STUDY ON THE EFFECTS OF VARIOUS RELAXATION MEADSURES FOR OUTDOOR THERMAL ENVIRONMENT IN THE DIFFERENT PRESENT URBAN BLOCKS USING COUPLED SIMULATION OF CONVECTION, RADIATION AND CONDUCTION

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1. INTRODUCTION

Heat island phenomenon has become remarkably worse, and causes various problems such as an increase of heat disorders or tropical nights. The main reasons of Heat island phenomenon are considered as artificial heat release, change of surface area coverage by urbanization, and a decrease of green space. Various relaxation measures for Heat island phenomenon have been proposed and researched, and the effects of these measures are evaluated by numerical simulation. Although these effects are highly dependent on the property of each city blocks, the comparison of these effects between different city blocks has not been conducted enough. Therefore, the authors have done coupled simulations of convection, radiation and conduction to evaluate outdoor thermal environment over the two different present urban blocks in Tokyo: Otemachi as a high-rise office building area and Kyobashi as a middle-rise office building area. The cases are set to compare the effects of the measures such as heat release point and way of air-conditioning, greening, high albedo of surface, and traffic volume.

2. ANALYSIS

2.1 ANALYSYS OUTLINE

Figure 1 illustrates analysis outline. Using the input data of day, place, weather, urban configuration, material and surface, radiation simulation has done first. After that, with the input data and surface temperature from the result of radiation simulation, CFD simulation has done.

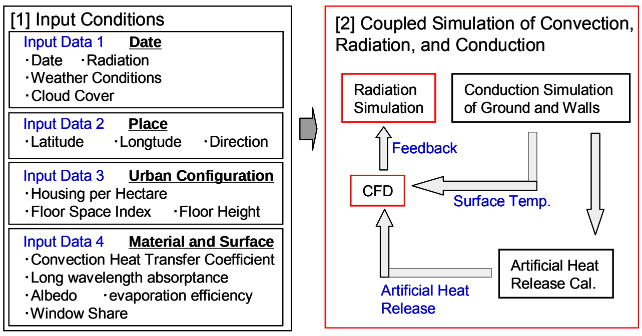

Fig. 1 Analysis Outline

2.2 ANALYSIS TARGET AND MODEL

Figure 3 shows analysis targets. Otemachi represents a typical high-rise office building area, and Kyobashi does a typical middle-rise office area in Tokyo. Otemachi and Kyobashi locate at west and east of Tokyo station.

Figure 2 illustrates urban configuration of each city, which are calculated by simulation model. While Otemachi has wider space between buildings, buildings in Kyobashi are crowded.

	Otemachi	Kyobashi
Mean Gross Building Coverage	75.8%	86.9%
Mean Net Building Coverage	62.9%	71.2%
Legal Floor Space Index	900% or 1300%	600%～800%
Mean Floor Space Index	1179.0%	664.3%
Mean Building Height	67.4m	28.6m

Fig. 2 Urban Configuration of Simulation Models

Figure 4 illustrates the analysis models for simulation which based on GIS data. Their grid system is unstructured. The model of Otemachi is

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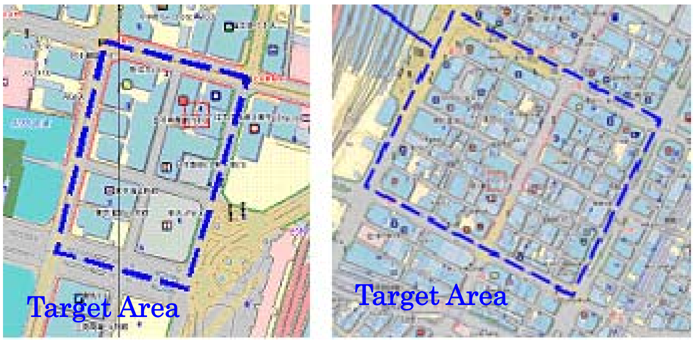
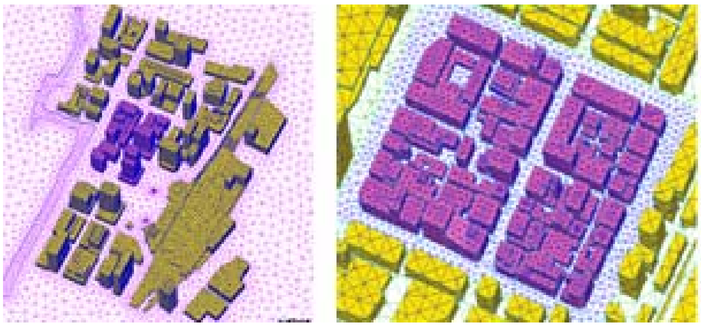


