COOLING EFFECTS OF WATERWAYS ON THERMAL COMFORT IN URBAN DISTRICTS DURING SUMMER

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ABSTRACT

This study assesses the extent of the cooling effects of waterways on the thermal environment of urban districts of Osaka by measurement and simulation. The thermal environments of districts with and without waterways were measured in summer. The effects of the change of configuration of the district near waterway were calculated using computer fluid dynamics simulation. Results show the following. 1) Measured daily mean air temperatures were 0.5–0.8 K lower and SET* was 1.4–2.9 K lower in the district with the waterway than those in the district without waterways in peak summer. Differences were also shown in thermal comfort surveys of passersby. 2) It was calculated that air temperatures in the district with waterways can be decreased about 1.0 K by changing the configuration of the buildings facing the waterway and by changing the waterway width.

KEYWORDS

Cooling Effects, Waterway, Thermal Comfort, Surface Temperature, CFD Simulation

INTRODUCTION

Traditionally, many artificial waterways have existed for water transportation in urban areas of Osaka, Japan. However, according to the decline of water transportation and rise of road traffic, most waterways were reclaimed for utilization as roads or parking areas in the age of rapid economic growth about 50 years ago. Elevated freeways were built in the central area of the city and some were built over the sites of waterways. The East Yokobori River was not reclaimed, but there was built an elevated freeway over and along it. On the other hand, the West Yokobori River running parallel about one kilometer west of the East Yokobori River was reclaimed. Now an elevated freeway runs over its site.

Osaka is known as a highly advanced city in Japan that displays heat-island effects. It has been said that not only the geographical features of the Osaka Plain but also the lack of green tracts of land and the high population density, which are peculiar to urban areas, cause warming. New technologies such as tree planting on rooftops or walls, water penetrating pavement, and high reflectance building materials are recommended to mitigate warming. This study assesses more primitive and readily apparent effects of waterways that remain in the central city area. The East Yokobori River is not an attractive waterway in the city now. Most buildings stand back to the river and the riverside space is deserted. The space would attract more attention if the cooling effects were evaluated properly. For that reason, more attractive city planning with waterways could be induced.

Measurements of thermal environments and thermal comfort surveys were carried out in peak summers for two districts with and without waterways: the East Yokobori River and West Yokobori River. Thermal environments of the east and west districts were compared. Then the thermal environment was simulated for the east district with a waterway. First, a basic model was built for the east district to be close to the measured environment and the modeling method was verified. Then the district configuration was changed to impart more effective cooling effects. Buildings back to the waterway were removed and the district faces the waterway directly in Improved model-1. The waterway width was extended in addition to removal of the buildings in Improved model-2. The cooling effects in air temperature for the models were inspected using computer fluid dynamics.

MEASUREMENTS

Methods

Measured districts and points

Fig. 1 shows the picture of East Yokobori river and riverside park from south to north taken from the bridge. A floodgate is closed in the picture. The width of the waterway is about thirty meter and the depth is about four meter in the objected area. Giant elevated freeway runs over the river. Fig. 2 shows map of the central city of Osaka. Both Ohkawa river and Dohtonbori river flow to Osaka bay west outside the map. East Yokobori river connects two rivers north and south. Center of the city had been developed between East and West Yokobori rivers in east and west, and between Ohkawa river and Dohtonbori river in north and south.

West Yokobori river and Nagahori river were reclaimed. Locations of the measured east and west districts are shown in the figure. The west district is about 1.0 km west to the east district. West district locates about 150 m south to east district because of the lack of suitable locations for measurement.

