Creating the 'Wind Paths' in the City to Mitigate Urban Heat Island Effects
A Case Study in Central District of Tokyo

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This paper is an introduction of recent study by NILIM and BRI on evaluating the effect of creating the "Wind Paths" in a densely built-up area in order to mitigate urban heat island. The measures are 1) Super-computer Simulations on wind speed and temperature and 2) Wind Tunnel Experiments with 3D model of build-up area. The Urban Heat Island causes problems on summer which not only make people discomfort outdoor, but also need more energy for air conditioners to cool indoor down. A few years ago in the central district of Tokyo, a large redevelopment project called Shiodome District, which has densely built skyscrapers in front of the harbour, was criticized because the wall of skyscrapers blocks the cool wind from the sea and is heating the inland up further. Stimulated by this event, we evaluated the three major redevelopment plans which include 1) avenue development from the slit between skyscrapers in Shiodome district to improve weak breezing zone, 2) demolition of a wall shaped building in front of Tokyo Station and 3) Removal and dig the elevated highway over the Nihonbashi River, to create the "Wind Paths". Some positive contributions but not so strong were surely found.

Keywords; *Heat Island, Wind Path, Sea Breeze, Spatial Planning, Tokyo*

1. Purpose

In daytime, direction of the wind is generally from the sea to the land. In cities in front of the sea, the sea breeze penetrates into the urban area and is expected to cool the heated air down or blow them away. However, the streaming line of the wind would be influenced by large buildings and structures, or streets and open spaces. These facts may suggest a possibility that if you can intentionally induce the cool sea breeze into the heated urban area, you could do urban planning that mitigates the urban heat island conditions in natural way.

In Japan, National Institute for Land and Infrastructure Management (NILIM) conducted a research project on urban heat island problem since 2004 to 2006, in cooperation with Building Research Institute (BRI), Waseda University, Tokyo Metropolitan University and Nippon Institute of

Technology. The purpose of this paper is introduce some of the results of the research project, especially on creating the 'Wind Paths' by executing urban renewal projects such as relocation of the buildings, digging the elevated highway and development of new avenue in the midst of the city. All of these renewal projects are actually on-going or on-planning.

2. Measure

In this study, three different measures are adopted. The first measure is the wind tunnel experiment using 1:750 physical model of the built-up area of central Tokyo. The second one is the large scale numerical simulation by CFD (Computational Fluid Dynamics) analysis using the Earth Simulator. The third one is also numerical simulation but using a personal computer.

The wind tunnel experiment was conducted by Dr. Koji KAGIYA and Masamiki OHASHI, both are senior researcher of NILIM. The numerical simulation system using the Earth Simulator, which is a super computer with one of the fastest calculation speed in the current world that managed by the Earth Simulator Center, was developed by BRI (Building Research Institute) team conducted by Dr. Yasunobu ASHIE. This time, BRI also implemented the simulation on request of NILIM. The reliability of the simulation system was already evaluated by the former experience in the project showing that computational results matched well with that of observation.

3. The Distance that the Sea Breeze Reaches

The central area of Tokyo is located in front of Tokyo Bay. Major wind direction in Tokyo area is from southeast in general, but In the sea front area, the wind usually breezing from the sea to the land perpendicularly to the coast line in daytime (Fig.1), and at night (or at least before dawn) it changes from the land to the sea. The sea breeze is cooler than the urbanized inland air so that it may mitigate the heated conditions in daytime on summer.

Before the experiments and simulations, we need to ensure that whether the cool sea wind really penetrates into the urban land or not, because the distance that the cool sea breeze reaches is thought to have its own limit, especially near the ground. Accordingly, actual observation was executed on July 29 to August 6 in 2005 by NILIM with three university teams including Waseda University. Anemometers and thermometers were installed in every 300 meters along the major streets in the seaside districts of Central Tokyo including the Tokyo railway terminal and the Shinbashi station.

As the results of that, the sea breeze which is cooler and more humid than the air around was observed at least 1.5 kilometers inside from the seashore along the streets at about 5 meters above the ground (Fig.2). In addition, it also recognized that broader streets make the breeze easier to intrude than narrow streets, and the structures of elevated highway are preventing the breeze on near the ground.

