Study on a simple evaluation method of urban heat island mitigation technology using upper air data

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(Background)

Rearranging table on the effect of urban heat island mitigation technology by *Cool Roof Committee of Architectural Institute of Japan*

public benefit ⟷ *private* benefit

Target	Menu	Heat island measures		Outdoor thermal environment		Energy saving		Other effects	Consideration matters
		Day time	Night time	Day time	Night time	Cooling	Heating		
Roof	Green	◎	◎	◎	◎	○	○	Improvement of landscape, ecosystem, real estate value, customers service, flood relaxation, environmental education	Maintenance
	High reflectance	◎	◎	-	-	○	△	Improvement of indoor thermal environment	Aging deterioration of performance, reflection for circumference, heating load increases
	Sprinkling	◎	○	-	-	○	-		
	Outside insulation	△	○	-	-	◎	◎		
Wall	Green	◎	○	◎	◎	○	○	Improvement of landscape, ecosystem	Maintenance
	High reflectance	○	○	△	○	○	△	Improvement of indoor thermal environment	Aging deterioration of performance, reflection for circumference, heating load increases
	Sprinkling	◎	○	○	-	○	-	Improvement of landscape	
	Outside insulation	△	○	△	○	◎	◎		
Road, Pavement, Parking, Open space	Green	◎	◎	◎	◎	-	-	Improvement of landscape, ecosystem	Maintenance
	High reflectance	◎	◎	△	◎	-	-		Aging deterioration of performance, reflection for circumference
	Retaining water	◎	◎	◎	◎	-	-	Rainwater penetration	Water reserving condition
	Sprinkling	◎	◎	◎	◎	-	-		

◎: Superior effect is expected, ○: Good effect is expected, △: Opposite effect may happen, -: Not intended

(Background)

Evaluation tool for the effect of *private* benefit by Prof. Kondo (Tokyo City University)

Calculation result

		Before		After	
Annual thermal road	Heating	9558	MJ	9846	MJ
	Cooling	20546	MJ	20176	MJ
	Saving annual thermal road			82	MJ

※正の値: 削減量、負の値: 負荷増加量

Annual electricity cost	Heating	10207	円	10514	円
	Cooling	25333	円	24876	円
	Saving annual electricity cost			149	円

※正の値: 節約金額、負の値: 増加した金額

Indoor air temperature without air conditioner in the afternoon	44.5	℃	43.7	℃
Air temperature reduction			0.8	℃

