Journal of Heat Island Institute International Vol.7-2 (2012)

National Research Project on Kaze-no-michi for City Planning: Creation of Ventilation Paths for Cool Sea Breezes in Tokyo

Koji Kagiya*[1] Yasunobu Ashie*[1]

*[1] National Institute for Land and Infrastructure Management,
Ministry of Land, Infrastructure, Transport and Tourism
Tsukuba, Ibaraki, Japan.

Corresponding author email: kagiya-k92js@nilim.go.jp

ABSTRACT

A national research project on ventilation paths is introduced as one effort to mitigate urban heat island (UHI) effects. This project is intended to establish a scientific background to promote effective UHI countermeasures suitable for the characteristics of each region. We focused on the ventilation paths of sea breezes, the effects of which had not yet been sufficiently and scientifically investigated. We conducted a large-scale measurement campaign, numerical simulations using a supercomputer, and wind-tunnel tests in order to develop assessment techniques that can be used to quantitatively predict the effectiveness of creating ventilation paths for sea breezes to achieve an enhanced sea breeze for urban design.

Introduction

Global warming has become a great concern of our time, and the urban heat island (UHI) effect has become increasingly severe over the years. While the annual average temperature in Japan has increased by 1° C over the past 100 years, the annual average temperature in Tokyo has increased by 3° C over the same period. This suggests that the UHI effect has contributed to the temperature increase in Tokyo by 2° C, in contrast with the 1° C contributed by global warming. The rate of increase in air temperature due to the UHI effect is faster than that due to global warming. Therefore, the UHI effect has become an environmental issue that requires urgent measures at the national level.

The UHI effect in summer varies by city, according to unique characteristics such as topography and urban structure (e.g., heat stagnation in a densely built-up area). The measures to counteract UHI are therefore left to the discretion of local governments. In large coastal cities (e.g., Tokyo and Osaka), it has been recognized that a cool sea breeze blows from the sea toward the land in summer. Thus, city planning, especially for major coastal cities, should take advantage of sea breezes, even though their effect has not yet been sufficiently and scientifically investigated.

Since the 1990s, many skyscrapers in Tokyo have been built in the waterfront area. This dense group of skyscrapers looks like a huge wall along the coast and likely blocks the sea breeze. Many TV programs and newspapers have reported on this topic and suggested that the so-called Tokyo Wall exacerbates the UHI effect inland of Tokyo (Photograph 1). People thereby widely concluded that inducing cool sea breezes in the urban space could serve as a major counter measure to the UHI effect.

In light of such circumstances, in March 2004, concerned ministries and agencies put four measures: the reduction of anthropogenic exhaust heat, improvement of urban surfaces, improvement of urban structures, and improvement of lifestyle. It also stipulates that the monitoring system of UHI effects should be improved, and research and development on the assessment technique for implementation of effective measures should be promoted.

Based on this policy framework, in 2004, we initiated a 3-year general technology development project for the “Development of Urban Thermal Environment Assessment and Mitigation Technology,” administrated by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) to promote effective countermeasures to the UHI effects, in cooperation with the National Institute for Land and Infrastructure Management, Building Research Institute, Geographical Survey Institute, Public Research Institute, Japan Metrological Agency, and other concerned organizations, agencies, and universities.

In this project, we focused on a measure that had not yet been sufficiently and scientifically investigated. This measure is called *kaze-no-michi* (ventilation path), which is an attempt to lower the summer temperature in the center of a large coastal city by securing a path for cool wind to flow in from the sea.

Photograph 1. Skyscrapers in the waterfront area called the "Tokyo Wall"

What is *Kaze-no-michi*?

The idea of *kaze-no-michi*, which has received attention as one countermeasure to UHI effects, is based on a German ecological city-planning approach. With this method, mountain and valley winds are used to mitigate air pollution and UHI effects in inland cities, such as Stuttgart. The nocturnal cool and fresh air that flows into a city from its peripheral hill slopes is believed to be as deep as a few meters to tens of meters and is located near the ground.

Most large cities in Japan are situated near coastal areas. Therefore, in contrast with the mountain and valley winds used in the ventilation paths in the inland cities of Germany, sea breezes with a depth of more than a few hundred meters to one thousand meters flow into large cities in Japan. The ventilation paths in Germany use relatively shallow mountain and valley winds, which can be considered planar. On the other hand, sea breezes with a depth larger than the height of a skyscraper can be used for large coastal cities in Japan. Therefore, *kaze-no-michi* is three-dimensional (Figure. 1).

Accordingly, we call the ventilation paths in Japan *kaze-no-michi* to distinguish them from the German ventilation paths. Kaze-no and michi stand for "wind's" and "path(s)" in Japanese (Kagiya and Ashie 2008).

.