Fig.1 Sea Breeze from Tokyo Bay

Fig.2 Observed Sea Breeze

4. Mitigation by Urban Renewal Projects

Next, case studies with wind tunnel experiments and numerical simulations were adopted to actual urban areas in Central Tokyo including major urban renewal projects. The targeted urban renewal projects are three cases. The aim of the series of studies is to ensure the possibilities that spatial planning could contribute the mitigation of urban heat island problems. Change of wind velocities and thermal conditions caused by the projects were estimated

A) Removal of a Department Store Building (Case A)

Case A is a simple study that demolition of a 9 stories building which is located at the end of Yaesu-Dori Avenue like a wall as if blocking the sea breeze. The building is actually occupied with a famous department store called Daimaru. Behind the building there is Tokyo Station which is one of the largest railway terminals in Japan with no high rise construction. The opposite side of Tokyo Station there is another avenue called Gyoko-Dori extending through the business center district to the huge green garden belongs to the Imperial Palace. This case includes not only demolition of the wall like building but also construction of twin skyscrapers instead with 200 meters height respectively at both side of the lot of demolished building (Fig.3). Thus, after completion of the whole project, it could be expected that the breezing wind from the sea running along the Yaesu Dori Avenue would be able to go further through vacant space between skyscrapers toward the garden of the Imperial Palace.

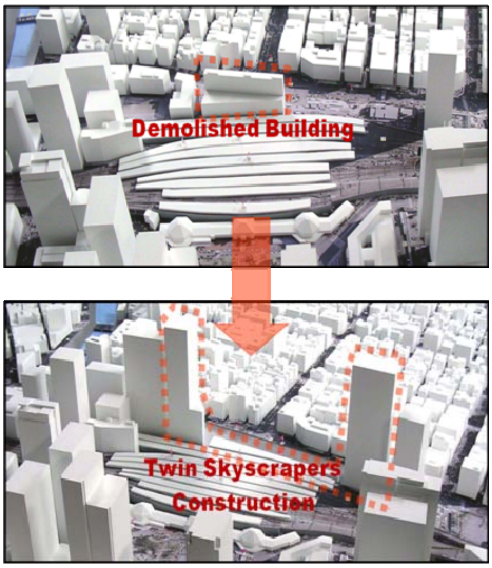

Fig.3 Urban Renewal Project Case A

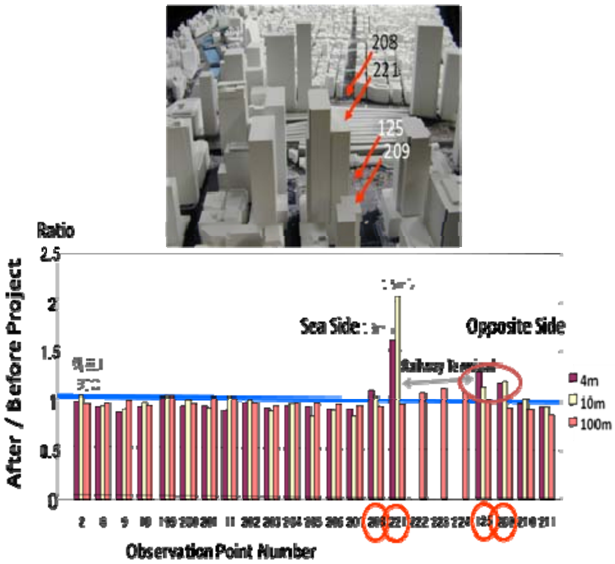

Fig.4 Change of Wind Velocity on Case A

First, we did physical experiment to observe the difference of wind velocity in comparison with before and after the project. This experiment was performed as wind tunnel test using 1:750 3D physical model of the actual area (Fig.4). The measuring instrument was thermistor velocity meter.

As the result of the wind tunnel experiment, the wind velocities were increased about 20 to 30 percent at the opposite side of Tokyo Station as well as around the demolished site (Fig. 4, see observation points No.125 and 209). Though the increased points were limited, we can recognize that this project has some positive effects in terms of extending the distance of the wind path.

B) Digging the Elevated Highway over a River (Case B)

Case B-1 is removal of elevated highway above a small river and digging it underground. Case B-2 is further improvement that lowering the buildings in both sides of the river in addition to digging the highway. So the broader open corridor with water surface in the center was created in Case B-2 (Fig.5). Historically, the highway was constructed in early 1960s when Tokyo Olympic Game was held and rapid growth of Japanese economy took off. However, landscape on this spot has long been badly criticized because it definitely ruins the traditional symbolic sight around the bridge called Nihon-bashi, which means the 'bridge of Japan' where the original point of the old high road is located. The highway overhangs on the traditional bridge. Therefore, the original purpose of this project is to regenerate the excellence of urban landscape of Tokyo.

