Current situation of outdoor wind environment in Japan

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ABSTRACT: This report introduces the current status of outdoor environmental issues in Japan. The outdoor environment is greatly affected by various wind conditions, commonly classified as strong winds and weak winds. Strong winds around high-rise buildings have been a social issue for over 30 years in Japan. Wind tunnel experiments have been conducted to assess the environmental impact of strong winds at the pedestrian level and are regarded as the most reliable prediction method. In recent years, the application of computational fluid dynamics (CFD) to this problem has been rapidly gaining popularity and acceptance. On the other hand, weak wind conditions can also cause problems. Air pollution and the heat island phenomenon intensify when winds are weak. Owing to the restrictions on the emission of harmful substances from both facilities and automobiles, Japan's outdoor air quality has been gradually improving. The annual averages of NO_2, SO_2, CO, and SPM concentrations have remained steady or gradually declined in recent years, but the compliance rates with the Environmental Quality Standards have been extremely low for photochemical oxidants. Heat island phenomenon currently occurs in most cities in Japan due to anthropogenic heating, poor urban ventilation and oversized artificial ground coverage areas. Several countermeasures have been taken by governmental authorities. Recent researches on urban heat islands in Japan are reviewed in the latter part of this article.

KEYWORDS: Air pollution, heat island phenomenon, pedestrian wind environment, wind tunnel experiment, CFD

1 INTRODUCTION

Winds have a great influence on the outdoor environment in urban areas. Problems they cause roughly be classified into strong wind and weak wind issues. The first half of this article addresses strong-wind issues, i.e., strong winds around high-rise buildings. It introduces the current situation of the pedestrian wind environment around high-rise buildings, environmental impact assessment methods using wind tunnel experiments and computational fluid dynamics (CFD), and the criteria for assessment in Japan. Next, the report considers the outdoor air pollution problem and the heat island phenomenon, both of which are more serious in weak-wind regions in urban street canyons. The importance of air ventilation in urban areas is now broadly recognized as a countermeasure to the urban heat island phenomenon and air pollution problem, so it is becoming extremely important to ensure adequate air ventilation in urban spaces. Nowadays, researchers in the field of environmental wind engineering are paying more attention to these weak-wind-related issues as opposed to strong-wind issues. The middle part of this report describes environmental quality standards and laws for outdoor air pollutants and the present situation of outdoor air pollution in Japan, based on the Environmental White Paper (Ministry of the Environment, Government of Japan (2012)). Lastly, the report reviews several countermeasures taken by the government authorities and recent studies on urban heat islands in Japan.

2 PEDESTRIAN WIND ENVIRONMENT AROUND HIGH-RISE BUILDINGS

2.1 *Present situation of the pedestrian wind environment*

Strong winds around high-rise buildings have been a social issue for more than three decades in Japan. Conflicts between construction companies and residents are not unusual, and occasionally develop into lawsuits. Although the assessment of the pedestrian wind environment is not regulated by Japanese law, some local governments require developers to make preliminary investigations, estimates and assessments regarding the environmental impact of their development projects. For example in Tokyo, developers who plan to build a high-rise building over 100 m in height with a total floor area of over 100,000m^2 must carry out procedures according to the "Environmental Impact Assessment Ordinance of the Tokyo Metropolitan Government." Wind tunnel experiments or CFD simulations are typically carried out for this kind of environmental impact assessment.

2.2 *Assessment of the pedestrian wind environment by wind tunnel experiment*

In the wind tunnel experiments for this type of assessment, multi-channel thermistor anemometers are widely used in Japan to measure wind speed. Since the anemometers are relatively strong and hard to break, they can be installed from under the turntable, as shown in Fig. 1. Once the anemometers are set at the measuring points, wind speeds of many points can be measured at the same time. Therefore, it does not take too much time to measure the wind speeds of many wind directions and of several experimental cases. However, the frequency response of the anemometers is low (lower than 1Hz). The gust wind speeds cannot be measured with this type of anemometer. This is one of the problems in estimating the occurrence frequency of maximum gust speeds as will be described later.