Effects of *Kaze-no-michi*

Large-scale Measurement Campaign

In the summer of 2005, a large-scale measurement campaign was carried out in the central and waterfront areas of Tokyo to quantify the effects of the sea breeze on the urban climate (Ojima et al. 2006). For this experiment, thermometers and hygrometers were deployed at 190 locations, including locations on streets, on high-rise buildings, and along rivers. In addition, at 40 out of the 190 points, wind speed and wind direction were observed through a weather observation system (Figure 2). At these locations, observations were made at 5- to 10-minute intervals over approximately 2 weeks throughout the

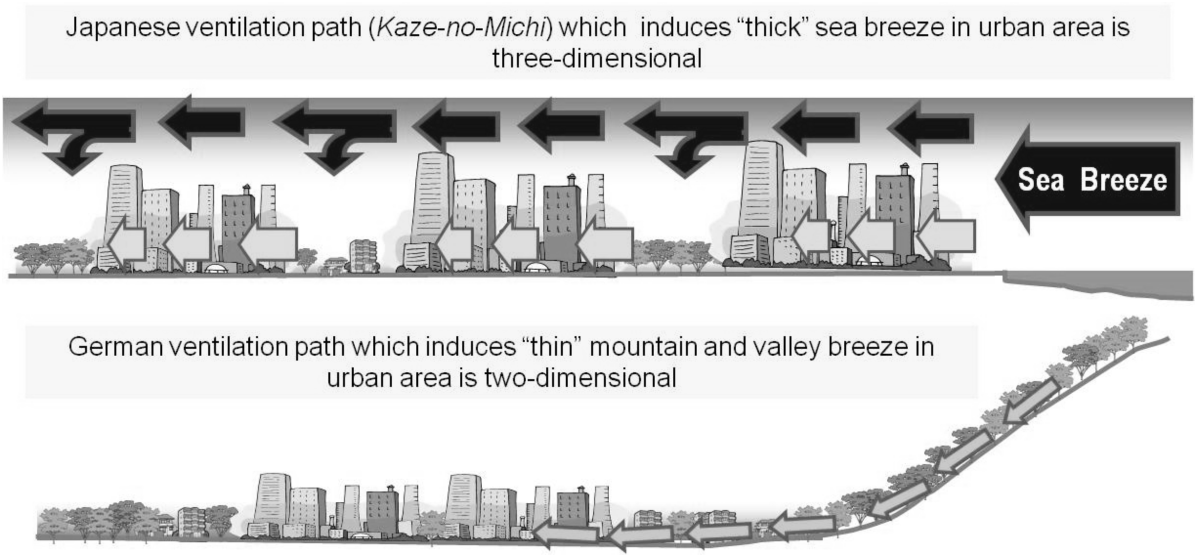

Figure 1. Comparison of ventilation paths in Japan and Germany.
The Japanese ventilation path (*Kaze-no-Michi*), which induces thick sea breezes in urban areas, is three-dimensional. The German ventilation path, which induces thin mountain and valley breezes in urban areas, is two-dimensional

day and night. In addition, midair airflow measurements were made for a few days by pilot and captive balloons.

The observational data showed that sea breezes in the Tokyo Bay Area reduced air temperatures in locations within approximately 2 km of the sea coast or more. The reduction of air temperature was largely along rivers and wide streets, where sea breezed flow in easily. This result suggests the importance of *kaze-no-michi*. Accordingly, we have focused our attention on the rivers and wide streets that constitute continuous vacant space within an urban area, and have examined the effects of rivers and wide streets on *kaze-no-michi*.

Figure 3 shows measurement results. A comparison of street width at the coastline indicates that wider streets have a greater capacity than do narrower streets to alleviate a rise in