Fig.5 Urban Renewal Project Case B; Digging Elevated Highway

On these cases, NILIM also did the wind tunnel test as same the way as Case A. It was more complicated case, but we can recognize definite increases of wind velocity in many points around the river (Fig.6). In comparison with Case B-1 and B-2, the wind velocities are more increased in Case B-2 than B-1. It suggests that we can get more comfortable out-door thermal condition as well as landscaping by lowering the river side buildings In this case, the effects seems to be widely influenced because the area where wind velocities are increased more than 10 percent might be reached 200 meters or more from the edge of the river.

Next, BRI team did the numerical simulation on the request by NILIM. The computational domain for CFD analysis is a size of 2.5km x 1.5km x 0.5km. The grid spacing is 1 meter square in horizontal, and total amount of grids are 500 millions including the buffer zone. Simulations are performed on the Earth Simulator operated by BRI team. Topographical information and three dimensional data of buildings and other artificial facilities were generated from GIS (Geographic Information System) database of Tokyo and DEM (Digital Elevation Model). The climate conditions were based on the day of July 31, 2005. The boundary and initial conditions are accepted the simulation results of a meso-scale model.

The numerical simulation was implemented to the target area where both Case A and Case B-2 are included. Fig. 7 shows the difference of wind velocity between before and after. The velocity changed areas are all located in the lee side from the projects, such as around the removed highway, opposite side area to the demolished building across the railway terminal. The velocities are increased from 1 to 2 meters per second in most of the changed areas, whereas in some areas we can find decreasing. As for impacts on temperature (Fig.8), it supposed that the difference of temperature is mostly well correspond with the difference of wind velocity, except the