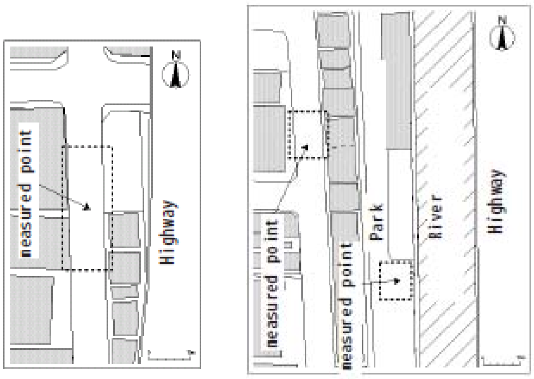
Fig.3 shows the measured districts. The widths of the streets are about ten meter. Buildings along the streets are from three stories to ten stories and most of them are for offices. Two points for east and west district each were selected for measurement. Main measured points were on the east side of the streets facing to the elevated highway. Subsidiary measured points are on the opposite side of the main points, i.e. on the west side of the streets. These points were selected not to disturb the public traffics and to be in street canyons, that is, not facing to unoccupied lots such as parks, construction sites, car lots or petrol stations, and apart from crossings. Distance between building walls and measured points were 1.0 to 1.2 m.

The sky factors were measured at several points in east and west districts beforehand and points were selected to be of similar sky factors so that the solar irradiance and air movement at the points were similar in two districts. Sky factors were 0.261 and 0.300 for main points and 0.296 and 0.367 for subsidiary points for east and west respectively.

Thermal environment in the riverside park was also measured. Measured point in the park faces to the back of the buildings in the east district. The buildings between the east street and the park are three to four stories. The measured point was halfway between the buildings and the riverbank. Tripod was placed 4.2 m apart from the riverbank footbridge and the sky factor was 0.56. There are planting along the buildings. The ground was covered with brick tiles in the park.

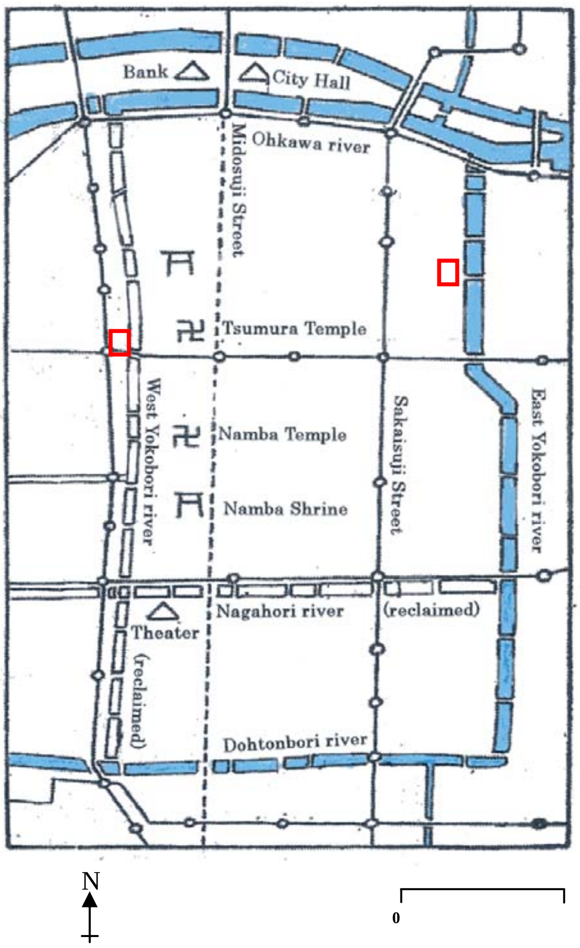
The width is about thirty m and the depth is about four m. Giant elevated highway hung over the river. Boats carry Kabuki

Figure 1 Picture of East Yokobori river



West district *East district*

Figure 3 Measured districts



West and east districts are shown by red squares.
Center of the city had developed with waterways.

Figure 2 Map of the central city of

Measured periods

Measurements were carried out from 9:00 to 17:00 simultaneously for east district, west district and park for five individual days in summer, July 6, July 26, August 8, August 30 and September 21. It is difficult as a matter of fact to collect data under clear skies for measurements outdoors. Therefore this study tried to offset the variation of weather conditions by comparing measurements carried out simultaneously. The weather conditions were among clear, partly cloudy and overcast. But the measurements after rainfall with drenched grounds or walls were avoided.