(1) Ootemachi (2) Kyobashi

Fig.3 Analysis Targets

Table1. Day and Weather Conditions

Date	23rd July 15:00
Wind Direction	south
Wind Velocity	3.0[m/s](at 74.6m)
Temp.	31.6℃
Absolute Humidity	0.0177[kg/kg]
Azimuth	83.2°
Altitude	45.2°
Normal Direct Solar Radiation	765[W/m²]
Diffused Solar Radiation	136[W/m²]



(1) Ootemachi (2) Kyobashi

Fig.4 Analysis Models

Table2. Building and Ground Conditions

Buidings	Wall	Concrete
	Solar Refrectance	0.2
	Solar Transmittance	0.0
	Thickness	0.2m
	Conductance	1.64[W/m/K]
	Indoor Convection Heat Transfer Coefficient	4.64[W/m/K]
	Indoor Air Temp.	26℃
	Long wavelength Emissivity	0.9
Ground	Ground	Asphalt
	Solar Refrectance	0.1
	Long wavelength Emissivity	0.95
	Ground Temp.	26° (under0.5m)

Table3. Analysis Cases (Ootemachi)

Case	Road			Ground	Building Surface		Heat Release		Release Point	Search Points
	Water Retention	High Albedo	Traffic Heat	Rate of green	Roof greening	Roof High Albedo	Sensible Heat	Latent Heat		
Case1-0	0%	0%	No	0%	0%	0%	0%	0%	—	NO heat release
Case1-1	0%	0%	No	0%	0%	0%	30%	70%	Roof	BASIC CASE
Case1-2	0%	0%	No	0%	0%	0%	100%	0%	Roof	AC Heat: Sensible
Case1-3	0%	0%	No	0%	100%	0%	30%	70%	Roof	Roof: Greening
Case1-4	0%	0%	No	0%	0%	100%	30%	70%	Roof	Road: High Albedo
Case1-5	100%	0%	No	100%	0%	0%	30%	70%	Roof	Road: Water retained Ground: Greening
Case1-6	0%	0%	No	100%	0%	0%	30%	70%	Roof	Ground: Greening
Case1-7	0%	100%	No	0%	0%	0%	30%	70%	Roof	Road: High Albedo
Case1-8	0%	100%	No	100%	0%	0%	30%	70%	Roof	Road: High Albedo Ground: Greening
Case1-9	0%	0%	YES	0%	0%	0%	30%	70%	Roof	Traffic Heat

Table4. Analysis Cases (Kyobashi)

Case	Road			Ground	Building Surface		Heat Release		Release Point	Search Points
	Water Retention	High Albedo	Traffic Heat	Rate of green	Roof greening	Roof High Albedo	Sensible Heat	Latent Heat		
Case2-0	0%	0%	No	0%	0%	0%	0%	0%	—	NO heat release
Case2-1	0%	0%	No	0%	0%	0%	100%	0%	Roof:50% Side:50%	BASIC CASE
Case2-2	0%	0%	No	0%	0%	0%	10%	90%	Roof:100%	Roof Latent:90%
Case2-3	0%	0%	No	0%	0%	0%	100%	0%	Roof:100%	All Heat from Roof
Case2-4	0%	0%	No	0%	100%	0%	100%	0%	Roof:50% Side:50%	Roof: Greening
Case2-5	0%	0%	No	0%	0%	100%	100%	0%	Roof:50% Side:50%	Roof: High Albedo
Case2-6	100%	0%	No	100%	0%	0%	100%	0%	Roof:50% Side:50%	Road: Water
Case2-7	0%	100%	No	0%	0%	0%	100%	0%	Roof:50% Side:50%	Road: High Albedo
Case2-8	0%	0%	YES	0%	0%	0%	100%	0%	Roof:50% Side:50%	Traffic Heat

1,930m (W)*2,720m (L)*600m (H), and the number of grids is 372,000. The model of Kyobashi is 2,460m (W)*3,630m (L)*600m (H), and the number of grids is 372,000. The analysis targets are set on some blocks around the center. The analysis targets are set on several blocks around the center.