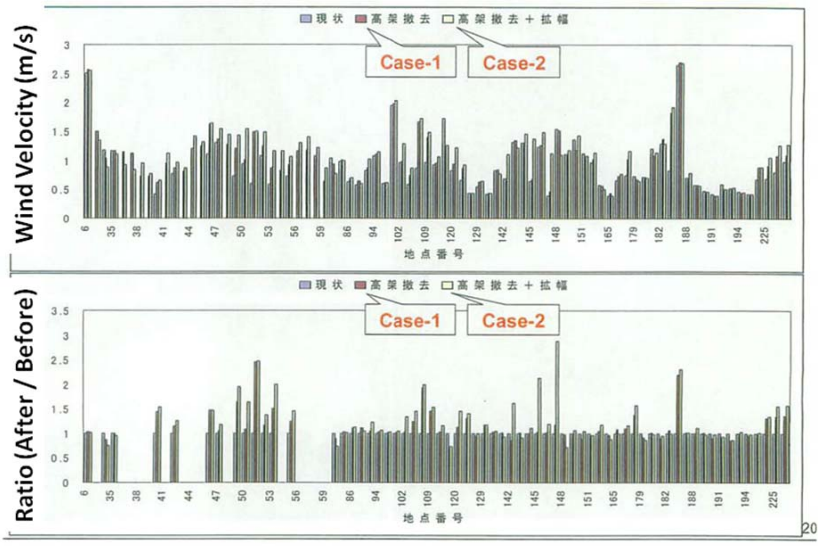

Fig.6 Change of Wind Velocity on Case B-1 & B-2 by Wind Tunnel Experience

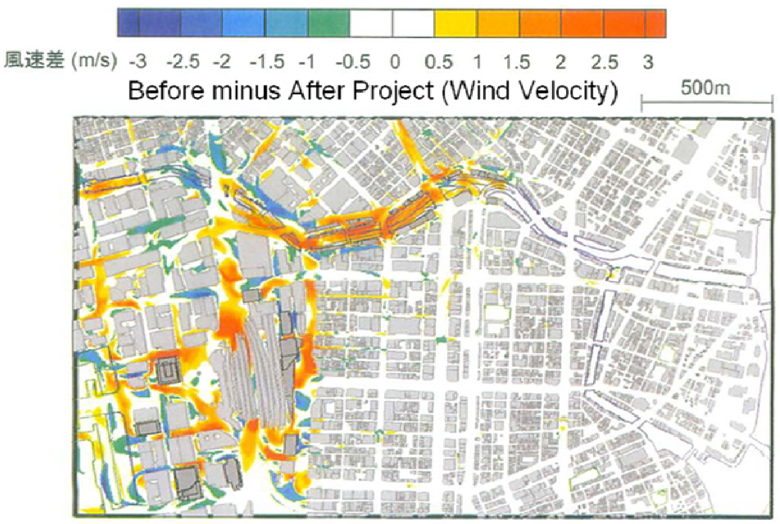

Fig.7 Change of Wind Velocity on Case A & B-2 by the Earth Simulator

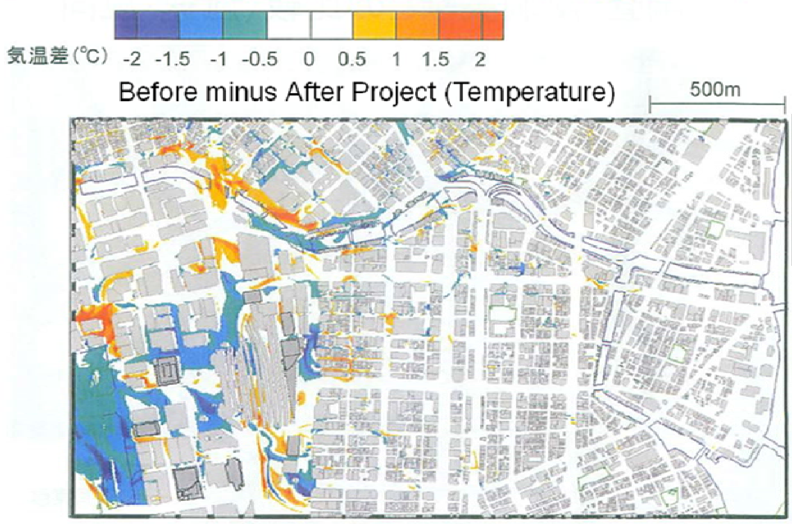

Fig.8 Change of Temperature on Case A & B-2 by the Earth Simulator

areas where temperature decreased with 0.5 to 2 degrees are widely spread in the west side area of Tokyo Station, which is considered not so small impact in mitigating urban heat island conditions. The reason is guessed that a cool breeze that run on the water surface of the river and another cool air that fell down by constructed skyscrapers are getting together in the west side area of Tokyo Station.

Totally speaking, it seems that above two urban renewal projects are expected to be contribute to mitigate heat island conditions because the results indicates that the temperature cooled down area is larger than the warmed up area. Moreover, large part of the cooled down area is occupied with more than 1 degree fall whereas the most part of the warmed up area is occupied with less than 1 degree rise.

C) Development of an Avenue behind a Wall of Skyscrapers (Case C)

Shiodome District is one of the largest redevelopment areas in Central Tokyo. Most of the skyscrapers in the project site were already completed in early 2000s. Each skyscraper commands a fine view of Tokyo Bay. A result of that, a mass of skyscrapers was constructed as if a huge wall was constructed between the sea and the land. The criticism that indicates the skyscrapers may got worse the heat island condition in the behind area was prevailed soon after a thesis written by Dr. Toshio Ojima and Dr. Yukihiro Masuda was released. The thesis pointed out that the wall of skyscrapers could be blocking the cool sea breeze and a mass of weak wind might be created in the area behind the skyscrapers.

On this area, we decided to assess the impact for thermal environment on the new avenue development which is actually planned and under construction. The congesting urban space with a lot of relatively small office buildings in the behind area will be cut through and separated by the constructed avenue from a spatial slit between skyscrapers (Fig.9), thus a mass of heated air staying behind the skyscrapers with weakened velocities might be cooled, separated and flown away. If this assumption is correct, the urban renewal project of this type could be said to have a positive effect on mitigation of urban heat island problem.

On assessing Case C project, numerical simulation was applied. This time we decided to use personal computer instead of the Earth Simulator for CFD analysis. For reducing the calculation load, the computation domain was set as 0.6km x 0.6km with 5 meters grid. The newly developed avenue called Kan-Ni Dori Avenue is 40 meters in width, which is actually authorized in the valid official plan as well as under construction. The buildings along both side of the avenue are also assumed to be reconstructed with avenue development by 60 meters in height.