※冷房をしない場合の8月1日15時での2F寝室の室温

※正の値: 低下した温度量、負の値: 高くなった温度量

Annual CO2 emission	2.835	t	2.827	t
Saving annual CO2 emission			0.008	t

※使用電力量から算出

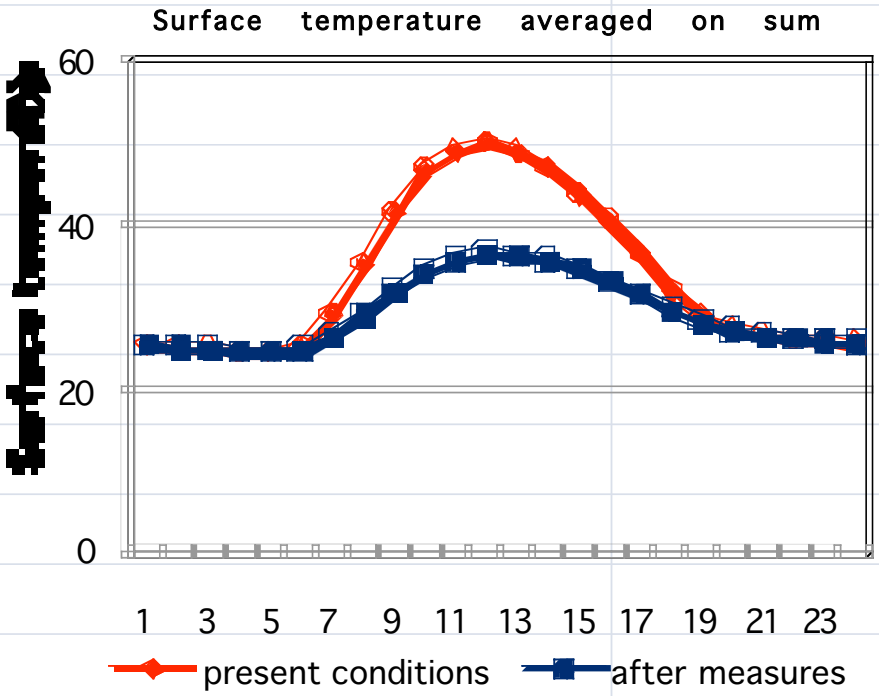
※正の値: 削減量、負の値: 増加量

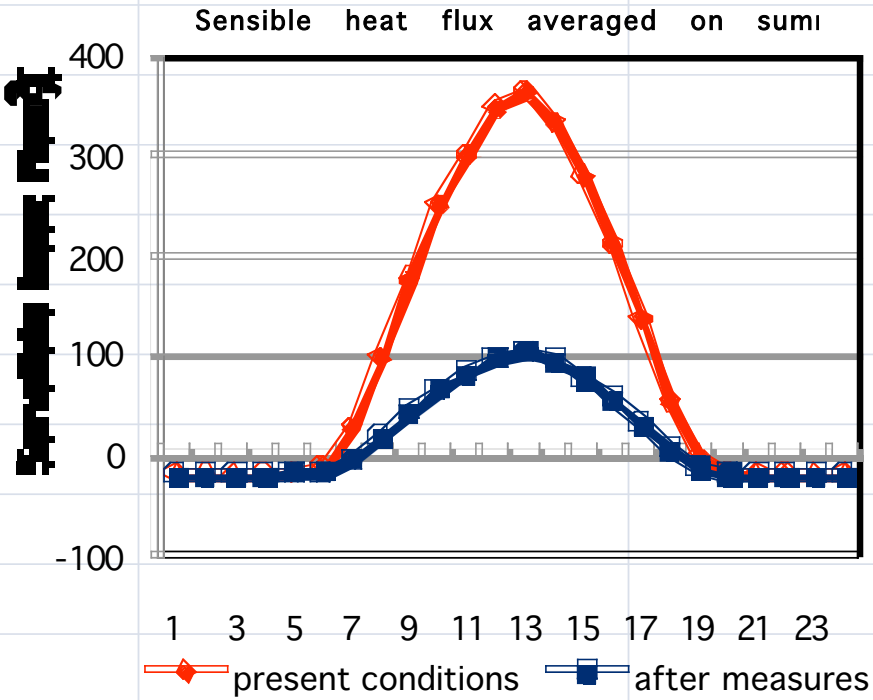
クールルーフによる効果が期待できます

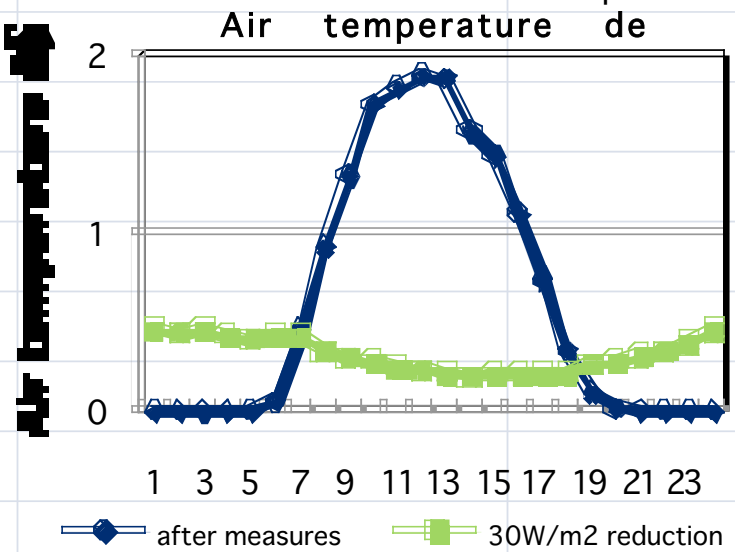
表紙 / はじめに / 各種条件選択 / 計算結果 / 各項目詳細説明

(Background)

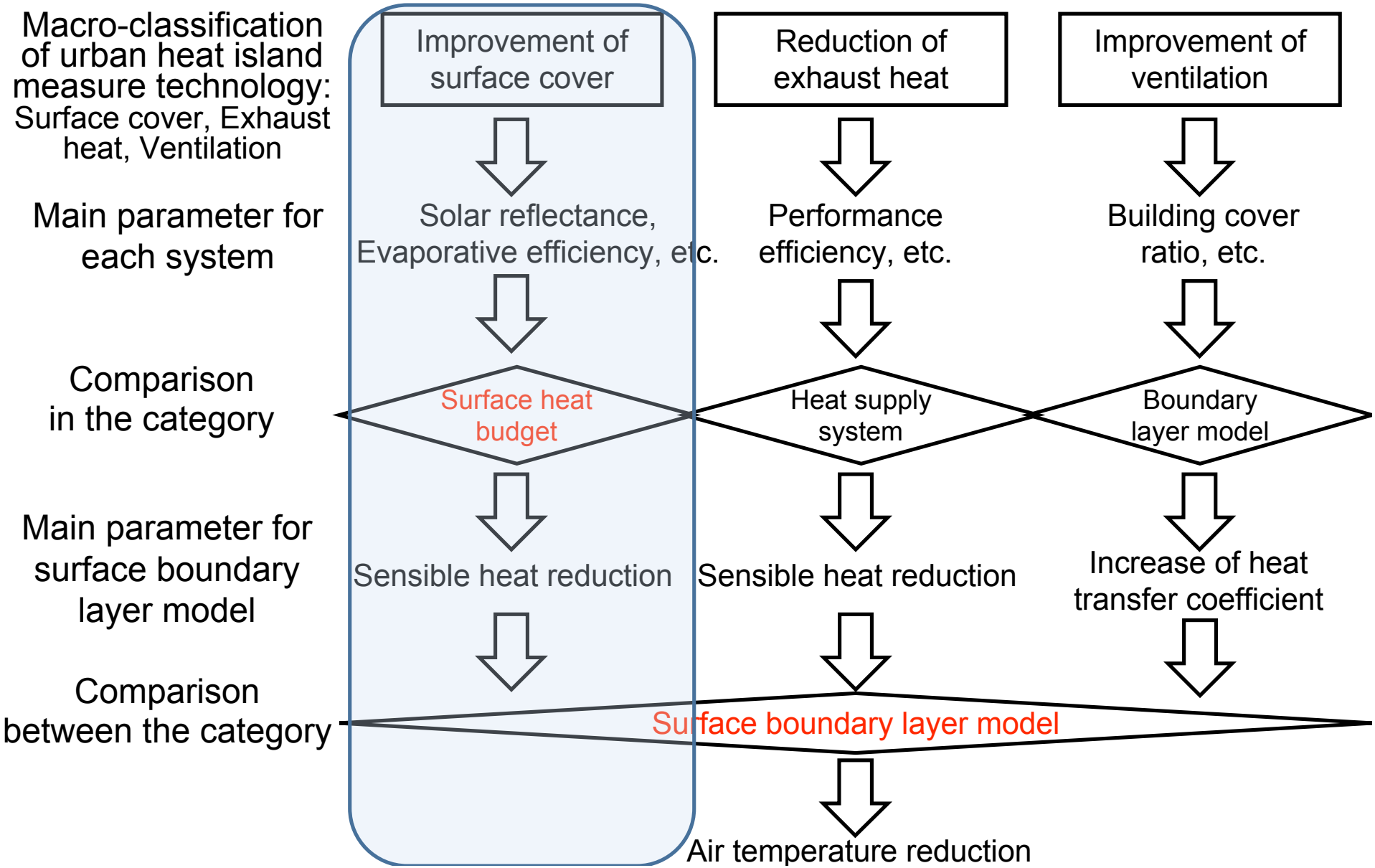
Evaluation tool for the effect of *public* benefit







