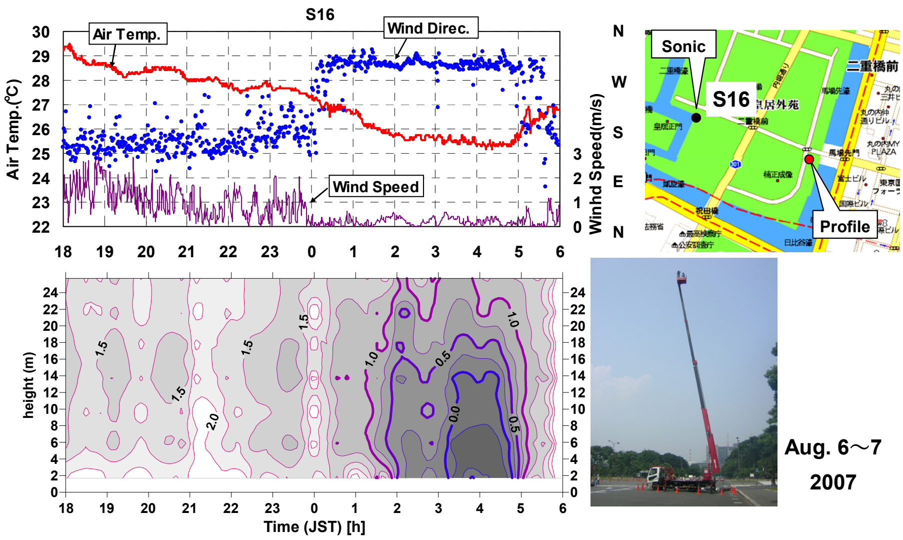

Fig.7 Depth of cool air seeping from Imperial Palace.

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