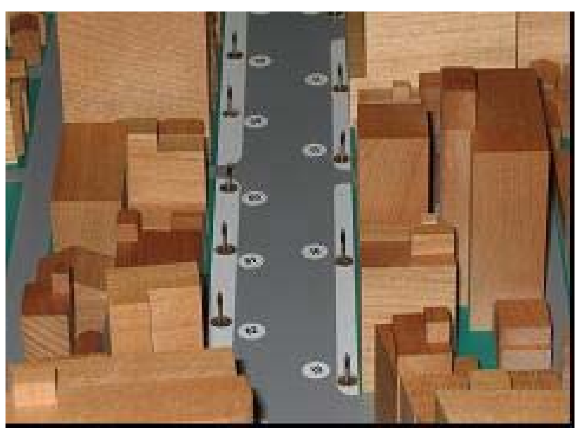


Fig. 1 Multi-channel thermister anemometers installed in building models.

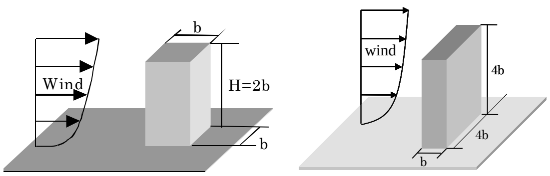
2.3 *Assessment of the pedestrian wind environment by CFD simulations*

The application of CFD to the prediction of wind environments has been rapidly increasing. Despite its widespread use, the accuracy of prediction and many factors that affect the simulation results was still not thoroughly understood. In order to clarify the ambiguities and make practical guidelines for CFD prediction of the wind environment, a working group was organized by the Architectural Institute of Japan (AIJ) in 1997. This group consists of researchers from several universities and private companies. The working group has conducted various comparative studies as follows.

・Flow field around a high-rise building without neighboring buildings, as shown in Fig. 2
・Flow field around a high-rise building within a model city block, as shown in Fig. 3
・Flow field behind a tree canopy, as shown in Fig. 4.
・Flow field around high-rise buildings in actual urban areas, as shown in Fig. 5.

The results of CFD were compared with those of wind tunnel experiments and field measurements, and many factors such as computational domain, grid, boundary conditions, numerical schemes for advection terms, and turbulence models were examined to clarify their influence on the simulation results (Yoshie et al., 2007).

Based on these investigations, "AIJ guidelines for practical applications of CFD to pedestrian wind environments around buildings (2007)" was published in 2007 (Fig.6). An English version was also published in 2008 (Tominaga et al., 2008).



(a) 2:1:1 square prism (b) 4:4:1 square prism

Fig. 2 Flow field around a single high-rise building

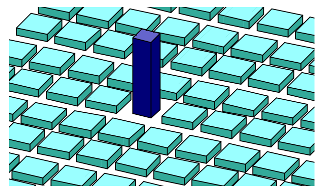
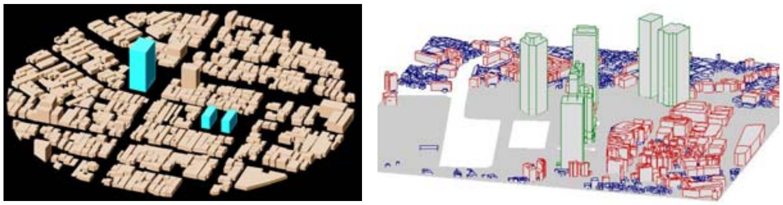


Fig. 3 Flow field around a high-rise building within a model city block.

Fig. 4 Flow field behind tree canopy.



(a) Niigata city (b) Shinjuku

Fig. 5 Flow field around high-rise buildings in actual urban areas.

Fig. 6 AIJ guidebook for numerical simulation of the wind environment in urban areas.

2.4 *Criteria for assessment of wind environment at pedestrian level*

The occurrence frequencies of wind speeds at the pedestrian level can be calculated using statistical wind data from a nearby meteorological observatory and the results of wind tunnel experiments or CFD simulation. One of the most widely used methods for assessing the wind environment is based on the occurrence frequency of the daily maximum gust speed proposed by Murakami et al. (1983) as shown in Table 1. The other assessment method based on the cumulative frequency of mean wind speeds (averaged over 10-minute periods) proposed by the Wind Engineering Institute (1989) as shown in Table 2 is also widely used in Japan. Murakami et al. (1983) conducted long-term observations of wind speed and wind-induced problems in cooperation with many inhabitants in downtown Tokyo. The criteria were determined considering the relationships between the daily maximum gust speeds and impressions of the wind environment or wind-induced problems.