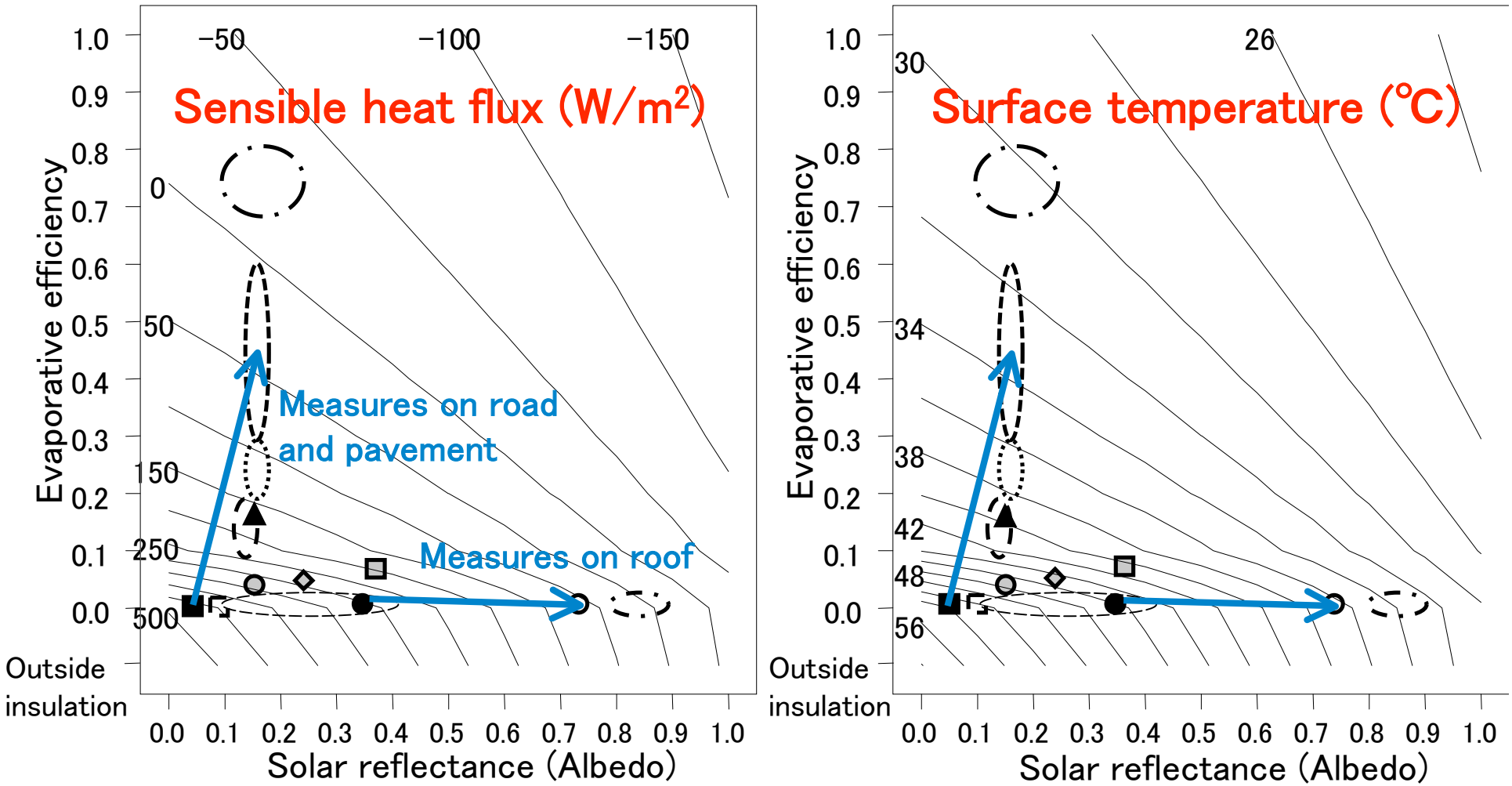
Evaluation process of heat island measures effect



(Surface heat budget)

Calculation result of Sensible heat flux and surface temperature *at 13:00* averaged in summer

(weather condition: 18 July to 15 September, 2005 at Osaka)



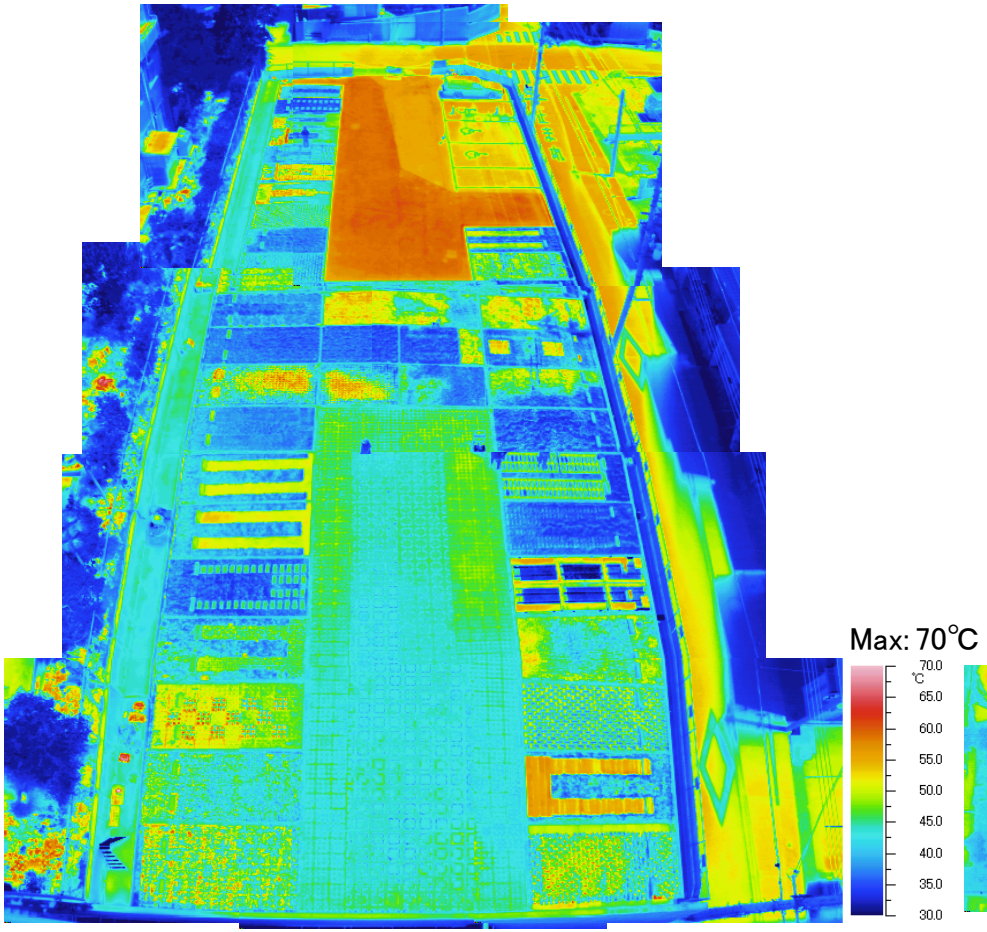
■ : Asphalt (0.044,0) ● Concrete(0.357,0) : ▲rass (0.15,0.14) : ○h reflectance white (0.74,0)(Solar reflectance, Evaporative efficiency)