Measured items

Air temperature, globe temperature and relative humidity 1.2 m above the ground, horizontal solar irradiance 1.8 m above the ground and wind directions and velocities 2.0 m above the ground were measured every min at the main measured points (east side) on the streets as shown in Table 1. Fig.4 shows measurement apparatus on the west district. Solar irradiance and wind were not measured at subsidiary points on the west side of the streets. Wind direction and velocity were also measured by ultrasonic anemometer every sec. in the park. Surface temperatures of the ground and buildings near the measuring points were measured by spot thermometers every 15 min.

Surface temperature of the walls of first, second and top floors for 35 buildings and 18 points of the streets were measured in detail in the east district. Surface temperature of the bridge columns, soundproofing walls of the elevated freeway were also measured. Water in the waterway was dipped up every 15 min and the temperature was measured.

Thermal comfort sensations by street passers in both districs were taken by using ASHRAE seven-point thermal sensation scale and four-point comfort scale. Clothings of passers were also surveyed.

Results

Fig.5 shows the variation of air temperature and air velocity for east, west main points and park on July 26 under clear sky all the day. Temperature at the streets increase sharply and temperature at the west street is the highest at the peak around 14:00. Mean velocity is 0.62 m/s for west, although 0.91 m/s for east and 0.89 m/s for the park.

Table 2 shows the results of the daily mean air temperature and SET*. Mean air temperature were 0.5 to 0.8 K lower and SET* are 1.4 to 2.9 K lower in the east district than in the west district. Mean activity level is assumed to be 2.0 met and mean clothing value is 0.61 clo. Differences were also shown in thermal sensations and comfort of passers 253 for east and 252 for west in Table 3. ‘Freq’ in the table shows the relative frequencies (%) of central three categories in thermal sensation and ‘comfort’ in thermal comfort. The frequencies are higher in the east district than in the west district.

Fig.6 and Fig.7 show the mean surface temperatres of the roads in the east district for five measured days for north-south and east-west streets respectively. Mean road surface temperature of the west side of north-south streets is higher in the morning and lower in the afternoon than that of the east side. Road surface temperature are higher than building surface temperature. For east-west streets, mean surface temperature of the north side of the road are the highest. Fig.8 is for the building wall temperature by direction of the walls. Surface temperature for north wall is the lowest in daytime. Surface temperatutre of west wall rise sharply in the afternoon. Fig.9 shows surface temperatures of the bridge column at three levels, sound proof wall, and water temperature on August 8 under clear sky all the day. Water temperature remains around 30 degree C even in the afternoon. Table 4 shows temperatures for simulation on the basis of the measurements.

Figure 4 Measuring apparatus

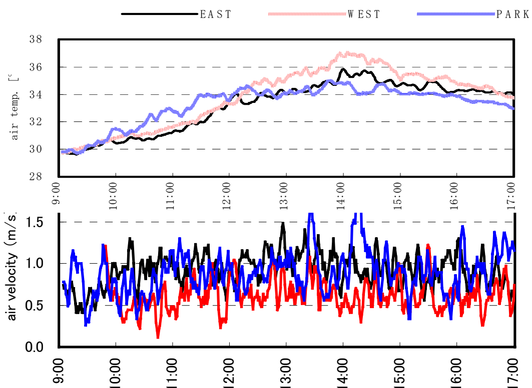


Figure 5 Air temperature and air velocity (July 26)

Table 1 Measured Items

Measured Item	Height	Inerval
Air Temperature	GL＋1.2m	1min
Globe Temperature	GL＋1.2m	1min
Air Velocity/direction	GL＋2.0m	1min
Solar Irradiance	GL＋1.8m	1min
Surface Temperature	－	15min