As mentioned above, because multi-channel thermistor anemometers with poor frequency response are used in the wind tunnel experiments, gust wind speeds cannot be obtained from the experiments. Furthermore, most of the CFD simulations for the assessments are based on Reynolds averaged turbulence models, so the obtained results are mean wind velocities and not gust wind velocities. Therefore, when using Murakami's criteria, the gust factor (the ratio of peak gust wind velocity to mean wind velocity) has to be assumed. However the occurrence frequency of the daily maximum gust speed strongly depends on the assumed gust factor. Nishimura and Takamori (2002), and Hongo and Nakayama (2003) have proposed gust factor estimation methods, but we have not reached a general consensus about the determination of the gust factor yet.

Table 1 Criteria for assessment of pedestrian wind environment based on occurrence frequency of daily maximum gust speed

Class	Effect of strong wind	Areas applicable (example)	Level of assessment of strong wind and acceptable exceedance frequency (at height of 1.5m)		
			Daily maximum gust speed (m/s)		
			10	15	20
			Daily maximum mean speed(m/s)		
			10/G.F	15/G.F	20/G.F
1	Areas used for purposes most susceptible to wind effects	Shopping street in residential area, Outdoor restaurant	10% (37 days per year)	0.9% (3 days per year)	0.08% (0.3 days per year)
2	Areas used for purposes not too susceptible to wind effects	residential area, park	22% (80 days per year)	3.6% (13 days per year)	0.6% (2 days per year)
3	Areas used for purposes least susceptible to wind effects	office street	35% (128 days per year)	7% (26 days per year)	1.5% (5 days per year)

Table 2 Criteria for assessment of pedestrian wind environments based on cumulative frequency of mean wind velocity

	Mean wind speed at cumurative frequency of 55%	Mean wind speed at cumurative frequency of 95%	Notes
Region A	≦1.2m/s	≦2.9m/s	Wind environment for residential area
Region B	≦1.8m/s	≦4.3m/s	Wind environment for residential area and urban area
Region C	≦2.3m/s	≦5.6m/s	Wind environment for office area
Region D	＞2.3m/s	＞5.6m/s	Wind environment around super high-rise building

3 OUTDOOR AIR POLLUTION

3.1 Environmental quality standard and laws for outdoor air pollutants

Table 3 indicates Environmental Quality Standards (EQS) for SO_2, CO, SPM, NO_2, and Ox specified in the "Basic Environmental Law". Other than these substances, EQS for benzene, trichloroethylene, tetrachloroethylene, dichloromethane, and dioxins are also specified in the "Basic Environmental Law" The EQS are policy objectives which are desirable for the protection of human health and conservation of the living environment. The "Air Pollution Control Law" restricts the emission of soot and smoke, volatile organic compounds, and particulates from factories and facilities. The Law also specifies maximum permissible limits on the amount of exhaust gases from motor vehicles. In areas where factories are concentrated and it is considered difficult to maintain EQS, the total load control is enforced for factory units according to the total amount reduction program prepared by the governor of each prefecture.

Table 3 Environmental Quality Standards in Japan

Substance	Environmental conditions	Measuring method
Sulfur dioxide (SO_2)	The daily average for hourly values shall not exceed 0.04 ppm, and hourly values shall not exceed 0.1 ppm (Notification on May 16, 1973)	Conductometric method or ultraviolet fluorescence method
Carbon monoxide (CO)	The daily average for hourly values shall not exceed 10 ppm, and average of hourly values for any consecutive eight hour period shall not exceed 20ppm (Notification on May 8, 1973)	Nondispersive infrared analyzer method
Suspended particulate matter (SPM)	The daily average for hourly values shall not exceed 0.10 mg/m^3, and hourly values shall not exceed 0.20 mg/m^3 (Notification on May 8, 1973)	Weight concentration measuring methods based on filtration collection, or light scattering method; or piezoelectric microbalance method; or β-ray attenuation method that yields values having a linear relation with the values of the above methods.
Nitrogen dioxide (NO_2)	The daily average for hourly values shall be within the 0.04–0.06 ppm zone or below that zone (Notification on July 11, 1978)	Colorimetry employing Saltzman reagent (with Saltzman's coefficient being 0.84) or chemiluminescent method using ozone.
Photochemical oxidants (Ox)	Hourly values shall not exceed 0.06 ppm (Notification on May 8, 1973)	Absorption spectrophotometry using a neutral potassium iodide solution; coulometry; ultraviolet absorption spectrometry; or chemiluminescent method using ethylene.