□ : Retaining water asphalt (0.37,0.084) ○etaining water concrete (0.153,0.029) : ◇aining water block (0.233,0.035)

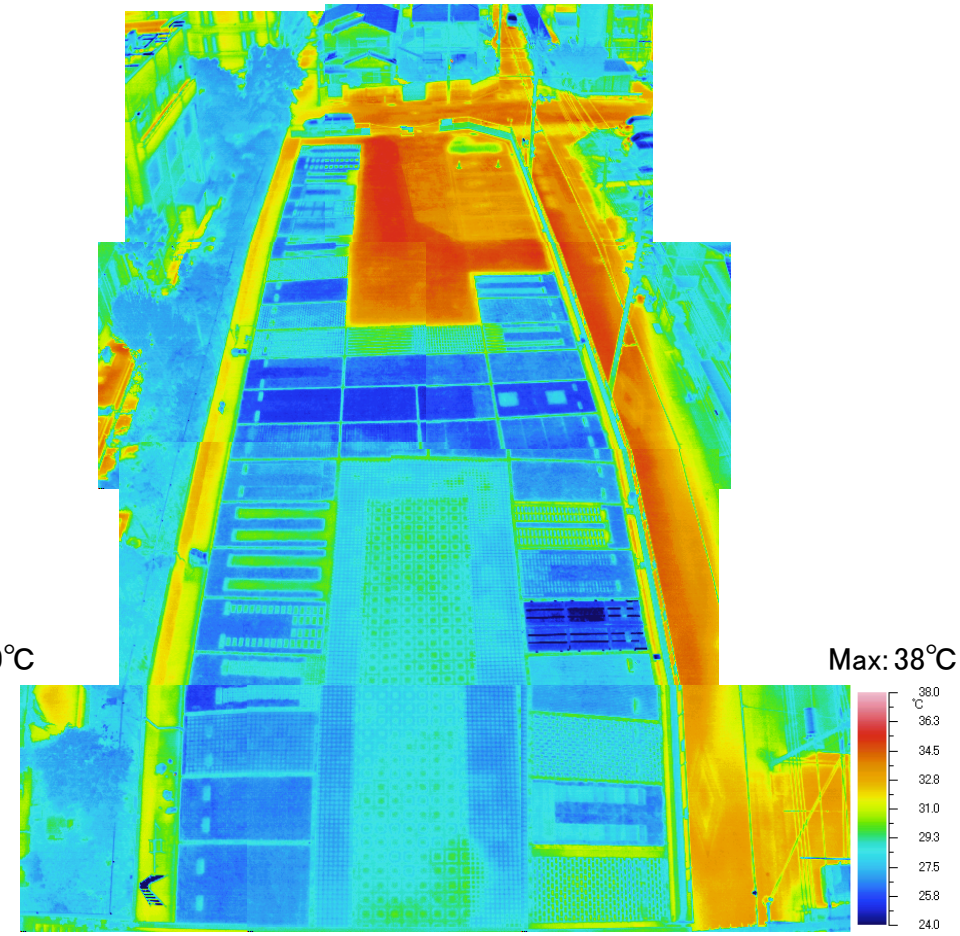
: Asphalt (by Yoshida) : Grass and other plants (by Misaka) Grass (by Misaka) : Green wall (by Hagishima)

: Retaining water pavement (by Akagawa) High reflectance white (by Fujimoto) : High reflectance black (by Fujimoto)

Examples of surface heat budget studies



At 12:00



At 21:00

Experiment of the parking

(Surface heat budget)