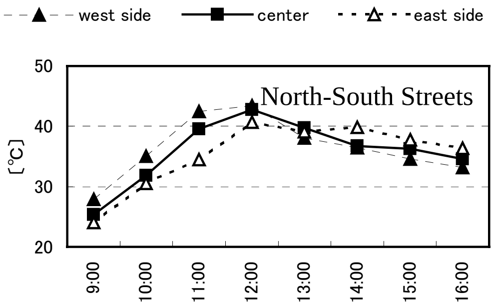


Figure 6 Mean road surface temperatures

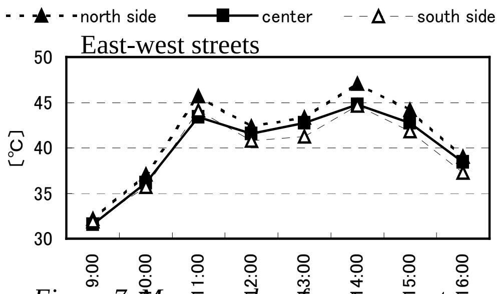


Figure 7 Mean road surface temperatures

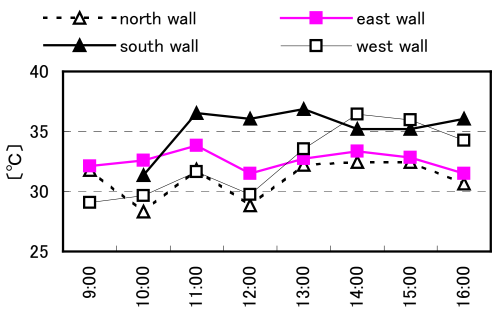


Figure 8 Mean wall surface temperatures

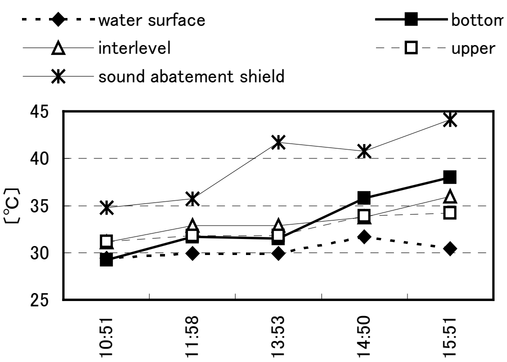


Figure9 Bridge surface temperatures (8-Aug.)

Table 2 Mean Temperatures in daytime

		6-Jul	26-Jul	8-Aug	30-Aug	21-Sep
West	air temp	27.6	33.8	33.3	30.1	28.1
Distr	SET*	-	38.4	37.0	34.0	32.3
East	air temp	27.3	33.2	32.5	29.5	27.6
Distr	SET*	-	36.1	34.1	32.3	30.9
Park	air temp.		33.3	32.5	29.4	27.6

Table 3 Mean thermal sensation

			Thermal Sensation			Thermal Comfort		
		n	Mean	SD	Freq	Mean	SD	Freq
6-Jul	East	39	2.03	1.33	28	1.00	0.55	15
	West	44	1.53	1.39	49	0.95	0.53	14
26-Jul	East	41	2.88	0.50	2	1.76	0.85	2
	West	31	2.84	0.51	6	1.73	0.77	3
8-Aug	East	40	2.48	1.07	15	1.33	0.93	18
	West	37	2.59	1.15	8	1.86	0.74	3
30-Aug	East	25	1.24	1.61	52	1.17	0.62	8
	West	31	2.13	1.36	29	1.23	0.71	13
21-Sep	East	30	0.63	1.66	40	0.60	0.61	30
	West	30	1.47	1.15	47	0.67	0.65	40

'Freq' shows the percentages of central three categories in thermal sensation vote and 'comfort' in thermal comfort vote.

Table 4 Surface temperatures for simulation

Building surface			
North wall	East wall	South wall	West wall
35.26	35.21	39.37	37.90
Roof	Inside wall		
51.80	36.00		
Road surface			
North-south street			
	West side	Center	East side
Street-0,1	38.33	35.17	45.33
Street-2	39.00	41.10	43.20
Street-3	38.00	41.70	46.40
Street-4	54.90	54.20	56.50
East-west street			
	North side	Center	South side
Street-0,1	53.50	50.10	50.90
Street-2	46.90	46.80	51.90
Street-3	56.50	53.70	54.30
Street-4	52.23	50.60	51.60
Ground surface			
Shaded	Not-shaded		
37.60	51.80		
Bridge			**Water**
Column	Wall		28.00
31.57	52.40		

