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Guidelines and evaluation tools for heat island countermeasures for several cities in Japan and other East Asian countries

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1. Introduction

Urbanization, such as land-use alteration and increase in anthropogenic heat release, degrades the thermal environment in urban areas during the Japanese summer season. The degradation causes various environmental problems, including increased energy consumption for cooling, and increased numbers of hyperthermia patients. Recently, some countermeasure techniques have been proposed to address the problem, and introduced into practical planning and design of urban areas and buildings. In Japan, various guidelines have been proposed by the following central and local governments: the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), the Ministry of the Environment (MOE), and local governments, including those at the level of prefectures and cities, as well as local areas around Tokyo and Osaka. However, it is difficult to perform a comparative analysis of each guideline, because there of differences in format and availability of numerical targets. If we shift our attention to circumstances around Japan, we observe severe urban warming and air pollution beyond Japan during the period of rapid economic growth in China and the Southeast Asian countries. Therefore, some international guidelines are required in order to form a common strategy to address these problems.

A working group for investigating countermeasure guideline against urban heat island of each city in East Asia has been established in the sub-committee on urban and climate adaptation, research committee on global environment, AIJ, since 2012. The aim of this group is to propose an international guideline of countermeasure against heat island phenomena in cities in East Asia, including major cities in Japan and China, and to compare the existing guideline of cities between Japan and China. This paper describes the investigation of the present situation of the existing guidelines for cities in Japan and other East Asian countries, and the comparison of differences of guidelines in each city in Japan.

2. Outline of Japanese guidelines for countermeasures against heat island phenomena

2.1 Guideline proposed by Ministry of Land, Infrastructure, Transport, and Tourism (MLIT)

The ministry of land, infrastructure, transport, and tourism (MLIT) proposed ‘A building design guideline for mitigation of heat island phenomena’ in 2004. The aim of this guideline is to summarize the considerations for a building design that contributes to mitigation of and adaptation to heat island phenomena. Table 1 outlines this guideline. The comprehensive assessment system for building environmental efficiency for heat island (CASBEE-HI), proposed in 2005, is a tool for evaluating both the mitigation and adaptation techniques against heat island phenomena. Table 1 also summarizes the relationship between the guideline and the CASBEE-HI. Through the comparison, it is clarified that applying the guideline to practical design of buildings and their surrounding areas, along with evaluating the performance of the BEE using the CASBEE-HI, gives us quantitative standards for optimum environmental design.

2.2 Guideline proposed by the Ministry of the Environment (MOE)

The Ministry of the Environment (MOE) proposed a guideline entitled ‘Countermeasure guidelines against heat islands’ in 2009. This guideline was proposed through the activity of the committee for investigating the execution of countermeasure scenarios against heat islands. This guideline was proposed on the assumption that the staff of local governments or official agencies will refer to it in order to effectively promote the countermeasure against heat islands. Therefore, this guideline does not include any quantitative targets because of the assumption of use in a wide range of fields, including building design and redevelopment of cities. The most interesting parts of this guideline are datasheets that summarize the effects, and specific examples of each countermeasure technique. Table 2 summarizes the relationships of mechanism, purpose, and effective region between the techniques described in this guideline. For additional information on other approaches related to the MOE committee, refer to Ichinose (2002).

Table 1 Relationship between building design guidelines for mitigating heat island phenomena and numerical targets of the CASBEE-HI