Surface heat budget model

$$R = V + lE + A$$

$$R = (1 - \rho)S\downarrow + L\downarrow - \varepsilon\sigma T_s^4$$

$$V = \alpha(T_s - T_a)$$

$$lE = l\beta(\alpha/C_p)(X_s - X_a)$$

$$A = \lambda/\Delta z(T_s - T_{z1})$$

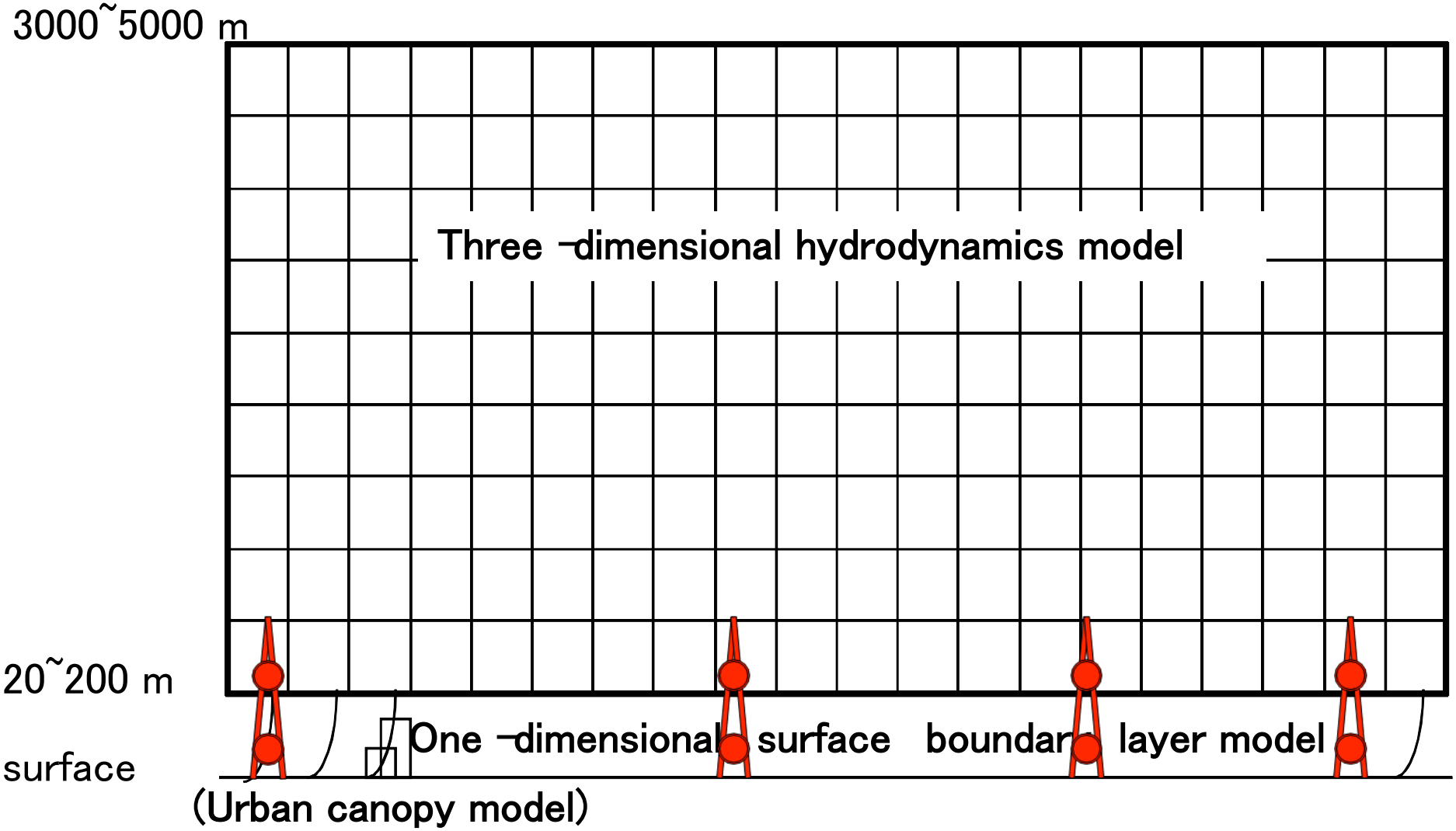
Main parameter

R: Net radiation (W/m^2)
lE: Latent heat flux (W/m^2)
ρ: Solar reflectance (Albedo)
$L\downarrow$: Long wave radiation (W/m^2)
σ: Stefan-Boltzmann constant (=5.67*10^{-8}W/m^{2}K^4)
α: Convection heat transfer coefficient (=4.2v+6.2W/m^{2}K)
T_s: Surface temperature (C)
l: latent heat (=2,512kJ/kg)
C_p: Specific heat of air (=1.0kJ/kgK)
X_a: Absolute humidity of air (kg/kg)
Δz: Distance from surface to first layer (m)

V: Sensible heat flux (W/m^2)
A: Conduction heat flux (W/m^2)
$S\downarrow$: Solar radiation (W/m^2)
ε: Emissivity (=1.0)
v: wind velocity (m/s)
T_a: Air temperature (C)
β: Evaporative efficiency (-)
X_s: Saturated absolute humidity (kg/kg)
λ: thermal conductivity (W/mK)
T_{z1}: Temperature in the first layer (C)

(Surface boundary layer heat budget)

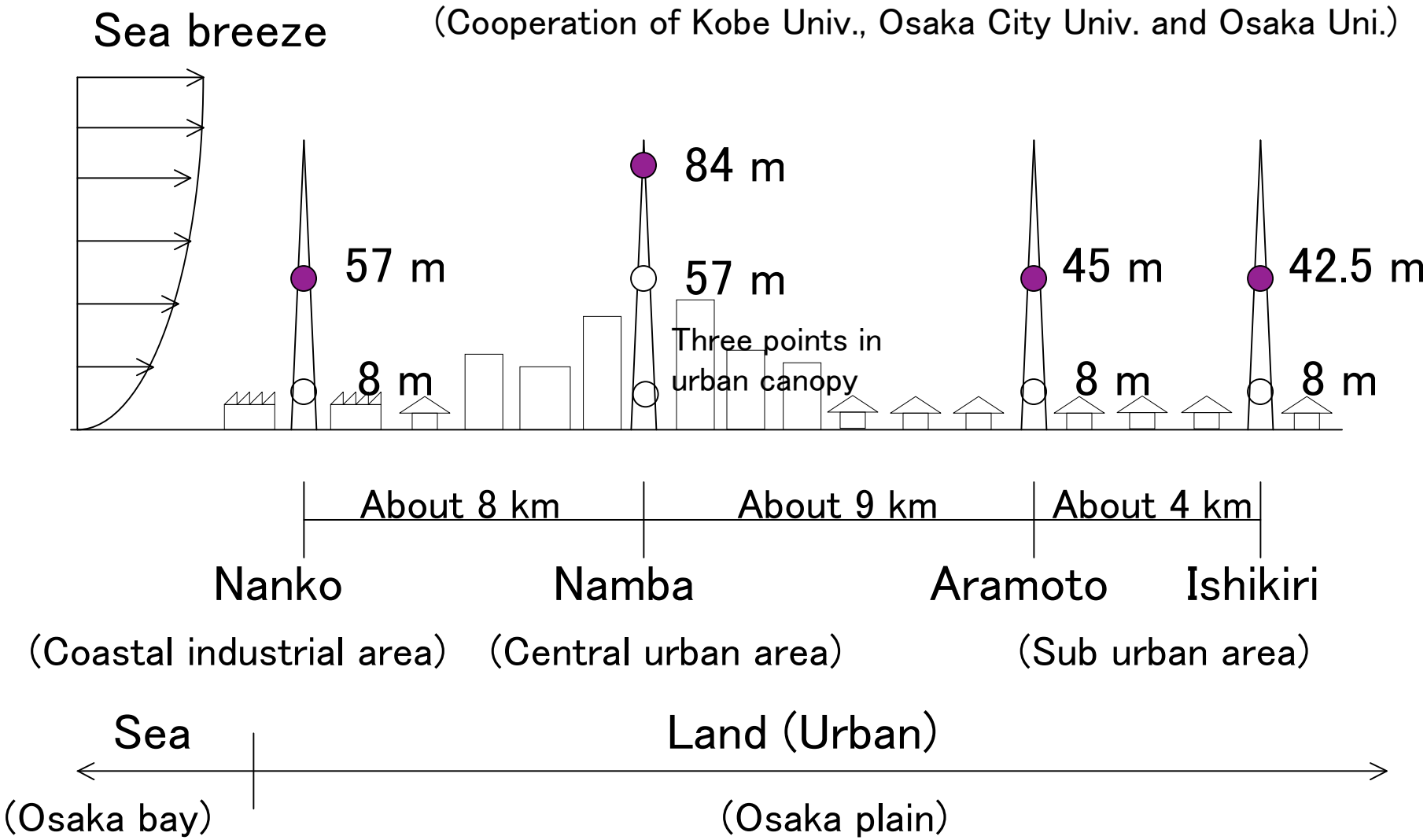
Structure of General Mesoscale Weather Simulation Model



(Surface boundary layer heat budget)

Outline of upper weather observation

(Cooperation of Kobe Univ., Osaka City Univ. and Osaka Uni.)