SIMULATION

Methods of simulation

The Computer Fluid Dynamics simulation model is the standard k- ε three dimentional turbulent flow model for incompressible fluid. The mass, momentum and energy are under the laws of conservation. The boundary condition is based on the measured surface temperatures as shown in Table 4. The inflow conditions are assumed to be under the law of exponent in the vertical distribution for air velocity and log-law for stress on building surface for turbulent energy.

$$\varepsilon(z) = C_t^{0.5} k(z) \frac{U_s}{z_s} \alpha \left(\frac{z}{z_s} \right)^{(\alpha-1)} \qquad (1)$$

$$T(z) = T_0 - 10^{-3} \Gamma z \qquad (2)$$

$$U(z) = U_s \left(\frac{z}{z_s} \right)^{\alpha} \qquad (3)$$

$$k(z) = \left(I(z) U(z) \right)^2 \qquad (4)$$

$$I(z) = 0.1 \left(\frac{z}{z_G} \right)^{(\alpha-1)} \qquad (5)$$

z_s : reference height$[m]$
U_s : air velocity at zs[m/s]
α : exponential order$[-]$(= 0.38)
z : height$[m]$
T_0 : ground surface temp.[℃]
Γ : rate of temperature decrease[℃$/km$]
ε : turbulence dissipation ratio[-]

The east district is modeled as shown in Fig.10. The calculation size is 336 m x 699 m x height 200 m. West part of the east district is used as a general urban district which exponential order is 0.38 accoding to the central area of Osaka. The inflow wind direction is assumed to be west according to the measurement. If five general parts and one modeled east district are connected for the assumed wind direction, the vertical distribution of horizontal wind velocity, air temperature and turbulent energy become constant. The inflow condition is decided after the pre-calculation. The free slip condition is used for side and top and log-law is used for walls and ground. Heat transfer coefficient is fixed at 23.3 (W/m^2). Steady state simulation is applied for the typical peak summar under clear sky, July 26 14:00.