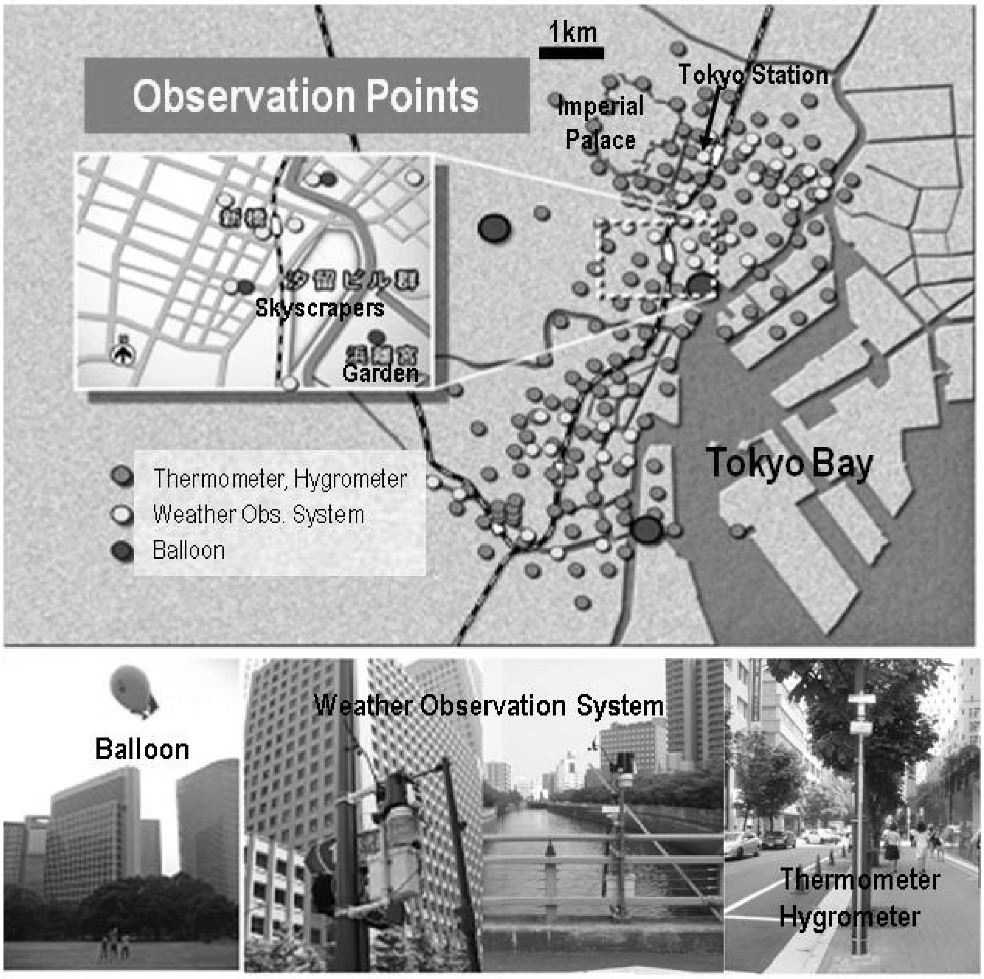

Figure 2. (a) Measurement points (190) in the central and waterfront areas of Tokyo (b,c,d) measurement devices

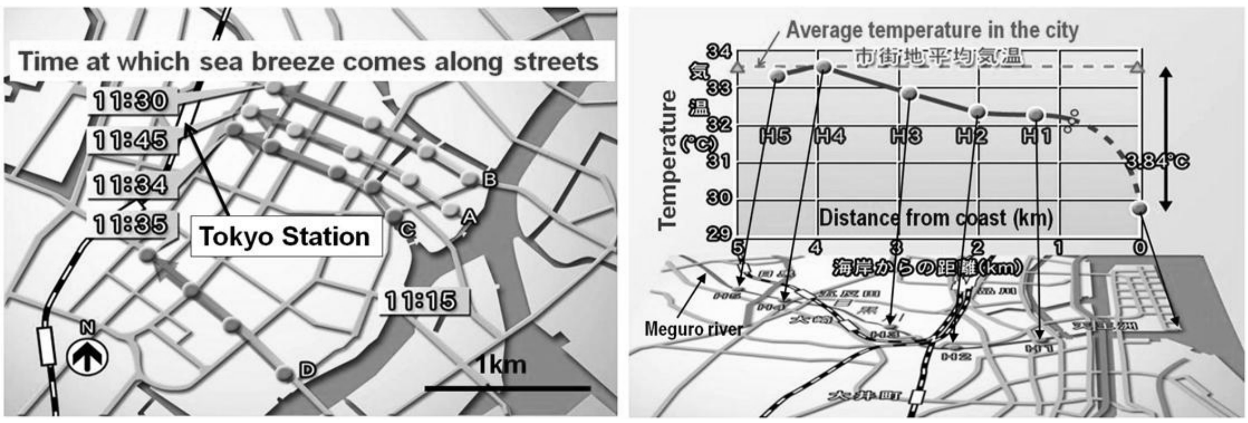

Figure 3. (a) Effect of width of streets on sea breeze flow (b) effect of distance from the coast on bridge temperatures

temperature. In addition, sea breezes pass more easily through wider streets than through narrower streets (Figure 3a). The average air temperature at the river mouth was about 4° C cooler than the average air temperature in the city around midday on good weather days. Similarly, air temperature on bridges increased gradually in relationship to their distance from the coast (Figure 3b).

The collected data are being compared with those obtained through simulations carried out on a supercomputer to analyze the influence of high-rise buildings, streets, parks, and rivers on local wind flow and temperature.

Case Study on Urban Redevelopment

To study the effects of *kaze-no-michi*, case studies were conducted using a wind tunnel (Kagiya et al. 2007). These case studies were for two areas in Tokyo: the Tokyo Station and its surroundings and the Nihonbashi River and its surroundings (Figure 4). In these areas, extensive redevelopment is currently being examined and implemented.

In the Tokyo Station area, twin towers have recently been constructed. Between the towers is a station building that is connected to Tokyo Station. The building is currently in the process of being removed, as a part of the redevelopment. When this redevelopment has been completed, the building will no longer appear like a castle wall from the sea side. Then, a *kaze-no-michi* is expected to form along a wide street that extends from the waterfront area through the Tokyo Station area to the Imperial Palace in the center of Tokyo.

The Nihonbashi River is connected to Tokyo Bay and has been flowing through Japan's center of commerce since the Edo Era. Thus, the area surrounding the river is a valuable district in terms of history and landscape. An elevated expressway was constructed over the Nihonbashi River during a period of high economic growth in the 1960s; the expressway has deteriorated since then. Due to the timing of its renewal, the removal of the expressway has been proposed so the river bank can be widened and the old riverside landscape can be restored. If this proposal is realized, a continuous open space will be formed along the Nihonbashi River from Tokyo Bay, and this space is expected to function as a *kaze-no-michi*.