1. Suspended particulate matter is defined as airborne particles with a diameter smaller than or equal to 10 μm.
2. Photochemical oxidants are oxidizing substances such as ozone and peroxiacetyl nitrate produced by photochemical reactions (only those capable of isolating iodine from neutral potassium iodide , excluding nitrogen dioxide.)

3.2 Present situation of outdoor air pollution

Owing to the restrictions of the "Air Pollution Control Law" on emission of harmful substances for both facilities and automobiles, the outdoor air quality has been gradually improving in Japan.

According to the Environmental White Paper (Ministry of the Environment, Government of Japan, 2012), the annual average nitrogen dioxide (NO_2) concentration at 1,332 Ambient Air Pollution Monitoring Stations (AAPMSs) was 0.011ppm and that at 416 Roadside Air Pollution Monitoring Stations (RAPMs) was 0.022ppm in FY 2010. The environmental quality standards (EQS) for nitrogen dioxides specify that the daily average of hourly values shall be within the range of 0.04 - 0.06 ppm or below this zone (Table 3). NO_2 concentrations have achieved a 100% compliance rate with the EQS at the AAPMSs and 97.8% at the RAPMs. Compliance with the EQS in areas designated for measures under the “Law concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matter from Automobiles in Specified Areas” (Automobile NOx/PM Law) was 95.7% in FY2010, a marked improvement from 43.1% in FY1998.

The annual average sulfur dioxide (SO_2) levels in FY 2010 were 0.003 ppm at ambient stations (AAPMSs) and roadside stations (RAPMSs), both remaining continuously at almost the same levels over the past several years. The environmental quality standards for SO_2 indicate that the daily average for hourly values shall not exceed 0.04 ppm, and the hourly values shall not exceed 0.1 ppm (Table 3). The compliance rates with the EQS for SO_2 were 99.7% at AAPMSs and 100.0% at RAPMSs in FY2010, showing satisfactory conditions in recent years.

The environmental quality standards for carbon monoxide (CO) indicate that the daily average of hourly values shall not exceed 10 ppm, and average of hourly values for any consecutive eight hour period shall not exceed 20 ppm (Table 3). The annual average values in FY 2010 were 0.3 ppm at AAPMSs and 0.5 ppm at RAPMSs, showing a gradual decrease in recent years. The compliance rates with the EQS for CO have been 100% for both AAPMSs and RAPMs.

The environmental quality standards for Suspended Particulate Matter (SPM) indicate that the daily average for hourly values shall not exceed 0.10 mg/m^3, and hourly values shall not exceed 0.20 mg/m^3 (Table 3). The annual averages of SPM concentrations were 0.021mg/m^3 at AAPMSs and 0.023mg/m^3 at RAPMSs in FY2010. The compliance rates with the EQS were 52.5% at AAPMSs and 34.3% at RAPMSs in FY 2002. In FY 2001, under the Automobile NOx/PM Law, particulate matter was added to the list of substances to be regulated. Owing to the law, compliance rates have improved to 93.0% at AAPMSs and 93.0% at RAPMSs as of FY 2010.

Photochemical oxidants are the cause of photo-chemical smog. In almost all regions throughout Japan, photochemical oxidants still exceed the environmental quality standards (EQS) (an hourly value of 0.06 ppm or less: see Table 3.). The compliance rate with the EQS in FY 2010 was as extremely low as 0.0% at AAPMSs and RAPMs. The number of days with warnings issued on photochemical oxidants was 82 (in 18 prefectures). There were 69 persons who reportedly suffered discomfort caused by photochemical air pollution. Air pollution due to photochemical oxidants is expected to improve through restricting the emission of nitrogen oxides and volatile organic compounds. To reduce hydrocarbons discharged from automobiles, restriction of exhaust gas has been enforced since 1973 in accordance with “the Air Pollution Control Law” issued in 1968. Subsequently, these restrictions have been successively renewed.