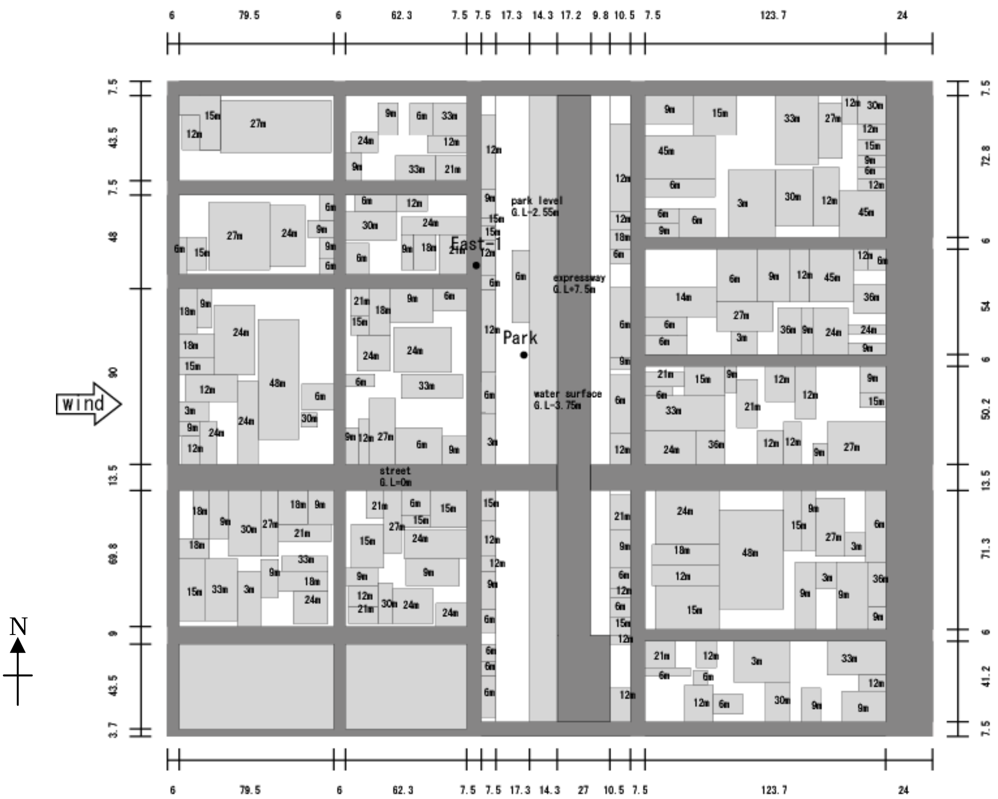


Figure 10 Model of east district

Simulation results and discussion

Basic model

Fig.11 shows the calculated distribution of the air temperature at the height of 1.2 m. The result is compared with the measurement. The differences of the measured values extracted from the calculated results are 0.20 K at the measured point in the east district (East-1) and -0.32 K at the measured point in the park (Park) respectively. Air temperature near waterway are lower than around wide streets. This tendency agrees with the measured results. Fig.12 shows the calculated distribution of the wind. The differences of the measured values extracted from the calculated are -0.28 m/s at East-1 and -0.96 m/s at Park. Measured air velocity in the park is larger than that in the east district, but the calculated result is the opposite. The wind directions near waterway are north-south by the measurement, but the calculated results show the east-west. The air movement cannot simulated properly. It can be said that air temperature near the ground can be simulated, although the air movement along waterway cannot.

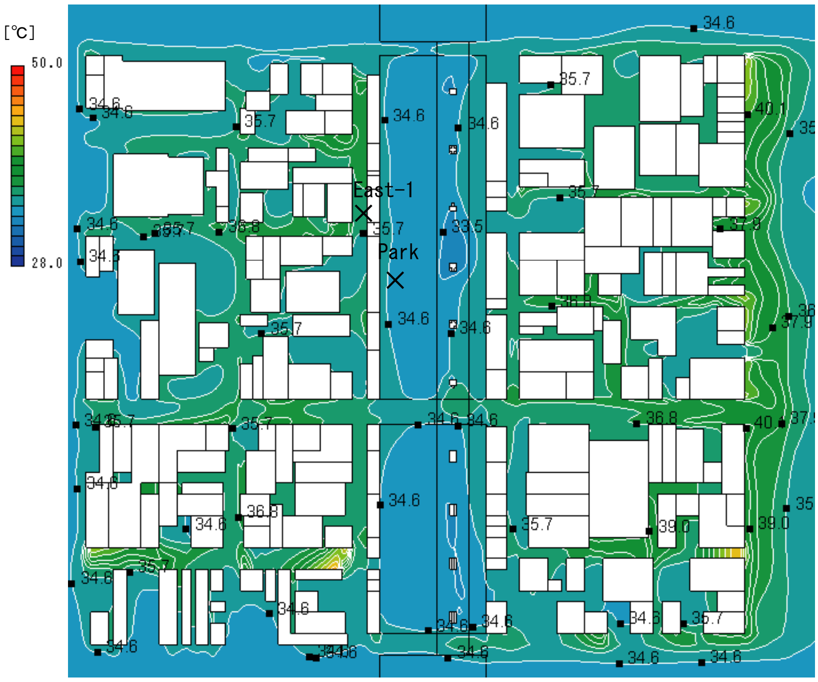


Figure 11Air temperature distribution (Basic model) height=1.2m

'East-1' and 'Park' in the figure show the easured points.