2.3 ANALYSIS CONDITIONS Table1 shows date and weather conditions. July 23rd, fine weather day, 15:00, was set for analysis. The sun's attitude was 45.1degrees, the wind direction was south, and the wind velocity was 3.0m/s at a height of 74.6m. Vertical wind profile of the inlet followed 1/4 log law. The air temperature was 31.6 degrees, and the relative humidity was 58%.

Table 2 shows building and ground conditions. Temperature of the building inside was fixed at 26 degrees, and the buildings are made from concrete. Reflectivity and long wave emissivity of concrete were set to 0.1, and 0.9, respectively. Indoor convection heat transfer coefficient was 4.64 [W/K/m^2].

Ground temperature was fixed at 26.0 degrees under 0.5m, and the surface of ground was covered with asphalt. Reflectivity and long wavelength emissivity of asphalt were set to 0.1 and 0.95, respectively.

Discrete Transfer Method (DTM) was used in radiation simulation. In CFD simulation, turbulence model was standard k-ε. Side and upper boundary was free slip. At wall boundary, wind velocity followed generalized log law. Outdoor convection heat transfer coefficient was fixed at 11.4 [W/K/m^2].

2.4 SETTING OF ARTIFICIAL HEAT RELEASE

The building internal heat load was assumed by product of total floor area and unit heat load intensity [1]. While all air-conditioning heat was assumed to be released from the roof in Otemachi area, a half of air conditioning heat was assumed to be released from the roof and the rest was from side of the buildings in Kyobashi area because city block of Otemachi is composed of large buildings which have cooling towers and many room air-conditioners are installed in small buildings in Kyobashi area.

2.5 ANALYSIS CASE

Table 3 and Table 4 show the analysis cases in Otemachi and Kyobashi respectively. There are 10 cases for Otemachi, and 9 cases for Kyobashi. Case1-1 and Case 2-1 are basic cases. Case 1-0 and Case 2-0 are cases without any artificial heat release. Case 1-3, 1-4 and Case 2-3, 2-4 are cases that roof surface of buildings in the target area changes to high-albedo or greening. Case 1-5, 1-6, 1-7, 1-8 and Case 2-4, 2-5, 2-6 are cases that road and ground surface in the target area become high-albedo, greening or water retained. Case 1-9 and Case 2-8 are cases with heat release from traffic.

3. ANALYSIS RESULT

3.1. *OTEMACHI*

(1) Horizontal distribution of Wind velocity and temperature

Figure 5 shows horizontal distribution of wind velocity at 1.5 m in Otemachi to evaluate pedestrian area. Figure 6 illustrates horizontal distribution of temperature of Case1-1. There is a relation that temperature is higher where wind is weaker. Especially, wind becomes weaker and temperature becomes higher on the leeward of the buildings.

(2) Air temperature distribution

Figure 7 shows differences of air temperature from basic Case1-1 at 1.5 m height. (1) illustrates the result of Case1-3, which changes roof surface to greening. In Case1-3, there is not big difference. Changing material of roof hardly

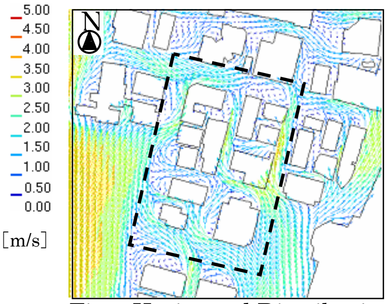


Fig.5 Horizontal Distribution of Wind Velocity in Otemachi (Basic Case) (Height:1.5m)

(1) Case1-3 (Roof: Greening)
(2) Case1-5 (Road: Water Retained)
(3) Case1-9 (Traffic Heat Release)

Fig.7 Difference of Temp. from Basic Case in Otemachi(Case1-1) (Height: 1.5m)