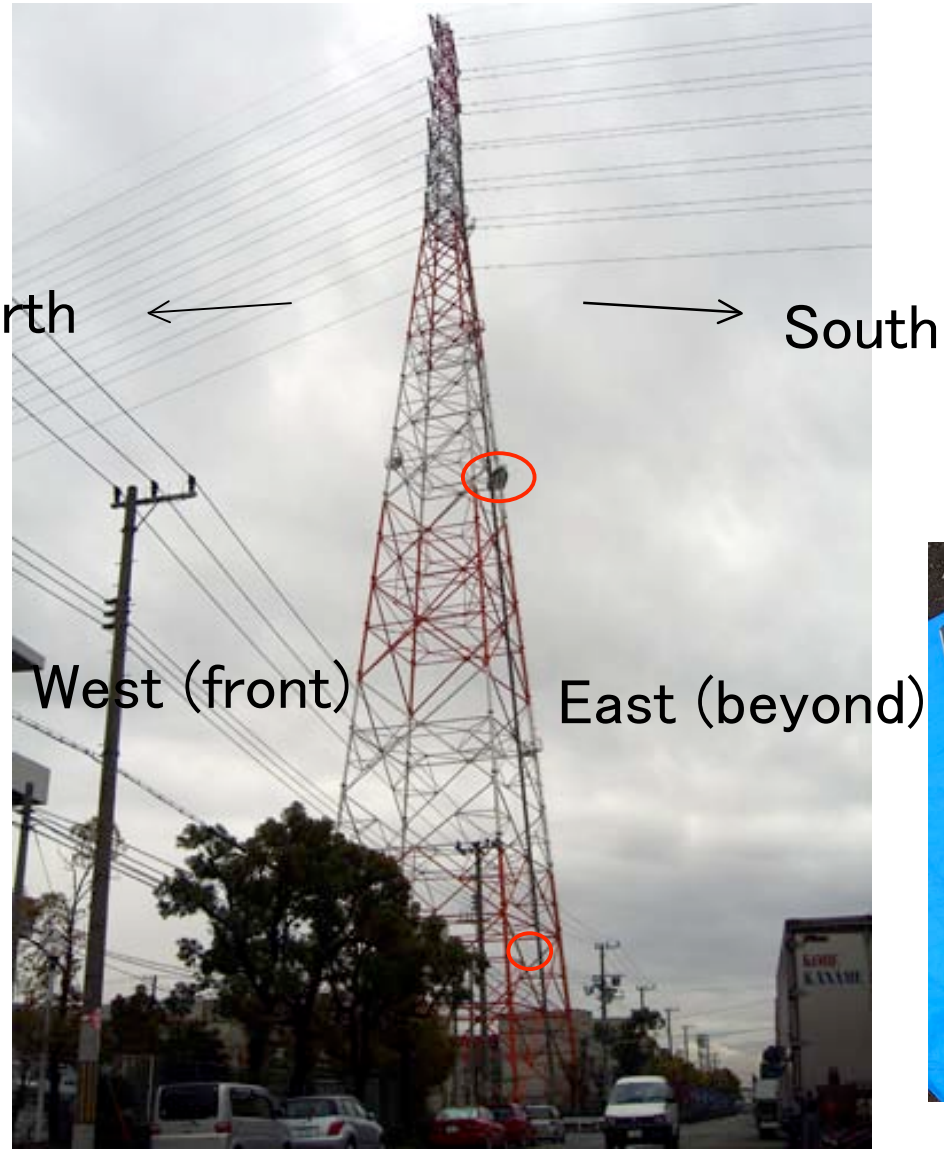


● : Observation point of wind velocity and direction, air temperature and relative humidity

○ : Observation point of air temperature

(Surface boundary layer heat budget)

Installation situation of measuring instruments



at Coastal point (Nanko)

Measuring instruments

Surface boundary layer model

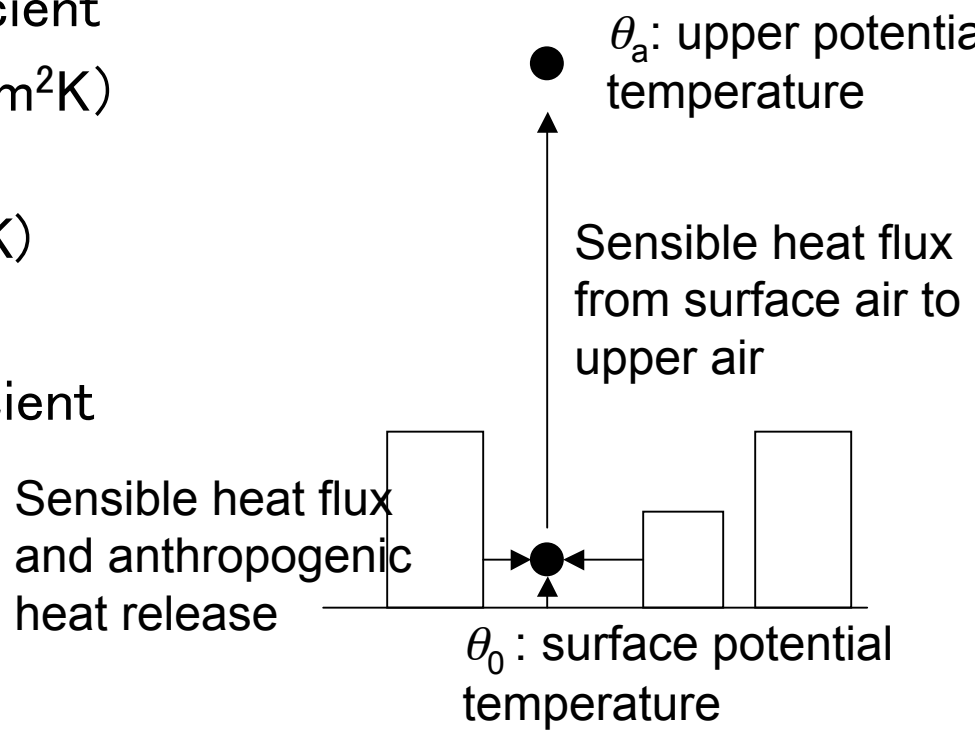
- Sensible heat flux V (W/m^2)

$$V = \alpha_c \left(\theta_0 - \theta_a \right)$$

α_c: convection heat transfer coefficient of surface boundary layer (W/m^{2}K)

θ_0: upper potential temperature (K)

θ_a: surface potential temperature (K)