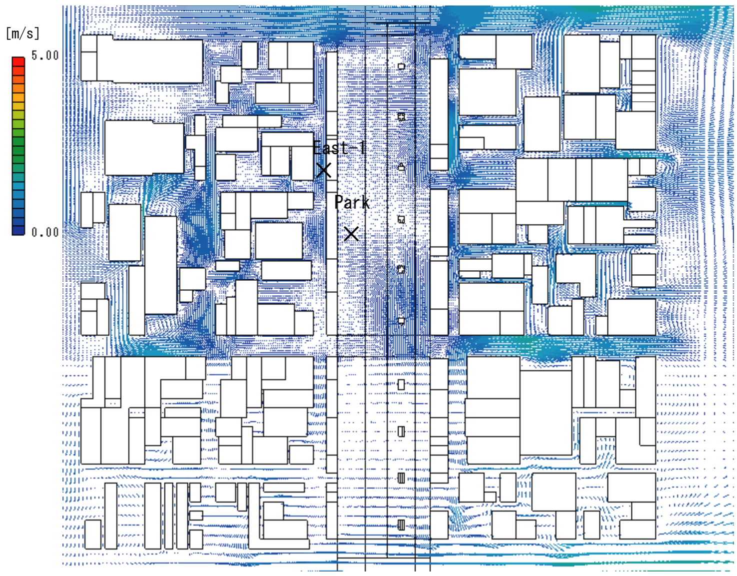


Figure 12 Distribution of wind. (Basic model) height=1.2m

'East-1' and 'Park' in the figure show the measured points.

Reformed Models

Model-1 is the case of the reform of the district configulation along waterway. There are buildings between the park and the east district impeding of extention of the cooling effects of waterway. The ground level of the park is lower than the east district and the waterway is hidden from the urban district. Model-1 removes these buildings (Fig.13). Model-2 is the case that the buildings were removed and width of the waterway is extended to the full in the park (Fig.14). The boundary inflow condition, heat transfer conditions and the calculated grid size are common to the basic model.

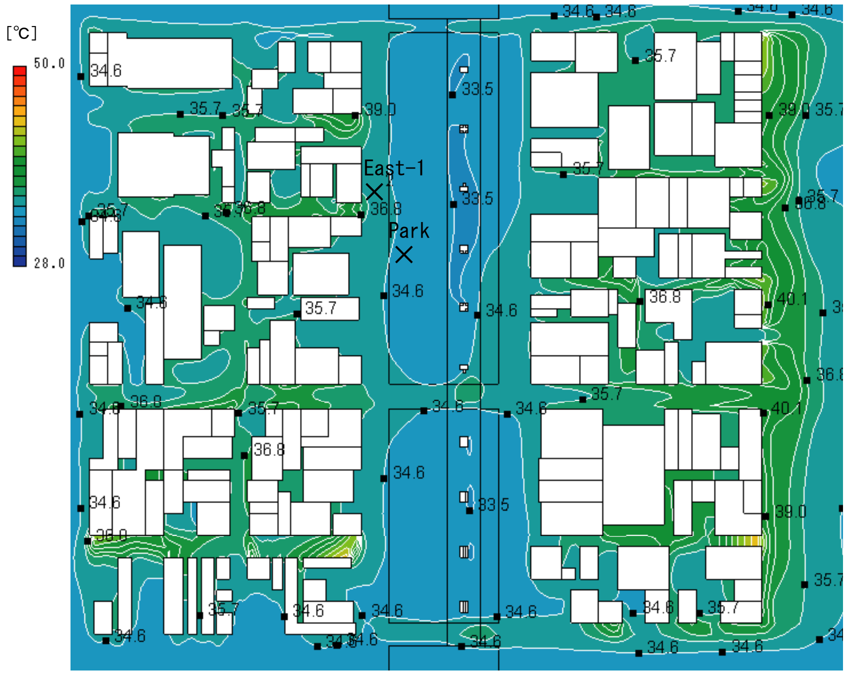


Figure 13 Air temperature distribution for Model-1

Buildings between the waterway and the street are removed. East-1 and Park show the measured points.