4 HEAT ISLAND PHENOMENON

The heat island phenomenon, in which the air temperature in urban areas is higher than in suburban areas, is now found in most large cities. According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2001, it is estimated that the average global surface temperature increased by 0.6°C ± 0.2°C during the 20th century. However, in major cities such as Tokyo and Nagoya, the average temperature increased by 2 - 3°C during the same period. Thus, compared with the mean change in the global climate, the increasing trend of heat islands in urban areas is remarkable. With these increases in air temperature, the numbers of “tropical nights” in which the temperature exceeds 25°C at night have been increasing in many cities. The annual number of the tropical nights in Tokyo was on the order of several days in the early 20th century, while it has reached a level of 30 to 50 days in recent years. Furthermore, the

area over which this phenomenon extends is increasing. This has detracted from the city's pleasant environment and has also created thermal pollution problems.
At present, a lot of administrative countermeasures are being taken against the heat island effect and studies have been performed to find ways to cope with the heat island problem. Among these countermeasures, recent attention has focused on the creation of ventilation paths in urban areas at the urban planning stage. In September 2006, a symposium entitled “Air Change and Ventilation Paths in Urban Areas” was held by the Architectural Institute of Japan. In this chapter, we review several countermeasures taken by administrative authorities and recent researches on the heat island phenomenon in Japan.

4.1 *Administrative countermeasures against the heat island effect*

4.1.1 Recent actions taken by administrative authorities

The Japanese government and local public organizations have taken various countermeasures and actions to mitigate the problem of the heat island effect. For these countermeasures to be effective, it is necessary to promote mutual cooperation among the relevant organizations and to take systematic action. An Inter-Ministry Coordination Committee was formed to mitigate urban heat island effects, and a basic policy has been determined in March 2004. As a result, the “General Principle of the Countermeasures to cope with the Heat Island Problem” was publicized. This systematically summarized actual measures to be taken (Governmental Liaison Council on Countermeasures Against the Heat Island Effect, 2004). In July 2004, the Ministry of Land, Infrastructure and Transport presented “Guidelines on Building Design for the Alleviation of Heat Island Phenomena” to local administrative authorities. In July 2005, CASBEE-HI (Comprehensive Assessment System for Building Environment Efficiency on Heat Island Relaxation) was publicly announced. In August 2006, the “International Workshop on Countermeasures to Urban Heat Islands” was held in Tokyo under the joint sponsorship of the Ministry of Land, Infrastructure and Transport and the International Energy Agency.

4.1.2 General principle of the countermeasures to cope with the heat island effect

The Governmental Liaison Council on Countermeasures Against the Heat Island Effect promulgated general guidelines in March 2004 as mentioned above. These guidelines focused on four major policies: ①reduction of anthropogenic heat, ②improvement of ground cover, ③improvement of urban forms, and ④modification of lifestyles. It also recommended reinforcing the atmospheric monitoring network and promoting research on the effects of these countermeasures.

(1) Reduction of anthropogenic heat

Anthropogenic heat is exhausted from air-conditioning units, electric devices, combustion facilities, motor vehicles, etc. Various measures have been taken to reduce anthropogenic heat. Some specific ones include: production of high-efficiency energy-consuming equipment, construction of houses and buildings with high energy-saving effects, development of low-emission vehicles, and taking measures to improve traffic distribution and encourage the use of public transportation. Table 4 indicates the targets for energy-saving performance in houses and buildings.

(2) Improvement of ground surface cover

Improving ground surface conditions may effectively retain water and prevent high temperatures on the ground surface. The target was to achieve open public spaces in urban areas with water and green areas from 12 m2 per person in 2002 to 13 m2/person in 2007, i.e., an increase of about 10%.