Fig.9 Urban Renewal Project Case C; Avenue Development behind Skyscrapers

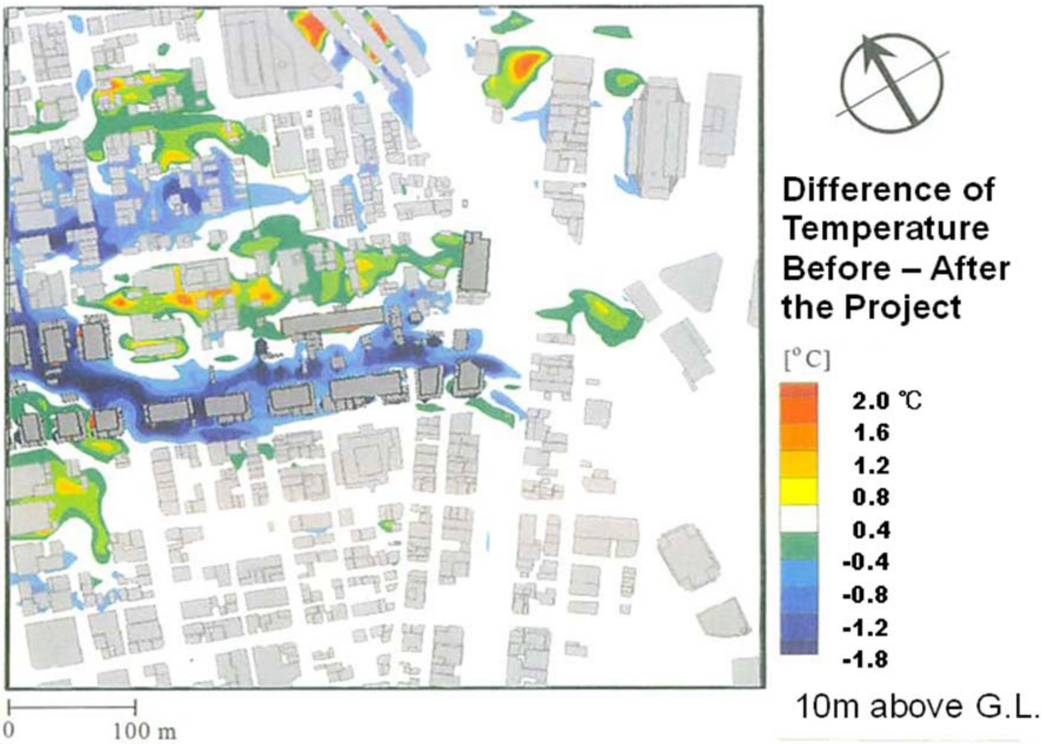

Fig.10 Mitigation of Heat Island on Case C Project

Fig 10 is the output of the simulation. The temperature at 10 meters above ground decreased more than 2 degrees in areas around the avenue as well as the lee side. Therefore it can be conclude that this case of urban renewal project, that is a new development of a broad street with high rise buildings in two rows behind the wall of skyscrapers, has a definite effect on mitigation of heat island problem.

5. Conclusion

In these case studies, we compared before with after the specific urban renewal projects in terms of out-door temperatures and wind velocities by wind tunnel experiments and numerical simulations, for the purpose of exploring a sort of technical way that spatial planning contributes mitigation of urban heat island effects. The results indicate some facts.

Firstly, it was recognized that the sea breeze have a certain influence on out-door temperature of urban built-up areas. The influence is recognized as not so small because cooled areas with more than 2 degrees down are distributed after the renewal projects were executed. However, we should not forget the fact that some warmer areas than before would be generated inevitably because the wind moves the heated air.

Secondly, the flows of the breeze are surely affected by the locations and shapes of the artificial structures such as buildings and elevated highways. However, the behavior of air flow is not so simple as it is always blocked its way by the buildings. For instance, high rise buildings sometimes stand in the way of sea breeze so that a heated air arrested behind the buildings, but contrary to that, they sometimes induce the cool air above in the sky down to the ground so that they facilitate ventilation and mitigate the heat island conditions. At least, we could find that the broad streets and rivers that running from the seashore to inland are supposed to create the wind paths, even if they are made behind the wall of skyscrapers.

6. Remarks

“A wind path is not like a dragon snake”, remarked Dr. Ken-ichi NARITA, who is professor of Nippon Institute of Technology. Behavior of the air in urban built-up space is not so simple than one dimensional movement.

Surely, a large building may block a breezing wind and generate low wind velocity area behind it. But on the other hand, it is generally known that a high rise building induces the aerial flow down to the ground. The urban street canyon also induces downstream between buildings. You should consider not only horizontal movements but also vertical movements for ventilating the warmed air.

Moreover, in densely and roughly features of urban spaces, behavior of the air is more complicated such as whirlpools and interactions.

In addition, the direction of the wind is swinging all the time and the velocity of the wind is varies from day to day. The cool breeze is not necessarily blowing in the midst day of summer. In fact, in the hottest day in the year in Tokyo in 2005, the wind was blowing from the mountain side. The main culprit of the day was foehn phenomenon, which was occurred by the wind blowing from the contrary side of the sea. The Wind Path is not a cure-all medicine.

However, according to the study above, we can at least say that creating the "Wind Paths" as broad linear uncovered corridors penetrating through densely urban areas in Central Tokyo is expected to be effective for mitigation of heat island phenomenon. Because they create sequence of breezing air from the sea and facilitate ventilation of the heated air in natural way without any artificial energy, even though the effective area is limited.

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