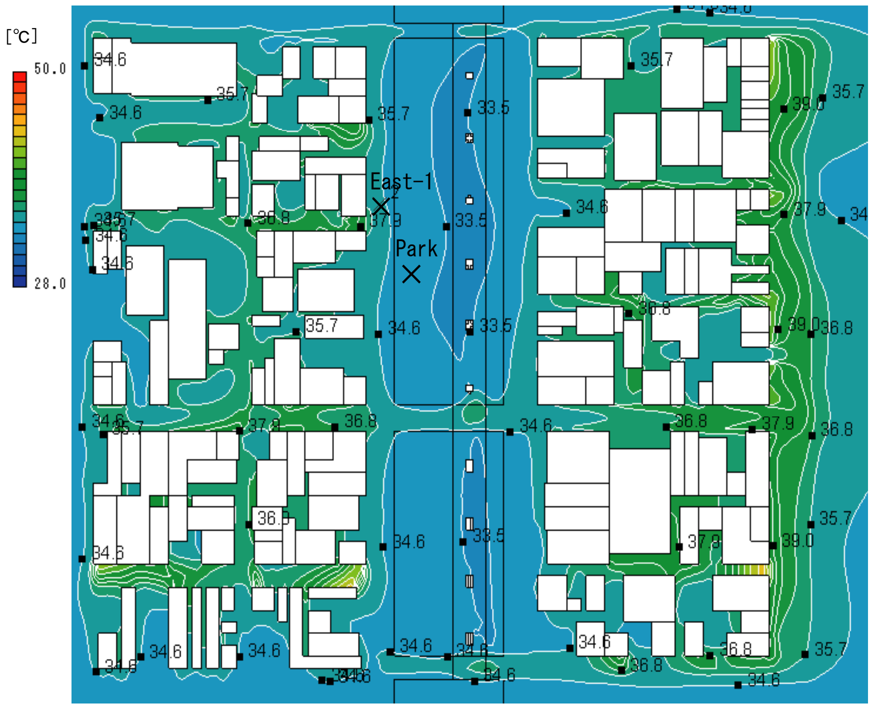
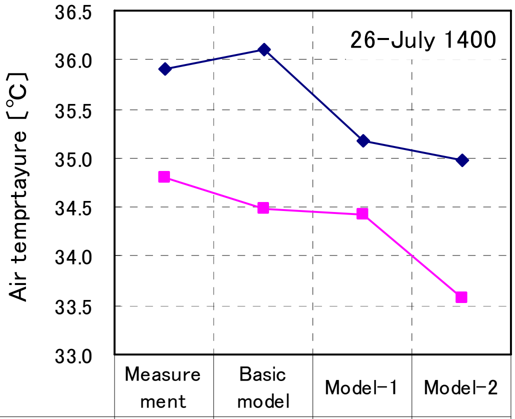


Figure 14 Air temperature distribution *for Model-2*
Width of waterway is extended to the full besides removing the buildings. East-1 and Park show the measured points.



	Measure ment	Basic model	Model-1	Model-2
East-1	35.90	36.1	35.18	34.98
Park	34.80	34.48	34.43	33.58

Figure 15 Comparison among air temperatures measured, basic model, Model-1 and Model-2.

Fig.15 compares air temperatures among measured and basic model, reformed model-1 and model-2 for July 26 14:00. Air temperature at East-1 is 0.92 K lower in Model-1 and 1.12 K lower in Model-2 than the basic model. It is notable that the effects of the reformed models are even larger than the measured difference between east and west districts. Cooling effects are recognized in reformed models, although air movement cannot be expressed so well by the simulation.

CONCLUSIONS

Measurements and calculations were carried out on the cooling effects of waterways in urban districts. The results are as follows.

- Cooling effects of the waterway were recognized by measurement of two districts with and without the waterway in the thermal environment and thermal sensation. Air temperatures in the district with the waterway were 0.5–0.8 K lower and SET* were 1.4–2.9 K lower than in the district without waterways in peak summer.
- The districts with waterways were modeled and the distributions of air temperature and wind were calculated using CFD simulations for the steady state in peak summer. The air temperature at the level of 1.2 m can be expressed properly by comparing measured and simulated results.
- The basic model was reformed to increase the waterway cooling effects. Air temperatures of the model with buildings removed between the waterway and riverside park was 0.92 K lower than the basic model. If the waterway width were fully expanded in the park in addition to removing buildings, the air temperature would be decreased another 0.20 K. Cooling effects by reforming the configurations around waterways were higher than the measured difference in districts with and without waterways.

ACKNOWLEDGMENT

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