No	Outline of each guideline	Numerical target. This is equivalent to the border value of CASBEE-HI Level 3.
(1) Air path		
When planning the location and shape of buildings, wind conditions around the site should be well understood, and the following should be considered in order to allow airflow to pedestrian spaces at the site, and to prevent blockage of airflow to leeward areas.		
(1)-1	Airflow should be ensured by creating open spaces such as gardens, grassy areas, or green areas with trees and shrubs.	The open area ratio should be greater than 40%.
(1)-2	A conscious effort should be made to prevent blockage of airflow by decreasing the frontal area of buildings in the direction of the prevailing summer winds, or by taking into account the height, shape, and pitch of buildings.	The frontal area ratio of a building to the prevailing wind should be less than 80%. The index of the pitch of a building should be greater than or equal to 0.3.
(2) Shade		
When planning the exterior of a building, the following should be considered to create shade to adopt thermal environment in a pedestrian space in the summer.		
(2)-1	Green areas consisting of medium or tall trees should be created for shade, particularly on the southern or western side of a building because the incident solar radiation on those sides is relatively strong.	The sum of horizontal projected area ratios of the pilotis, eaves, and pergolas should be equal to or greater than 10%. The CASBEE-HI does not include an evaluation for creating shade on the southern or the western sides of a building.
(2)-2	Pilotis, eaves, or pergolas should be installed to adapt the thermal environment for pedestrians in the summer season.	
(3) Ground cover of exterior of buildings		
When planning the exterior of a building, the following should be considered for installing green areas and ponds to curb the rise of surface temperature.		
(3)-1	Gardens, grassy areas with shrubs, trees, and ponds should be installed to curb the rise of temperature of the ground surface and air near the ground.	The sum of ratios of green areas, water surfaces, and horizontal projected area of medium or tall trees should be equal to or greater than 10%. The effect of each type of green area should be weighted. For example, the effect of water surfaces should be equivalent to twice that of green areas with trees/shrubs, and 1.5 times that of medium or tall trees.
(3)-2	Paved areas in should be reduced. In particular, effort should be made not to install large paved areas, including carports, near the southern or western sides of a building, where the incident solar radiation is relatively strong.	The ratio of paves areas should be less than 30%. The effects of shade on the southern or western side of a building are given more weight by not including the area of paved surfaces of pilotis and surfaces with no direct incident solar radiation.
(3)-3	Water-retentive, permeable, or highly reflective materials should be used for areas that need to be paved.	The ratio of the sum of surfaces covered with material with effective vaporization or highly reflective material or paint should be equal to or greater than 15%.
(4) Exterior building materials		
When planning the exterior of a building, the air-conditioning load of the building should be reduced, and the following should be considered to reduce the heat released to the neighbourhood, as well as to adapt the thermal environment in outdoor spaces, including pedestrian spaces.		
(4)-1	The heat flow into a building should be reduced by choosing highly solar-reflective roof materials.	The ratio of the sum of roof surface area covered with materials with a high vaporization effect or a highly reflective material or paint should be equal to or greater than 20%. That of outdoor surfaces of a building wall should be equal to or greater than 10%. In the sum of surface areas covered with vaporization-effective material, the weighted effects of each type of material of species are considered.
(4)-2	In particular, effort should be made to create greening on certain segments, such as roof surfaces of low-rise buildings, and southern or western wall surfaces, because the amount of incident solar radiation on these surfaces is quite large.	
(5) Anthropogenic heat release from building equipment		
When planning building equipment, the following should be considered to reduce the exhaust heat released to pedestrian spaces and neighbourhoods.		
(5)-1	The amount of exhaust heat released to the atmosphere should be reduced by decreasing heat flow to outdoor spaces through building walls and windows, as well as by utilizing energy effectively for HVAC equipment. In particular, a conscious effort should be made to reduce heat release from buildings that have a large amount of equipment capacity, or are intended for long-term use.	The maximum specific energy consumption should be less than 120 W/m^2. The utilization time of a building, or the length of time in which the exhaust heat is released should, be less than 16 hours per day. If focusing only on daytime, the ratio of the length of time should be equal to or greater than 40%.
(5)-2	Exhaust heat should be released from a high location on a building.	Less than half the amount of equipment capacity, including cooling towers, and the outer units of air-conditioning systems, should be installed on lower locations of a building, or within a height of 10 m from the ground.
(5)-3	Exhaust heat should be released at low temperature to curb the increase in air temperature.	Less than half of the devices used to release exhaust heat at high temperature should be installed at lower locations of a building.