- Convection heat transfer coefficient of surface boundary layer

$$\alpha_c = \frac{C_p \gamma k^2 u_a}{F_m F_h}$$

C_p: specific heat of air (=1.0kJ/kgK), γ: density of air (=1.2kg/m^3)

k: karman constant (=0.35), u_a: upper wind velocity (m/s),

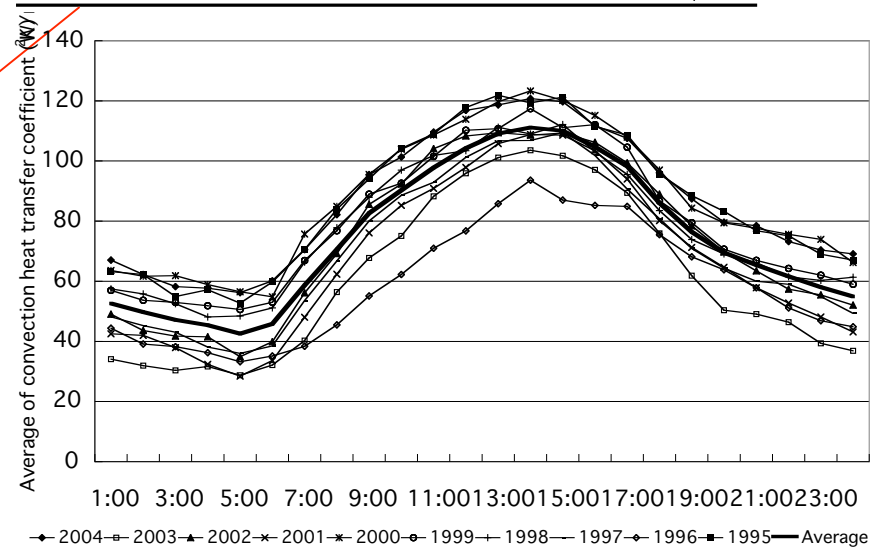
F_m, F_h: Integral value of universal function (–)

(Surface boundary layer heat budget)

Estimation results of Convection heat transfer coefficient and quantity of air temperature rise in the case of *additional thermal road of 10W/m²*

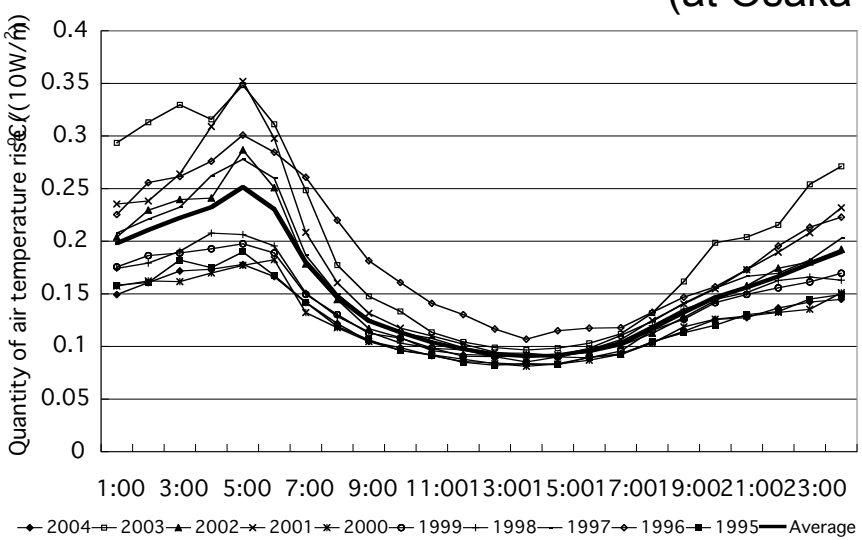
$$V + \Delta V = \alpha_c' \{(\theta_0 + \Delta\theta) - \theta_a\}$$

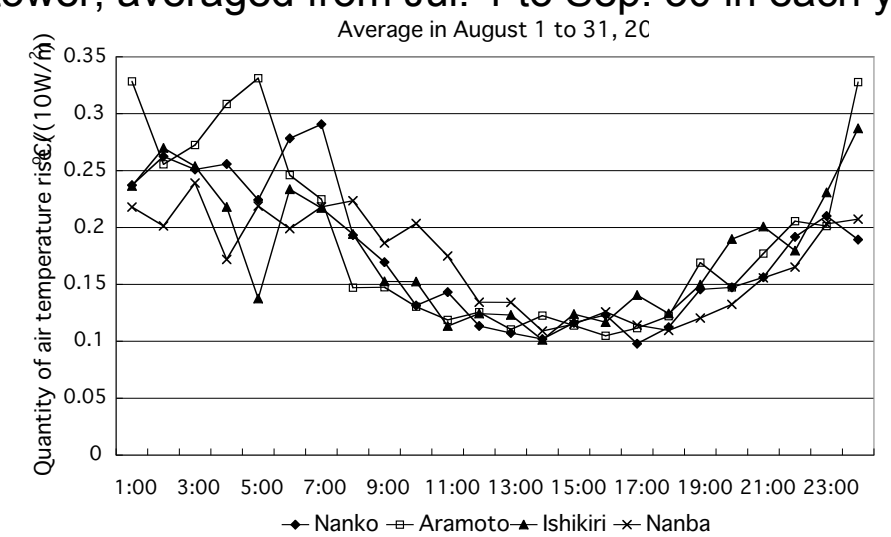
$$\Delta\theta = \Delta V / \alpha_c$$



Convection heat transfer coefficient

(at Osaka tower, averaged from Jul. 1 to Sep. 30 in each year)





(Estimated by observation results at *Osaka tower*) (Estimated by observation results at *each tower*)

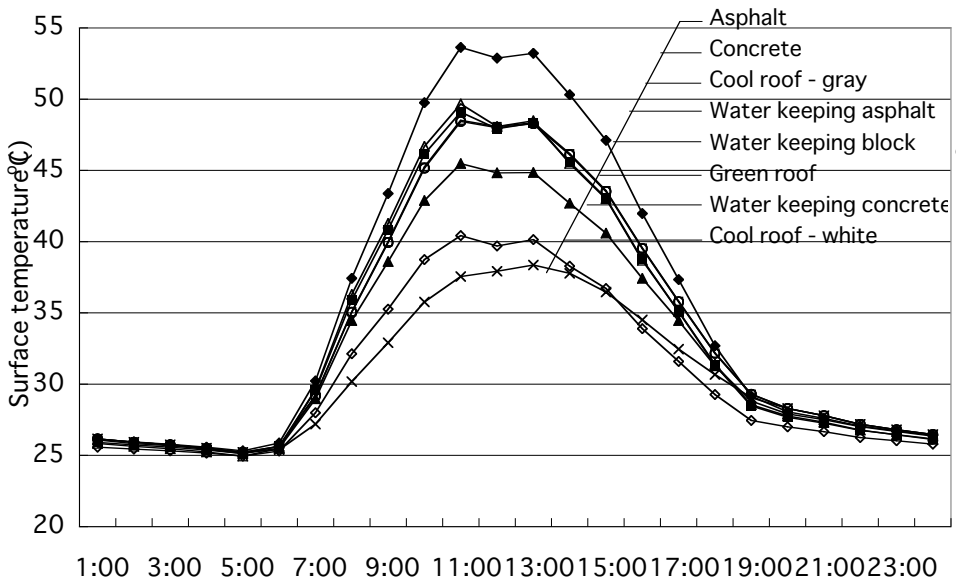
Quantity of air temperature rise in the case of additional thermal road of 10W/m²