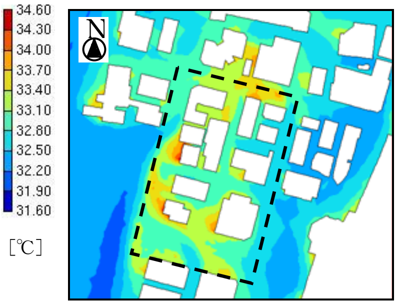
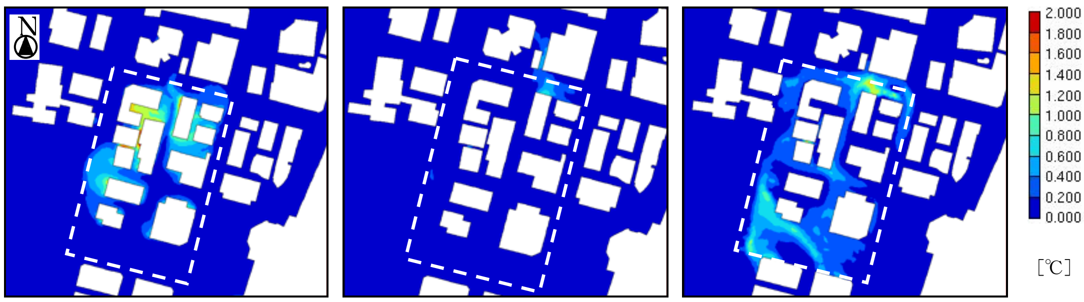


Fig.6 Horizontal Distribution of Temperature in Otemachi (Basic Case) (Height:1.5m)



(1) Building Surface
(2) Air-conditioning Heat Release
(3) Traffic Heat Release

Fig.8 Horizontal Distribution of Impact Index in Otemachi (Height:1.5m)

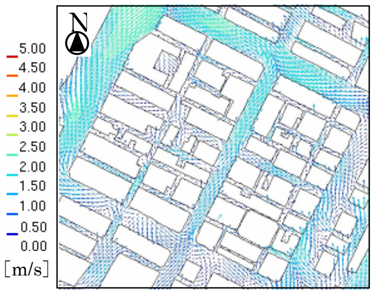
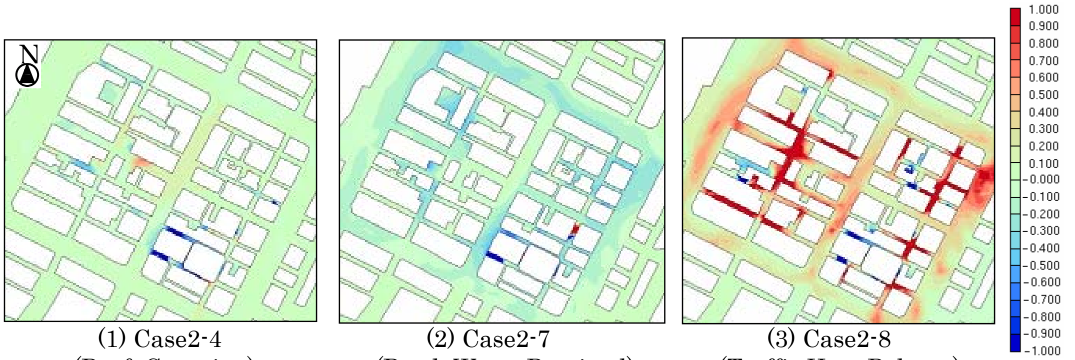


Fig.9 Horizontal Distribution of Wind Velocity in Kyobashi (Basic Case)



(1) Case2-4 (Roof: Greening)
(2) Case2-7 (Road: Water Retained)
(3) Case2-8 (Traffic Heat Release)

Fig.11 Difference of Temp. from Basic Case in Kyobashi (Case2-1)