We examined the airflow change between pre- and post-development with wind-tunnel tests. For these tests, the aforementioned districts were reconstructed with detailed 1/750 models and a thermistor anemometer was employed for measurement of wind velocity at over 200 points. According to the experiments, the proposed and ongoing development will create a *kaze-no-michi*, and wind velocity will increase within a few hundred meters of the development site. This increase in wind speed is likely the result of enhanced ventilation; thus, it likely will be accompanied by effects that promise to reduce the air temperature.

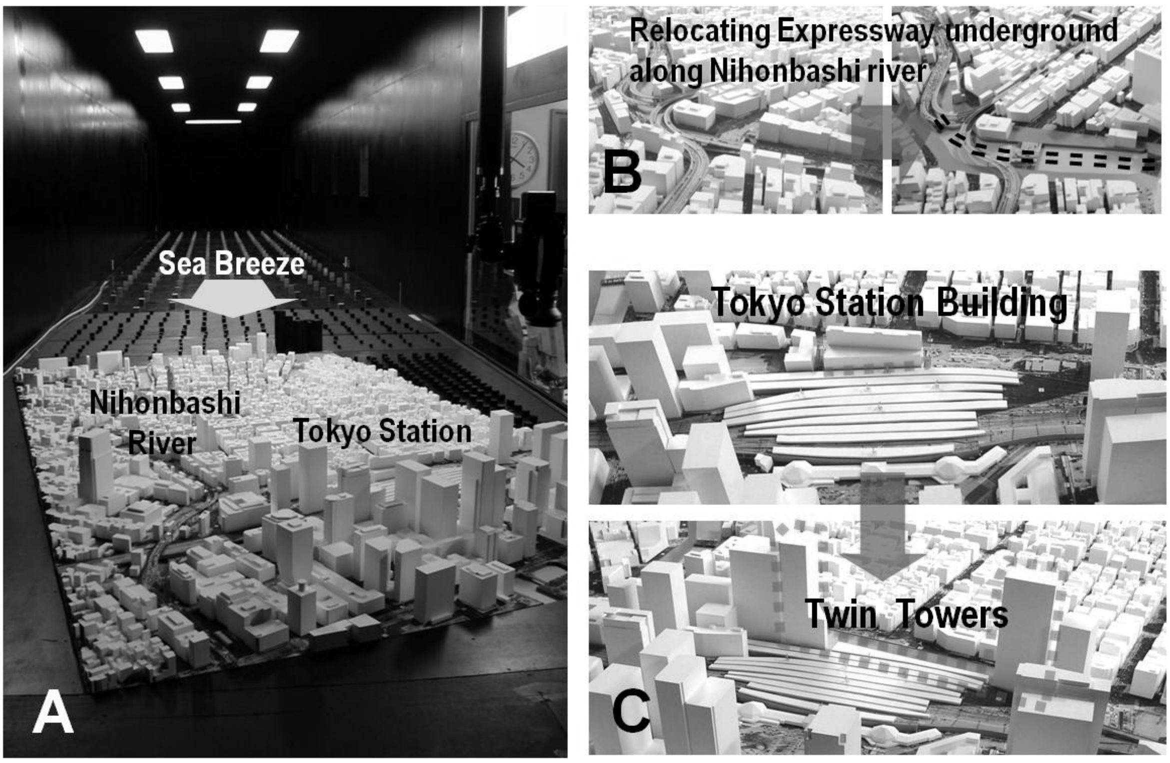

Figure 4. Wind-tunnel test using an urban district model: (a) urban district model installed in BRI's turbulent boundary layer wind tunnel, (b) proposed plan to relocate the expressway underground along the Nihonbashi River, (c) Tokyo Station redevelopment plan

How to Make the Best Use of *Kaze-no-michi*

CFD Study Using the Earth Simulator

We have confirmed the presence of *kaze-no-michi* and its cooling effects in Tokyo. To make the best use of this *kaze-no-michi* concretely for effective and practical applications in urban planning, the details of its path between the coast and the city center need to be clarified. The key component that enabled this clarification was the use of simulations by a supercomputer. The present project used the Earth Simulator, which possesses one of the fastest computing speeds in the world and is known as Japan's supercomputer.

With the Earth Simulator, researchers from the Building Research Institute (BRI) set out to reconstruct the UHI effect that has been observed over the entire city (Ashie et al. 2007, 2008). In this reconstruction, very fine details of the UHI effect were computed using the vast amount of data for air temperature, wind speed, and wind direction.

In this effort, a new thermal environmental analysis system that incorporated potential temperatures and Coriolis force into a standard k-ε scheme was used to evaluate a mitigation effect on the local thermal environment. The boundary and initial conditions accepted the simulation results of a mesoscale model. Information pertaining to the terrain, land use, and geometry of buildings and streets was generated by the Digital Elevation Model (DEM) and Geographical Information System (GIS) database for the Tokyo metropolitan area.

This effort enabled simultaneous visualizations of the air temperature and wind conditions between the surface and height of 500 m in the 23 wards of Tokyo (Figure 5). This horizontal area corresponds to approximately 33 km^2, and the simulation results showed the details of the air temperature and wind conditions around the city's approximately 160 million buildings and along their surrounding squares, streets, and rivers, with 5 m grid horizontal spacing (Figure 6).