(3) Improvement of urban forms

Ventilation paths from green belts and water surfaces are thought to improve the thermal environment in urban areas very effectively. While conserving green spaces in urban areas, it is necessary to establish a firm network of water and green areas, so as to encourage the development of cities with lower environmental load. For long-term planning, the target is to establish moderate-sized urban areas with low environmental loads.

(4) Improvement of life styled

To alleviate the heat island effect closely associated with social and economic activities in urban areas, actions are now being taken with the aims of improving the life style of the inhabitants. Specifically, it is aimed to reduce carbon dioxide emission by 440,000 tons - 850,000 tons by setting the air-conditioning temperature to 28°C in summer and the heating temperature to less than 20°C in winter.

4.2 *Recent researches on countermeasures against the heat island effect*

4.2.1 Numerical simulations

To evaluate the heat island effect, it is important to understand correctly the heat flux within an urban area and to elucidate the structure of the heat island. Sato et al. (2008) established a method of evaluating the heat balance over an entire urban area from the results of numerical analyses based on a meteorological meso-scale model and they used it to analyze the heat island effect in the urban area of Tokyo. Most cities in Japan are located along the sea coast, and sea breezes exert a considerable influence on the regional climatic characteristics as a cooling source. Ooka et a. (2008) proposed a mean kinetic energy balance model based on the meso-scale climate analysis to estimate the structure of the sea breeze. The balances of four areas in the Tokyo metropolitan were analyzed by using this method. It was clarified that the sea breeze was interrupted by the resistance and turbulence caused by buildings at the inter city. Furthermore, they (Sato, Ooka, and Murakami 2008) proposed a new concept "moving Control Volume" along the sea breeze in order to clarify the interaction between sea breeze and urban climate. By using this model, they investigated the sensible heat, latent heat and mean kinetic energy balances of the moving Control Volume. Sasaki et al. (2008) proposed a “heat balance map” for Sendai City based on a meso-scale numerical climate analysis. This “heat balance map” illustrated the areas where the influence of sea breezes was significant in contrast with heat generated from ground surfaces and anthropogenic heat release, and it could be used as the basis of a new city planning and urban canopy project. In order to accounts for drag force by buildings and heat transfer inside the urban canopy, Ashie et al. (2004), Harayama et al. (2005) and Kawamoto et al (2009) incorporated the urban canopy model with the metrological meso-scale model.

However, the analysis based on the metrological meso-scale model described above cannot evaluate winds in detail that flow between buildings or along streets and rivers. To analyze wind flows that are tiny-scale compared to meso-scale flows, it is necessary to perform a micro-scale CFD analysis with buildings and trees adequately reproduced. Ashie et al. (2008) applied a large-sized parallel computer called an “Earth simulator” to the study of urban environmental problems. Specifically, large-scale numerical calculations were performed for 10 square kilometers in the Tokyo Bay area with 5m × 5m horizontal grids. By accurately reflecting the arrangement of buildings, topography and land utilization, the wind flows through spaces between rivers, canals and buildings were reproduced, and air ventilation performance in the area was clearly evaluated from the viewpoint of alleviation of the heat island effect. Furthermore, Kataoka et al. (2006) has also applied Large Eddy Simulation to a study on the climate in the Shinjuku area of central Tokyo and evaluated the blockage effect of high-rise tower buildings on sea breezes. In order to quantitatively clarify the effect of various relaxation measures to the heat island phenomenon, Tsuchiya et al. (2008) conducted coupled numerical simulations of convection, radiation and conduction in Otemachi area, as a high-rise office block, and in Kyobashi area, as a middle-rise office block in Tokyo. The result showed that the measures of high albedo material and greening on ground and road were effective in Otemachi, and heat release point and way of air-conditioning affect very much in Kyobashi.

4.2.2 Field measurements

Recently in Tokyo, high-rise tower buildings have been constructed along the bay. They are said to have prevented the penetration of sea breezes into the downtown area. Mikami et al. (2006) performed field measurements in downtown Tokyo. From airflow characteristics and air temperature distributions, he indicated that the temperature in the wake region of high-rise tower buildings was 2 - 3°C higher than that near an upwind large green space. Taniguchi et al. (2008, 2009) carried out the field measurement in the urban district in Hiroshima City. They measured wind velocity and temperature in the sea breeze in summer. They showed mitigation effect of the sea breeze and river breeze for heat island phenomenon in Hiroshima. Hashimoto et al. (2008) clarified the effect of the sea breeze blowing over the Horikawa Canal on the urban climate in Nagoya by field measurements at 10 fixed points along the canal. They observed that the sea breeze proceeded along the Horikawa Canal up to 9km from the sea.