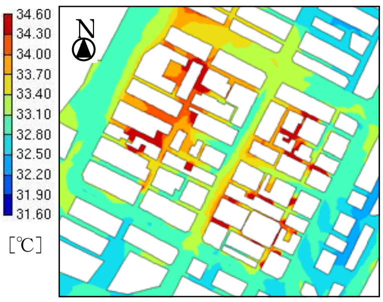
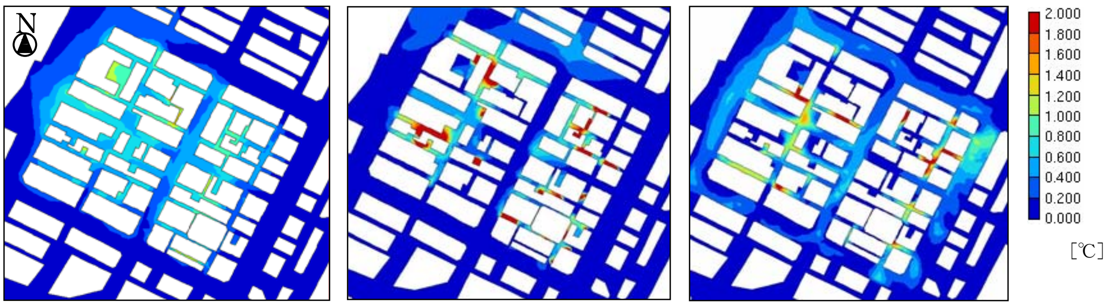


Fig.10 Horizontal Distribution of Temperature in Kyobashi (Basic Case) (Height:1.5m)



(1) Building Surface
(2) Air-conditioning Heat Release
(3) Traffic Heat Release

Fig.12 Horizontal Distribution of Impact Index in Kyobashi (Height: 1.5m) affects to temperature in pedestrian area. (2) is Case1-5, which changes ground surface to water retained material. Temperature decreases broadly. In specific on the leeward of buildings, the decrease is large. (3) is Case1-9, which releases heat from traffic. There is a same trend as Case1-5, and the maximum increase of temperature is more than 1 degrees.

(3) Horizontal Distribution of Impact Index

To compare the effects of surface temperature, air-conditioning heat release and traffic heat release, the impact index, which Hong CHEN proposed[Note1][2] was calculated. Figure 8 shows Horizontal Distribution of Impact Index at 1.5m height. (1) shows the affect of surface temperature rise of 1 degree. Surface temperature of buildings affects to air temperature very much. In specific, it affects remarkably in the small canopy space and nearby the buildings. (2) is air-conditioning heat release. It does not affect air temperature in pedestrian area. (3) Is traffic heat release. Compared with building surface, it affects larger area.

3.2. *Kyobashi*

(1) Horizontal distribution of Wind velocity and temperature

Figure 9 shows horizontal distribution of wind velocity at 1.5 m in Otemachi to evaluate pedestrian area. Figure 10 shows horizontal distribution of temperature. Same as Otemachi, there is the relations between wind and temperature. However, compared with in Otemachi, maximum temperature is very high because buildings are crowded and wind can not exhaust heat from the small canopies in Kyobashi.

(2) Air temperature distribution

Figure 11 illustrates differences of air temperature from basic case2-1 at 1.5 m height. (1) is Case2-4, which changes roof to greening. (2) is Case2-7, which changes ground and road to greening or water retained material. While changing roof material decreases air temperature very little, changing road and ground material decreases air temperature broadly. Same as Otemachi, temperature decreases in the small canopies and where wind is weak. (3) is Case2-9, which releases traffic heat. Temperature increases locally. Compared with on the road, in the small canopies it increases very much. Maximum increase is over 1 degree. There is several places where air temperature decrease. The reason is thought that the flow field has changed widely because of large traffic heat release.

(3) Horizontal Distribution of Impact Index

Figure 12 illustrates Horizontal Distribution of Impact Index. (1) shows the effects of building surface. It affects broadly in target area. Especially the impact is big nearby building and in the small canopies where wind is weak. (2) shows differences of air-conditioning heat release from basic case. Because a half of air-conditioning heat release is from side of the buildings in Kyobashi area, its impact is huge and affects really locally. Nearby heat release from side air temperature increase more than 2 degrees. (3) is traffic heat release. Compared with air- conditioning heat release, it affects broadly on the road, but it also affects to locally such as in the small canopies.