Moreover, the simulation result was found to be highly accurate, with an RMS error of less than 1° C, with respect to the data from the aforementioned large-scale measurement campaign. Having verified the availability of the simulation models, we developed PC software for use with the models (described in the following section).

Thus, we can now map the detailed pathway of the sea breezes, up to a few hundred meters in thickness, from the ocean to the center of Tokyo, and the resulting reduction of air temperature along the streets. The sea breezes can be expected to lower air temperature in the summer. However, no statistical techniques were available to use this flow and predict its effects quantitatively. As a result, urban planning could not yet take into account sea breezes. So further simulations were performed on the Earth Simulator to evaluate the effects of the development in the Tokyo Station and Nihonbashi River areas, for which case studies were conducted with the aforementioned wind-tunnel experiments (Cho et al. 2007). The target area of these case studies was Nihonbashi-Yaesu. The size of the simulation area

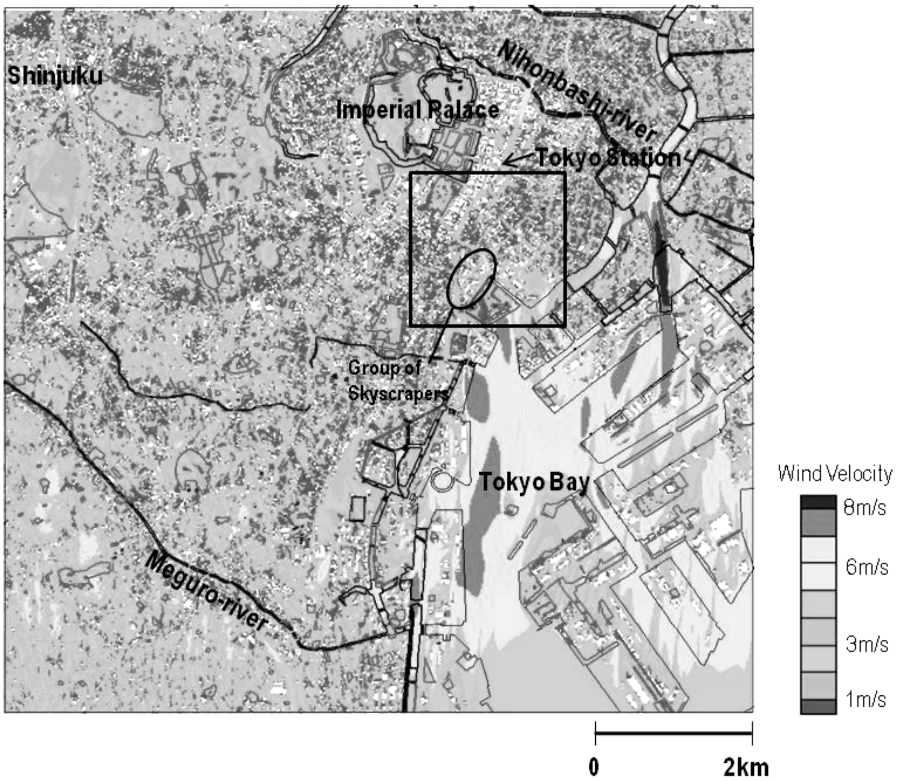

Figure 5. Result of a numerical simulation by the Earth Simulator (excerpted 10 km x 10 km from 33 km x 33 km); wind velocity and wind direction at 10 m above ground level at 14:00 on July 31, 2005 (rectangular frame indicates area of Figure 6.)

was 2.5 km x 1.5 km, with 1 m grid spacing.

Figure 7 shows a comparison of wind speed and direction, from the results of the measurement campaign, wind-tunnel test, and numerical simulation. These results are in agreement with each other. The simulations predicted that the creation of *kaze-no-michi* would strengthen wind and reduce air temperature as much as 2° C along the Nihonbashi River and around Tokyo Station after relocating the elevated expressway beneath the river, redeveloping the buildings along the river bank, and reconstructing Tokyo Station into twin towers (Figure 8).

Having learned with certainty that a continuous wind flow is present over streets and rivers in urban spaces and that creating *kaze-no-michi* is feasible through urban development, we wish to use this wind flow effectively for city planning.