Table 2 Relationship of mechanism, purpose, and effective region between each countermeasure technique described in the heat island countermeasure guideline by Ministry of the Environment

No	Countermeasure technique		Expected effect of countermeasure: Mitigation, Daytime	Mitigation, Night-time	Adaptation, Daytime	Adaptation, Night-time	Reduction in energy consumption	Expected scale of effect: City (A few dozen km)	Area (A few km)	Street (A few hundreds m): Road, pedestrian space, and car park	Street (A few hundreds m): Building and site
1-1	Wind	Utilization of sea wind and mountain–valley wind	*	*	*	*		*	*		
1-2		Utilization of wind from river	*		*			*	*		
2-1	Greening	Utilization of parks and green areas	*	*	*	*		*	*		
2-2		Utilization of roadside trees	*	*	*	*				*	
2-3		Greening of car parks	*	*	*					*	
2-4		Greening of building sites	*	*	*	*					*
2-5		Rooftop greening	*	*			*				*
2-6		Wall greening	*	*	*		*				*
3-1	Water	Utilization of fountains and water landscapes	*		*						*
3-2		Sprinkling and increasing the water-holding capacity of pavements	*	*	*	*				*	
3-3		Increasing the water-holding capacity of building surfaces	*	*			*				*
3-4		Utilization of sprinkling around houses			*	*				*	
3-5		Utilization of mist cooling			*						*
4-1	Reflection	Utilization of shade for pavements	*	*	*	*				*	
4-2		Raising reflectivity of roof surfaces	*	*			*				*
5-1	Energy release	Utilization of district heating and cooling systems	*	*	*	*	*		*		*
5-2		Reduction of exhaust heat from buildings	*	*	*	*	*				*
5-3		Reduction of exhaust heat from cars	*	*	*	*	*	*	*	*	
6-1	Public awareness	Information service for preventing heat stroke			*						

2.3 Guideline proposed by local government

Several Japanese local governments, such as those of Tokyo, Osaka, and major cities located in the western area in the Kanto region in Japan, have also proposed original guidelines against the heat island phenomena. This seems to be caused by the fact that it is difficult to set quantitative numerical targets based on evaluation tools, including the CASBEE-HI, because local governments prefer browse-able guideline for various purposes, such as redevelopment of cities and local areas, and environmental planning.

3. Outline of heat island countermeasure guidelines in other East Asian countries

Through the present investigation, we have found two proposals for countermeasure guidelines against heat island phenomena.

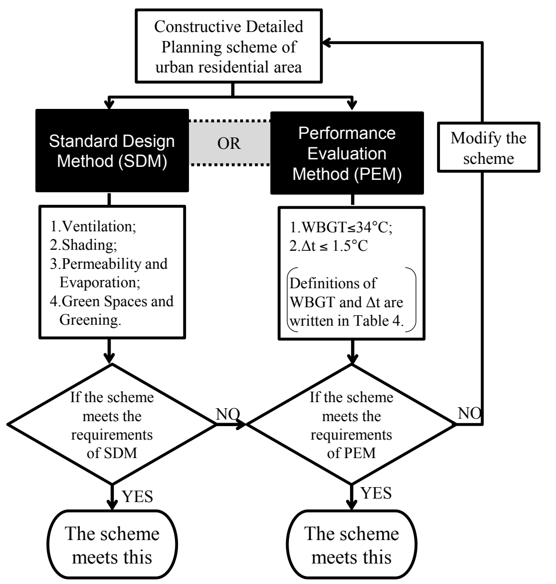

Fig. 1 Evaluation Scheme for Chinese guideline.

In the People's Republic of China, a research team at the South China University of Technology proposed a guideline entitled 'Design Standard for the Thermal Environment of Urban Residential Areas' (Meng et al., 2012). This guideline includes a description of a method to design residential houses with consideration of climatic divisions in China. This guideline is also represented in collaboration with the Ministry of Housing and Urban–Rural

Development, and has been adopted as the national standard in China.

Figure 1 illustrates the evaluation scheme of the Chinese guideline. The Standard Design Method (SDM) and Performance Evaluation Method (PEM) comprise this guideline. The SDM is equivalent to the first-step evaluation based on comparison of values for each parameter between the practical planning and requirements of the SDM, while the PEM is the second-step fine evaluation. The PEM is used when the practical design does not satisfy the requirements of the SDM, or when the planners would like to finely evaluate their own plans. For details of this guideline, refer to Meng et al. (2012).