(Air temperature reduction)

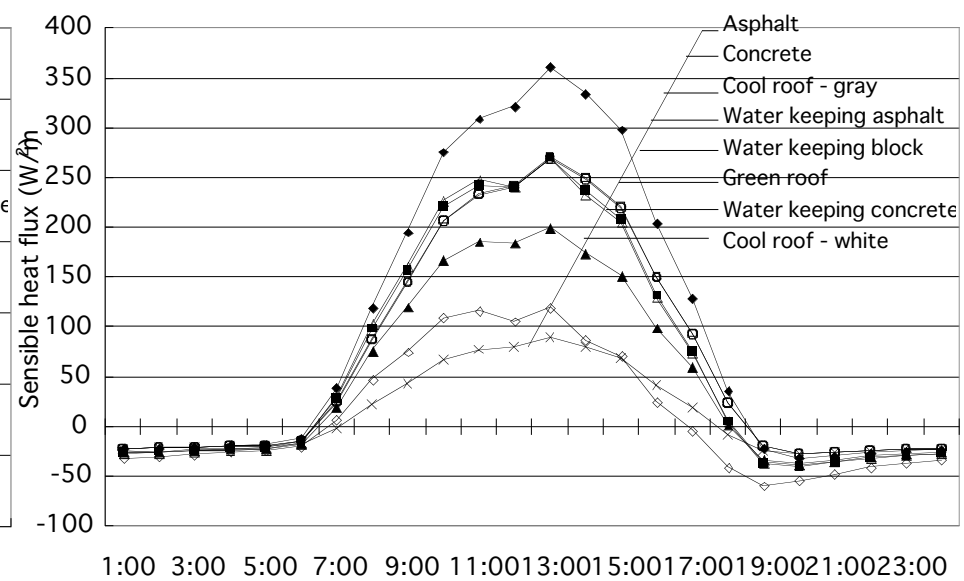
Surface heat budget on various urban heat island measures technology

Parameter of surface heat budget

	Asphalt	Concrete	Green roof	Cool roof - white	Cool roof - gray	Water keeping asphalt	Water keeping concrete	Water keeping block
Albedo (-)	0.044	0.357	0.15	0.74	0.36	0.37	0.153	0.233
Evaporative efficiency (-)	0	0	0.14	0	0	0.084	0.029	0.035
Thermal conductivity (W/mK)	0.84	1.59	0.6	1.59	1.59	0.87	0.99	0.65
Thermal capacity (J/m^3K)	7000000	1000000	2900000	1000000	1000000	1500000	5000000	30000



Calculation result of surface temperature



Calculation result of sensible heat flux

(Averaged in each hour from 1 to 31 August 2006, at Osaka)

(Air temperature reduction)

Estimation results of air temperature reduction

Sensible heat flux reduction averaged in daytime and nighttime based on surface heat budget model (averaged in each hour from 1 to 31 August 2006, at Osaka)

The difference with concrete in the case of roof, the difference with asphalt in the case of road

W/m^2	Green roof	Cool roof - white	Cool roof - gray	Water keeping asphalt	Water keeping concrete	Water keeping block
daytime	34.5	92.6	0.73	30.1	11.2	11.0
nighttime	4.21	0.58	0.00	2.57	1.02	1.10

Air temperature reduction averaged in daytime and nighttime at Nanko *(Coastal)*

(averaged in each hour from 1 to 31 August 2006, at Osaka)

℃	Green roof	Cool roof - white	Cool roof - gray	Water keeping asphalt	Water keeping concrete	Water keeping block
daytime	0.42	1.19	0.01	0.38	0.14	0.13
nighttime	0.08	0.01	0.00	0.05	0.02	0.02

Air temperature reduction averaged in daytime and nighttime at Namba *(Central urban)*

(averaged in each hour from 1 to 31 August 2006, at Osaka)

℃	Green roof	Cool roof - white	Cool roof - gray	Water keeping asphalt	Water keeping concrete	Water keeping block
daytime	0.48	1.37	0.01	0.43	0.16	0.15
nighttime	0.07	0.01	0.00	0.04	0.02	0.02

Evaluation tool for the effect of *public* benefit

Cool roof and Green roof calculator

1. Setting of Solar reflectance and Evaporative coefficient

	present conditions	after measures	change quantity
Solar reflectance (Albedo)	0.25	0.75	0.5
Evaporative efficiency	0	0	0

2. Calculation of surface temperature (°C)

	present conditions	after measures	surface temperature decrease
At 13:00 on typical summer day	49.0	36.5	12.5
At 21:00 on typical summer day	26.6	26.5	0.0

3. Calculation of sensible heat flux (W/m^2)

	present conditions	after measures	sensible heat flux decrease
At 13:00 on typical summer day	367	110	256
At 21:00 on typical summer day	-19	-19	0

4. Estimation of decrease of air temperature (in the case that all roofs which occupied 60% of the object area change)

	surface temperature decrease	sensible heat flux decrease	air temperature decrease
At 13:00 on typical summer day	12.5	256	1.86
At 21:00 on typical summer day	0.0	0	0.00

5. Calculation of SET*(°C)

	present conditions	after measures	SET* decrease
SET* at 13:00 on typical summer day (°C) in the case that albedo of human is 0.3	44.6	46.8	-2.2
SET* at 13:00 on typical summer day (°C) in the case that albedo of human is 0.6	42.2	42.9	-0.7

Conclusions

- Methods *based on the surface-boundary layer model* are used for estimating the coefficient of heat transfer from surface air to upper air by convection.
- The change in the surface air temperature with the release of additional sensible heat flux into the surface air is estimated *using the convection heat transfer coefficient*.
- Urban heat island mitigation strategies are implemented, and their effectiveness is evaluated *by estimating the decrease in the surface air temperature* in the night – and daytime.