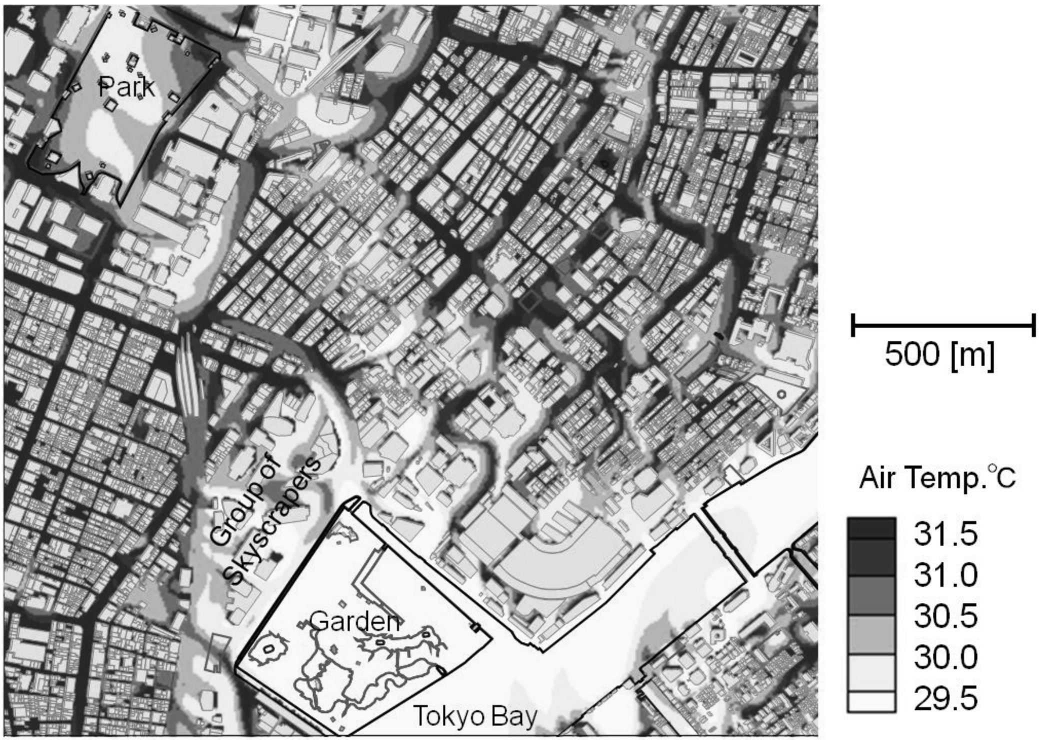

Figure 6. Result (partial) of a numerical simulation on air temperature at 14:00 July 31, 2005, 2 m above ground

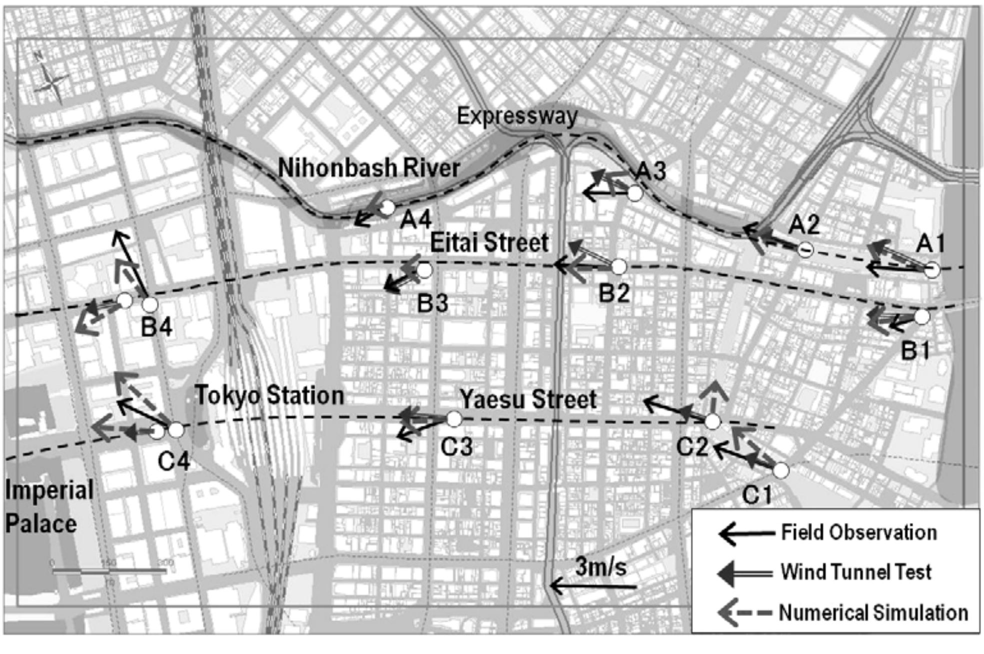

Figure 7. Comparison of wind velocity and direction at 5 m above ground level, using field observations, a wind-tunnel test, and numerical simulation by the Earth Simulator