3.3 *COMPARISON BETWEEN OTEMACHI AND KYOBASHI*

To compare the effect of urban block configuration, mean velocity, temperature, and mean impact index at 1.5m were calculated. Table 5 shows mean temperature and wind velocity in target area. In both areas, Case1-0 and Case2-0, which do not release heat release, decrease mean wind velocity. And Traffic heat release increase air temperature more than 0.2 degrees in both areas. Besides, wind velocity increases clearly in Case1-9 and Case2-8.

Table 6 shows mean impact index. In Otemachi, because the buildings are high, air conditioning heat release from roof hardly affects. With the same reason, roof does not affect although surface temperature of roof is high. In Kyobashi roof and south affect very much because the buildings are middle-rise and the surface temperature of south and roof are higher than the other surfaces. Besides, air-conditioning heat release affects too.

Table5. Mean Temp. and Wind Velocity

(1)Ootemachi

Case	Mean Temp. (℃)	Mean Wind Velocity (m/s)
1-0	32.96	1.47
1-1	32.96	1.51
1-2	32.96	1.49
1-3	32.96	1.49
1-4	32.96	1.49
1-5	32.82	1.45
1-6	32.93	1.48
1-7	32.86	1.49
1-8	32.82	1.48
1-9	**33.16**	**1.58**

(2)Kyobashi

Case	Mean Temp. (℃)	Mean Wind Velocity (m/s)
2-0	32.99	0.90
2-1	33.19	1.19
2-2	32.97	1.10
2-3	33.07	1.26
2-4	33.20	1.16
2-5	33.18	1.15
2-6	33.05	1.17
2-7	33.07	1.25
2-8	**33.57**	**1.28**

Table6. Mean Impact Index

(1) Ootemachi

East	0.052
West	0.042
South	0.060
North	0.037
Roof	0.004
All Surface	0.195
Air-conditioning	0.019
Traffic	0.232

(2) Kyobnashi

East	0.005
West	0.052
South	0.117
North	0.020
Roof	0.108
All Surface	0.303
Air-conditioning	0.205
Traffic	0.381

4. CONCLUSION

(1) In Otemachi area as a high-rise office blocks area and Kyobashi as a middle-rise office blocks area, coupled simulation of conduction, radiation and convection has done. With the cases changing heat release point and way of air-conditioning, greening, high albedo of surface, and traffic volume. various relaxation measures are quantitatively compared.

(2) In both Otemachi and Kyobashi areas, artificial heat release from traffic increase air temperature in overall of target area at 1.5 m height, in particular on the leeward of the buildings are affected very much. By the same token, the relaxation measures of ground and road surface affects in both areas.

(3) While heat release from air-conditioning system does not increase air temperature at 1.5 m height in Otemachi, it increase air temperature locally, especially in low wind velocity narrow street air temperature increases dominantly. It was shown that the effects of relaxation measures are different according to the configuration of urban blocks.

Note 1

The impact index for outdoor thermal environment focuses on sensible heat to evaluate the influence on air temperature increase of open space from heat flux from building walls and ground, and artificial heat release.

a) Impact index of sensible heat from building surface to outdoor thermal environment [℃]

$$imp_{jw} = \left(\frac{\Delta T_{airj}}{\Delta T_{walli}} \right) \times \left(T_i - T_{ai} \right) \quad (1)$$

b) Impact index of heat release from building equipment to outdoor thermal environment [℃]

$$imp_{jb} = \left(T_{jb} - T_j \right) \quad (2)$$

c) Impact index of traffic heat release to outdoor thermal environment [℃]

$$imp_{jr} = \left(T_{jr} - T_j \right) \quad (3)$$

Signs :

imp_{jw}: Impact index of building surface at cell j

imp_{jb}: Impact index of heat release from building equipment at cell j

imp_{jr}: Impact index of traffic heat release at cell j

ΔT_{airj}: air temperature rise at cell j (case of high wall temperature – basic case)

ΔT_{walli}: surface temperature rise at wall I (i: north, south, east, west)

T_i: surface temperature of wall I

T_{ai}: mean air temperature of cell attached to wall

T_{jb}: air temperature of cell j considering air-conditioning heat release

T_j: air temperature of cell j in basic case

T_{jr}: air temperature of cell j considering traffic heat release

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