Table 3 Investigation objects

1. Prefectural governments: 3
1-1 Tokyo, 1-2 Osaka, 1-3 Saitama
2. Municipal governments: 5
2-1 Chiyoda, 2-2 Chiba-city, 2-3 Osaka-city, 2-4 Hirakata-city, 2-5 Sakai-city
3. Local area: 6 (in Tokyo)
3-1 Shinagawa and Tamachi stations area, 3-2 Otemachi, Marunouchi, and Yurakucho area, 3-3 Shibuya station central area, 3-4 Nakano station area 3-5 Shibuya station central area 3-6 Area around loop line 2 of city planning road in Tokyo

In the Republic of China, Lin has proposed the Ecology, Energy Saving, Waste Reduction, Health (EEWH-HI) in collaboration with the Ministry of the Interior. The format of this guideline corresponds well to that of the CASBEE-HI guideline proposed by the MLIT in Japan.

4. Comparison and investigation of Japanese heat island guidelines

4.1 Introduction (purpose of investigation)

As mentioned in the preceding section, it has been clarified that there are various types of countermeasure guideline to address heat island phenomena in Japan. In the present section, we attempt to compare these guideline. A reference guideline is needed for this comparison, because it is difficult to directly compare these various guidelines. In the present investigation, we selected the MOE guideline as the reference guideline. This is because the relationships of mechanism, purpose, and effective region between the countermeasure techniques described in Table 2 are useful for the comparison.

4.2 Investigation objects

Table 3 summarizes the guidelines for the investigation in the present study. We investigated the guidelines of three prefecture (Tokyo, Osaka, Saitama), five cities (Chiyoda, Chiba, Osaka, Hirakata, Sakai), and six areas (all areas are located in the Tokyo metropolitan district).

4.3 Comparison of targets described in each guideline

Table 4 summarizes the comparison of targets of each guideline. First, focusing on the comparison between each prefecture's guideline, it is interesting that the Tokyo metropolitan area guideline describes individual items as countermeasures against heat island phenomena for each area or utilization of a building. The Osaka guideline uniquely points to numerical targets as uncontrollable natural phenomena as proposing policy. The Saitama guideline describes improvement in lifestyle, such as adjusting clothing, heating and cooling in buildings, and sprinkling on streets and around residential buildings. Second, we focus on the guidelines of cities and regions. The Osaka City and Sakai guidelines include numerical targets because they refer to the Osaka Prefecture guidelines. Finally, focusing on local areas, most of the guidelines include various targets that do not concern countermeasures against heat islands, except for the guideline for the Shinagawa and Tamachi station areas, which includes a description of targets with consideration of the properties of the location.

4.4 Comparison of countermeasure menus included in each guideline

In this section, we examine the difference between the countermeasure menus in each guideline by relating them to the countermeasure items described in the MOE guidelines. These items are classified with an asterisk (*) according to both the expected benefits and region of effect of the countermeasure. The expected benefits consist of mitigation of the phenomena, adaptation to the phenomena, and mitigation of energy consumption, while the regions affected by the countermeasures consist of urban spaces, local areas, and street blocks. In the present analysis, we extract the property of each guideline by counting the number of asterisks.

Figure 2 shows a comparison of the improvements achieved by installing a countermeasure item from each guideline. It was found that the ratio of daytime effects is slightly larger than that of night-time effects, and the ratio of expected mitigation of heat island phenomena is also larger than that of the expected adaptation. As a whole, there are only small differences between each guideline, except for the numbers marking each item. Figure 3 shows a comparison of the effective regions of improvement by installing items from each guideline. Compared with Fig. 2, the following two points are observed: (1) The differences between the results of each guideline are large, and (2) The ratio of items expected to improve the environment in street areas is larger than others. In order to examine the reason for the differences in Fig. 3, Fig. 4 summarizes the ratios of the installed countermeasure methods, such as wind, greening, water, reflection, reduction of exhaust heat, and public awareness. It can been seen that both the ratio of the methods of greening, including rooftop or outer wall greening, and that of reducing heat exhaust are significantly larger than other methods. These methods contribute to the improvement of thermal environments at the street scale, or spaces in and around buildings, and are marked by asterisks in the following