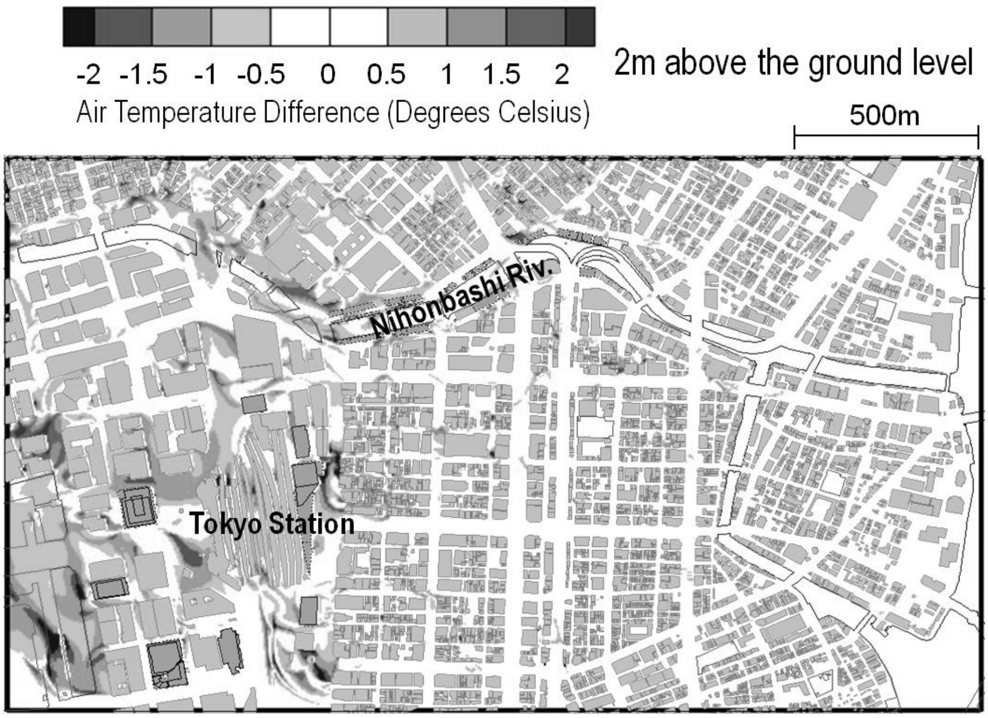

Figure 8. Numerical simulation of air temperature change due to redevelopment of Tokyo Station and relocation of the expressway along Nihonbashi River at 12:00, July 31, 2 m above ground level

Applying *Kaze-no-michi* in City Planning

To apply *kaze-no-michi* in city planning, we have classified this concept into three types (Figure. 9). This classification is based on past research about *kaze-no-michi*. Type 1: *kaze-no-michi* that is created by sea breezes that flow from the coast into the city along the earth's surface and along routes such as streets and rivers. Type 2: *kaze-no-michi* that originates from sea breezes aloft; these sea breezes are directed to the earth's surface in the city by building complexes along streets and rivers. Type 3: *kaze-no-michi* that is generated by sea breezes blocked by skyscrapers. When sea breezes are blocked by skyscrapers, warm air stagnates leeward of the buildings and cold air from above the skyscrapers is brought close to the surface. This cold air generates an area of low temperature located a small distance from the skyscrapers.

We are continuing our research on how to include *kaze-no-michi* in the city planning system of Japan. For example, we are making efforts to incorporate *kaze-no-michi* into city planning guidelines that take the UHI effect into consideration.

It is imperative that regional mitigation measures be simultaneously and systematically implemented in order to produce satisfactory results. So we have developed PC software to simulate the effect of various measures suitable for national and local governments and companies to use in target areas for effective city planning and urban development (Figure 10).

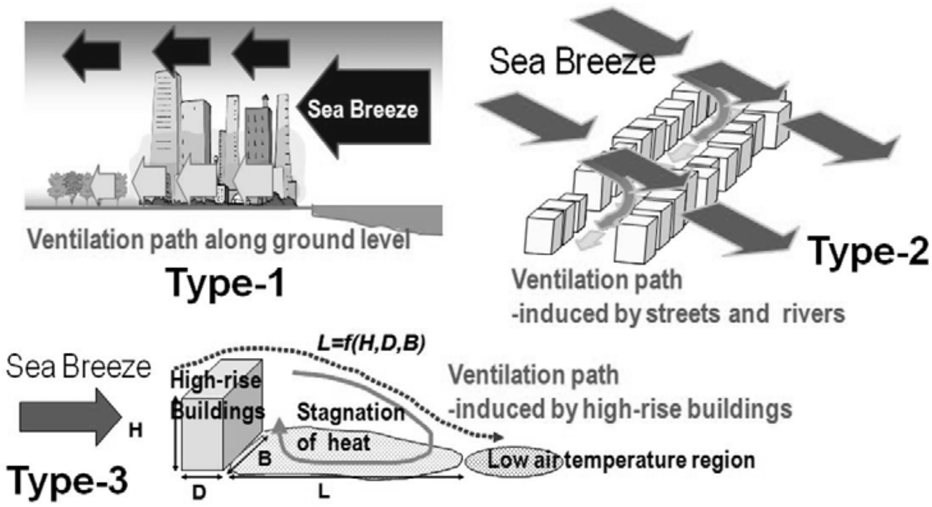

Figure 9. Classification of *kaze-no-michi*, which brings cool sea breezes into urban areas