4.2.3 Reflective painting and greening on buildings and ground surfaces

Studies have been performed on light-colored surfaces intended to reduce solar absorption on roofs and walls of buildings and on the ground to determine their effectiveness in mitigating the heat island effect. It was found that they suppress increases in ambient temperature and heat storage in ground coverage and building frames. Roof coatings with highly reflective materials are called “Cool roofs”. A Cool Roof Committee was also established in the Architectural Institute of Japan, and studies have been carried out to determine the performance of cool roofs and walls in alleviating the heat island effect. The Tokyo Metropolitan Government is actively promoting the adoption of roof greening and roof coatings with highly reflective materials. Kondo et al. (2008) conducted field measurements on pavement where two areas of surface were coated with high reflective paint and ordinary material. The heat flux on the urban surface was calculated on the basis of heat budget equation with the measured data, and the result was compared with the artificial heat release from buildings etc. in 23 wards of Tokyo. They showed that the high reflective pavement (cool pavement) could reduce sensible heat flux from pavement to urban air and it was very effective to relax the heat island problem. But they pointed out the possibility that the surface temperature of human body and SET* became higher on the cool pavement than those on ordinary pavement according to the amount of reflective heat (Kondo et al. 2009). Sato et al. (2004) analyzed the environmental influence by greening and high albedo surface. In summer season, they have great effect on urban thermal environment. On the other hand, they had less impact in the winter season. Hirano (2005) quantified the mitigation effect of urban greening on urban heat island and its effects on energy consumption for air-conditioning and water heating. A scenario of urban greening was that the vegetation coverage in Tokyo metropolitan increased by 11.8%. Urban climate simulations were conducted using a meso-scale meteorological model and the energy consumption of air-conditioning and water heating was estimated based on the simulated air temperatures. The energy consumption decreased by 13.8TJ/day on a typical summer day, and increased by 6.7TJ/day on a typical winter day. Ichinose et al. (2006) investigated heat and water budget characteristics of rooftop greening based on long term actual measurement, and estimated mitigation effect of heat island phenomenon.

4.2.4 Wind tunnel experiments on urban ventilation

Urban ventilation is one of the effective countermeasures for the heat island phenomenon. The urban ventilation is greatly dependent on urban forms. There are some recent researches on this issue based on wind tunnel experiments. Kubota et al. (2008) investigated the relationship between the building density and the average wind velocity at pedestrian level in residential neighborhoods. They conducted wind tunnel tests on 22 residential neighborhoods selected from actual Japanese cities. The results show that there is a strong relationship between the gross building coverage ratio and the mean wind velocity ratio. They proposed guidelines for realizing acceptable wind environment in residential neighborhoods using the gross building coverage ratio. Yoshie et al (2008) investigated characteristics of air ventilation and thermal environment in a built-up area with closely-packed high-rise buildings by wind tunnel experiments. As the experimental results, spatial average of wind velocity ratios at pedestrian level could be expressed by “vertical average of gross building coverage ratio”, and the height variation of buildings was very effective for improving the air ventilation and the thermal environment in this dense area. The height variation buildings increased the vertical transport of air and heat both by advection and turbulent diffusion. They called this effect “vertical ventilation path”. On the other hand, Hagishima et al. (2007) investigated a bulk drag coefficient of rectangular blocks in a wind tunnel, and they found out the height variation of blocks makes the bulk drag coefficient large.

4.2.5 Comprehensive Assessment System of Building Environmental Efficiency

CASBEE is a method of evaluating and rating buildings for their environmental efficiency (Murakami et al. 2006-1, 2006-2, 2007). It is a comprehensive system for assessing building environmental efficiency, including not only the reduction of environmental load such as energy-saving, resource-saving and recycling efficiency, but also environmental quality and improvement of efficiency by taking indoor comfort and various scenarios into account. The CASBEE assessment has been developed in accordance to the following three concepts:

· Assessment can be made throughout the life cycle stages of the buildings.