Table 4 Comparison of target described in each guideline

1-1 Tokyo metropolitan	(1) Curb increase of ground surface temperature by creating green areas, and installing water-retentive materials. (2) Contribute to energy savings and curb increase of surface temperature using rooftop and wall greening. (3) Reduction of heat storage using highly reflective paint on building rooftops. (4) Reduction of anthropogenic heat release from buildings and transportation. (5) Provision of countermeasure menus considering utilization of buildings, and properties of local areas.
1-2 Osaka Prefecture	(1) The number of sweltering nights should be reduced to 70% of the present value by lowering night-time air temperatures of residential areas in the summer by 2025. The present number of sweltering nights in each city is as follows: 49, 36, 29, and 21 days for Osaka, Toyonaka, Hirakata, and Sakai, respectively. (2) The sensible temperature should be lowered by creating cool spots in outdoor spaces for improving the daytime thermal environment in the summer.
1-3 Saitama Prefecture	(1) Improvement of ground coverage by utilizing rooftop and wall greening, and highly reflective paint. (2) Reduction of anthropogenic heat release from cars and HVAC equipment in buildings. (3) Improvement of urban configurations, e.g. by installing airflow paths, and redeveloping cities with low heat loads for movement of people and logistics. (4) Improvements in lifestyle, such as reducing the use of air conditioning, adjusting clothing, eco-driving, utilization of public transport systems, and the use of bamboo blinds and sprinkling.
2-1 Chiyoda City	(1) Promotion of greening. (2) Improvement in artificial cover. (3) Curbing anthropogenic heat release. (4) Creating and restoring waterfront areas. (5) Improving urban configuration.
2-2 Chiba City	(1) Implementation of energy savings, including adequate running of HVAC equipment, improvement in heat insulating properties, and reduction in anthropogenic heat in urban areas by utilizing renewable energy. (2) Creating parks and green areas, rooftop and outer wall greening, and improvement in ground cover, including improvement in permeability of paved surfaces. (3) Improvement in urban configurations by installation of air paths, and urban geometry. (4) Improvement in lifestyle by promoting further understanding of countermeasure techniques in citizens and companies.
2-3 Osaka City	The number of sweltering nights and annual mean air temperature should be reduced relative to the present condition, by until through 2020. The annual air temperature and number of sweltering nights are, respectively, 17.2°C, and 43.5 days.
2-4 Hirakata City	Implementation of countermeasures that are focused on main urban areas for adapting the thermal environment in pedestrian spaces.
2-5 Sakai City	(1) The number of sweltering nights should be reduced relative to the present condition for the entire city. (2) The daytime hot environment on streets in the summer should be improved by creating cool spots on the length scale of streets.
3-1 Shinagawa and Tamachi station	(1) Redeveloping an environmental model city, e.g. by creating air paths, installing networks of water and greening, and reducing CO2. (2) Redeveloping a city for a succession of visitors. (3) Creating the Tokyo south gate.
3-2 Otemachi, Marunouchi, and Urakucho	(1) International business city leading the generation. (2) Cultured city where people gather. (3) A city of resources to send and exchange information for adapting to the information age. (4) A stately city that harmonizes well with a vibrant society. (5) A convenient city where people can walk comfortably. (6) A symbiotic city. (7) A secure and safe city. (8) A city developed with collaboration between citizens, local government, and visitors.
3-3 Nakano station	There are no written guidelines.
3-4 Takeshiba area	Promotion of redeveloping a city with attractive resources in and around Takeshiba area.
3-5 Shibuya station	Cool the valley: Creating an environment in the valley space using greening and water. (Extracted from the description only concerning heat islands.)
3-6 Area around loop line 2 of city planning road in Tokyo	Redeveloping the city to curb the release and storage of heat. (Extracted from the description only concerning heat islands.)
4. MLIT with CASBEE-HI	(1) Planning the location and shape of buildings to direct airflow to pedestrian spaces, as well as to prevent blocking air paths to leeward areas. (2) Planning exteriors that create shade in order to adapt thermal environments in pedestrian spaces in the summer. (3) Planning exteriors for creating green areas and water spaces to curb the increase of ground surface temperature in pedestrian areas. (4) Planning facing walls of buildings to a heat release to neighbourhoods, as well as to adapt the thermal environment in outdoor spaces, including pedestrian spaces. (5) Planning building equipment to reduce exhaust heat release to pedestrian spaces and neighbourhoods.

item numbers: 2-4, 2-5, 2-6, 5-1, 5-2, and 5-3. Hence, it is thought that adopting countermeasure menus corresponding with these items in most of the guidelines affects the results shown in Fig. 3. In the guidelines for the Shinagawa and Tamachi station area, the ratio of adapting the countermeasure technique based on ‘wind’ is nearly 40%, and is significantly large any other guideline. It is thought that this result causes an increase of the ratio of expected improvement on the thermal environment in urban and local areas.