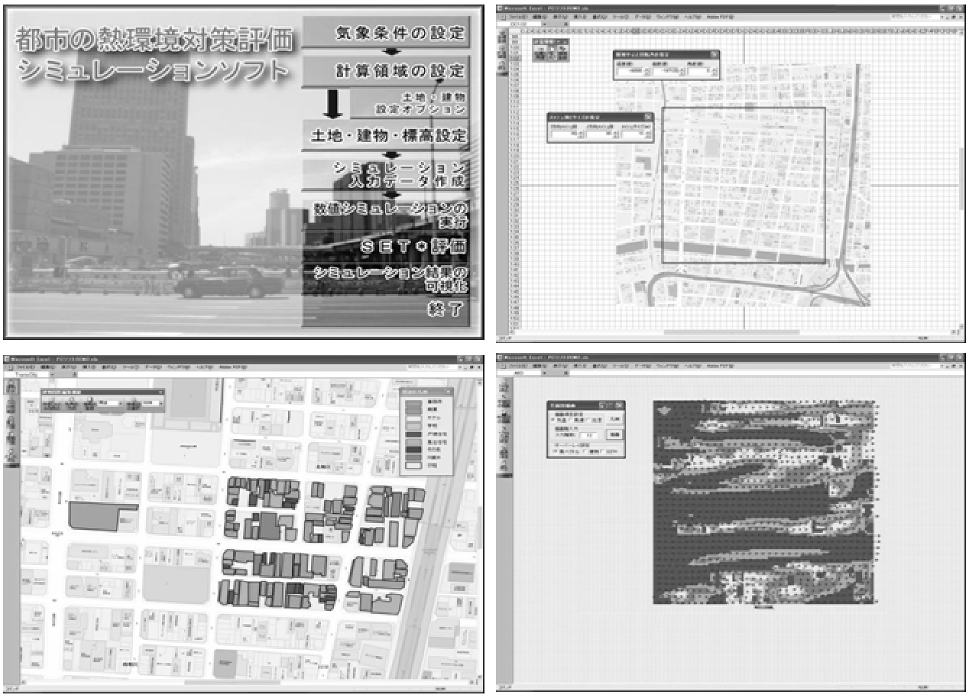

Figure 10. Images of the PC software for assessment of UHI countermeasures

For this PC software development, the aforementioned simulation models created for the supercomputer were used. With entry of data pertaining to an area of interest, the software is able to assess the effects of various UHI countermeasures (e.g., greening, installation of water-retentive pavement, "cool roof" installation, installation of energy-saving building equipment, district cooling and heating installation, maintenance and improvement of parks and green spaces, and creation of *kaze-no-michi*) in light of the prevailing wind direction for the corresponding area.

In the near future, we aspire to release this software to the public so national and local governments can use it for their decision-making procedures. By combining this assessment with city planning guidelines, they will be able to discuss and choose the measures that are best suited for the circumstances of the relevant area.

Summary and Outlook

In this paper, we introduced a national research project on ventilation paths, known as *kaze-no-michi*, for urban planning and on the development of PC software for the assessment of UHI countermeasures for national and local governments and other concerned parties.

We will provide the PC software as a user-friendly and practical tool and release it to the public in FY2009. We believe that UHI measures such as ventilation paths should be designed within the overall framework of city planning, so we will organize action plans suitable for local use and will include these in city planning guidelines to suit the needs of each city.

Information about this research project is available at http://www.nilim.go.jp/lab/jeg/heat.htm

Acknowledgments

The authors received considerable cooperation and advice from the following specialists during the committee meetings established to promote the present project (affiliations and positions are those at the time of the meetings): Dr. Ojima, Toshio (chairperson, professor at Waseda University), Dr. Hanaki, Keisuke (professor at the Graduate School of the University of Tokyo), Dr. Hoyano, Akira (professor at the Graduate School of the Tokyo Institute of Technology), Dr. Maruta, Yorikazu (professor emeritus of Chiba University), Dr. Mikami, Takehiko (professor at the Graduate School of Tokyo Metropolitan University), Dr. Narita, Ken'ichi (professor at Nippon Institute of Technology)

The large-scale measurement campaign in the central and waterfront areas of Tokyo was performed jointly by NILIM, Waseda University, Tokyo Metropolitan University, and the Nippon Institute of Technology.

References

Kagiya, Koji and Yasunobu Ashie, 2008, "National Research Project on *Kaze-no-michi* for Urban Planning- Making the Best Use of the Cool Sea Breeze in Tokyo" In Proceedings of 5th Japanese-German Meeting on Urban Climatology, University of Freiburg.

Ojima, Toshio et al. 2006, "Measurement and Numerical Simulation of Heat Island Phenomena in Tokyo: Part 1-12" In

Summaries of Technical Papers of Annual Meeting. Architecture Institute of Japan (in Japanese)

Kagiya, Koji et al. 2007, “Measurement and Numerical Simulation of Heat Island Phenomena in Tokyo: Part 13-18” In Summaries of Technical Papers of Annual Meeting, Architecture Institute of Japan (in Japanese)

Ashie, Yasunobu, Kohin Cho and Takaaki Kono, 2007, “Large-scale CFD Simulation of Heat Island Phenomenon and Countermeasures in Tokyo” In Annual Report of the Earth Simulator Center April 2007-March 2008, The Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology.

Ashie, Yasunobu, Kohin Cho and Takaaki Kono, 2008, “Large-scale CFD Simulation of Heat Island Phenomenon in Tokyo's 23 wards using the earth simulator” In Proceedings of 5th Japanese-German Meeting on Urban Climatology, University of Freiburg.

Cho, Kohin, Takaaki Kono, Koji Kagiya and Yasunobu Ashie, 2007, “The Improvement Effect on Thermal Environment of Urban Area Redevelopment Projects via Large-scale Numerical Simulations” In Proceedings of the Second National Conference of Heat Island Institute International (in Japanese)

(Received Feb 9, 2012, Accepted Oct 10, 2012)