· Assessment can be made from two viewpoints: the “environmental quality and building efficiency (Q)” and “environmental load of the buildings (L)”.

· Assessment is made using the newly developed assessment index BEE (building environmental efficiency) based on the concept of “environmental efficiency”.

Under BEE, buildings are given 5-step ratings. CASBEE utilizes four basic tools depending on the life-cycle stage of the buildings and additional extended tools to suit individual purposes. These are collectively called the “CASBEE Family”. Of these, CASBEE-HI has been developed as a tool for assessing the alleviation of the heat island effect in buildings (Murakami et al., 2006). This plays a role in detailed and quantitative evaluation of items to be assessed which relate to the heat island effect. It performs detailed assessment of the outdoor thermal environment and the heat island load. In CASBEE-HI, the environmental efficiency (BEEHI) of the alleviation of the heat island effect is evaluated by the following equation:

$$BEE_{Hi} = \frac{Q_{HI}}{L_{HI}} = \frac{improvement\ \ of\ \ thermal\ \ environment\ \ inside\ \ the\ \ virtual\ \ boundary}{Heat\ \ island\ \ load\ \ outside\ \ the\ \ virtual\ \ boundary}$$

CASBEE-HI is now widely used for evaluating and rating newly planned buildings and existing buildings.

5 CONCLUSIONS

The report has demonstrated the present status of outdoor wind environmental issues and studies in Japan based on recent researches and reports, and one can summarize the results as follows:
1) For the environmental impact assessment of strong winds around high-rise buildings, researchers often carry out wind tunnel experiments or CFD simulations. In particular, use of the CFD method has been rapidly increasing. To ensure the reliability of CFD simulations, "AIJ guidelines for practical applications of CFD to the pedestrian wind environment around buildings" was published in 2007.

2) The criteria for assessing the wind environment based on the occurrence frequency of daily maximum gust speed proposed by Murakami et al. and the criteria based on the cumulative frequency of mean wind velocities (averaged over 10-minute periods) proposed by the Wind Engineering Institute are widely used in Japan.

3) The "Basic Environmental Law" specifies environmental quality standards (EQS) for SO_2, CO, SPM, NO_2, Ox, benzene, trichloroethylene, tetrachloroethylene, dichloromethane and dioxins

4) The "Air Pollution Control Law" restricts the emission of soot and smoke, volatile organic compounds and particulates from factories and facilities. The Law also specifies maximum permissible limits on the amount of exhaust gases from motor vehicles.

5) Owing to the restrictions on emission of harmful substances from both facilities and automobiles, the outdoor air quality has been gradually improving in Japan. The annual averages of NO_2, SO_2, CO, and SPM concentrations have remained steady or gradually declined in recent years, but the compliance rates with the Environmental Quality Standards were extremely low for photochemical oxidants.

6) The compliance rates with the EQS in FY 2010 were as follows.

- NO_2 : 100% at Ambient Air Pollution Monitoring Stations (AAPMSs), 97.8% at Roadside Air Pollution Monitoring Stations (RAPMs) and 95.7% at areas designated by the Automobile Mox/PM Law
- SO_2 : 99.7% at AAPMSs and 100% at RAPMs
- CO : 100% at AAPMSs and 100% at RAPMs
- SPM : 93.0% at AAPMSs and 93.0% at RAPMs
- Ox : 0.0% at (AAPMSs) and at (RAPMs)

7) The governmental liaison council on countermeasures against the heat island effect has publicly announced the "General Principle of the Countermeasures to Cope with the Heat Island Problem" in 2004. This has systematically summarized actual measures to be taken.

8) Resent researches in Japan on countermeasures against the heat island effect (numerical simulation, field measurement, wind tunnel experiment, reflective painting and greening) were reviewed.

9) Murakami et al. has proposed CASBEE-HI (Comprehensive Assessment System of Building Environmental Efficiency for Heat Island Relaxation) in 2006, and it is now widely used for evaluating and rating buildings for their environmental efficiency.

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