5. Conclusion

(1) In this paper, we outlined the existing countermeasure guidelines for urban heat islands in Japan, Japanese local governments, and other East Asian countries, and conducted a detailed comparison of targets and countermeasure menus included in each countermeasure guideline of Japanese local governments.

(2) The differences between the expected effects of each local government guideline are small. However, those of scale, in which the effects of the countermeasure are expressed, are large. This is caused by the differences between the adopted countermeasure methods in each guideline.

(3) In future studies, the differences between the guidelines of governments in East Asian countries should be examined using the methods presented in this paper.

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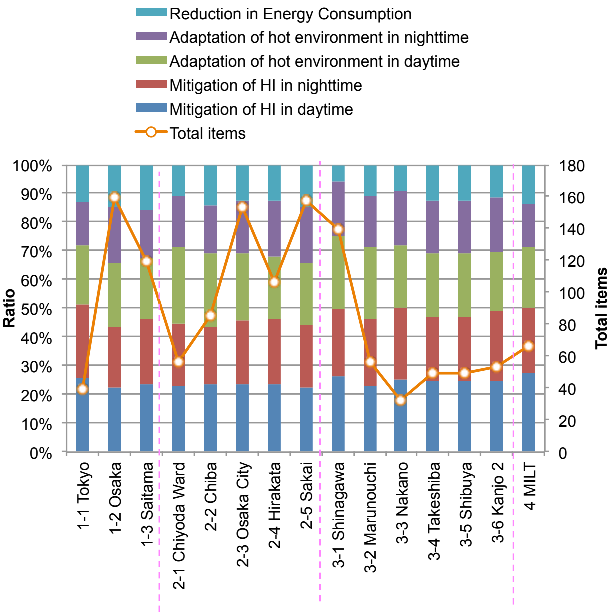

Fig. 2 Comparison of expected effect between each guideline.

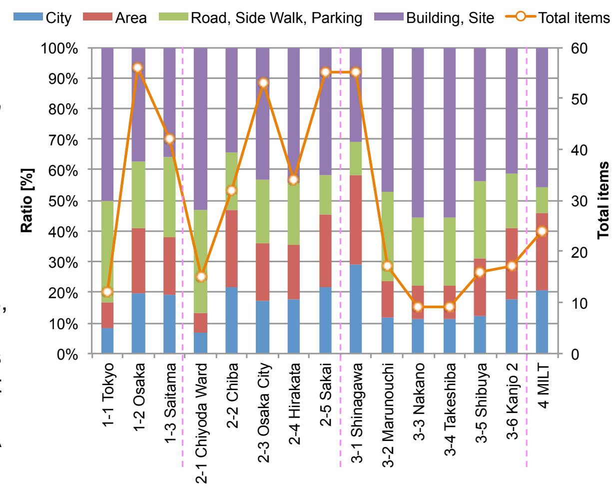

Fig. 3 Comparison of space length expressed effects of countermeasure between each guideline.

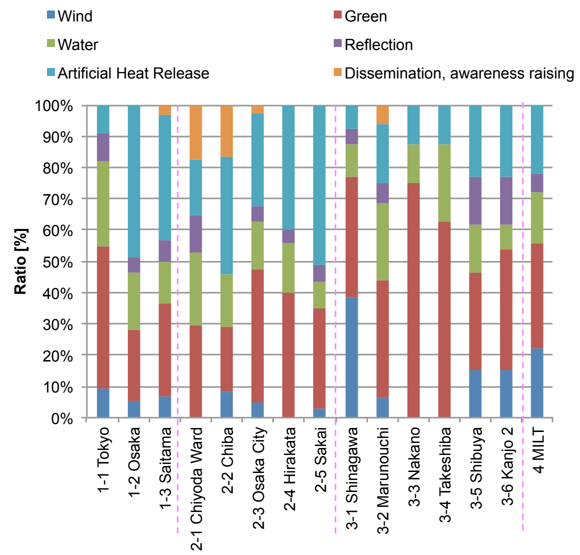

Fig. 4 Comparison of adopted countermeasure method between each guideline.