IBPSA – Nordic seminar, 19th-20th September 2013, Lund university

Building energy controlled by the reflective facades

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   - Multiple regression analysis
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NTNU, Norway

Takeshi Ihara

Introduction

◆Solutions for Energy efficient buildings

◆Japan: high density, high rise building, cooling/heating

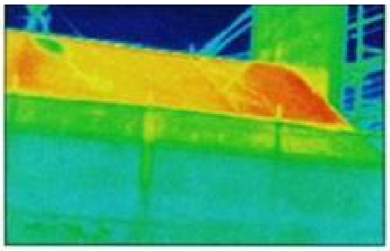
Tokyo, Japan

◆Highly reflective materials

Introduction

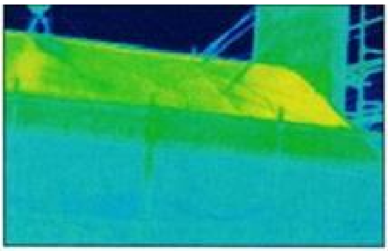
The current researches

◆Main concern　: Roofs (many papers)



Roof with conventional materials
Temperature: 48～54℃

Gray



Roof with highly reflective materials
Temperature:　41～47℃

Gray

◆Recent concern: Facades (Not many papers)

－Not many researches were done.

－Energy benefit was pointed out.

Purpose

◆The investigation of the energy benefits in quantitative way

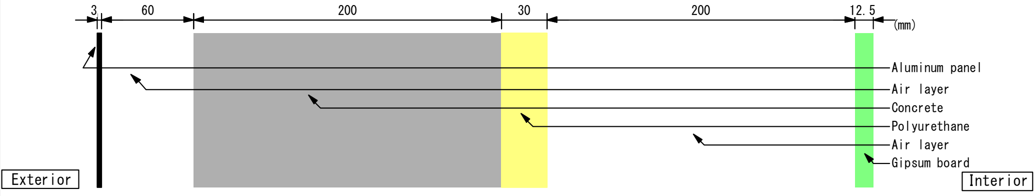
◆The easy method to predict the energy benefit

－The location was fixed to be Tokyo, Japan

－relatively high rise buildings

Method

Metal wall model



Wall specification

- U=0.59
- Exterior solar reflectance: 0.1, 0.4, 0.7

Method

Heat flux simulation

- WUFI
- Heat flux in summer, winter

Method

Annual energy simulation

◆ WUFI Plus

No.	Parameters	contents
1	The number of floors	5, 15, 30 floors
2	A floor aspect ratio	0.49, 1.00, 2.04
3	A floor area	1225, 2401, 3969 m^2
4	The ratio of the window area to the wall area	10, 20, 40%
5	The wall solar reflectance	0.1, 0.4, 0.7

◆ The fixed parameters

-Office

-Rectangular buildings (north-south direction) were considered.

-Location: Tokyo, Japan

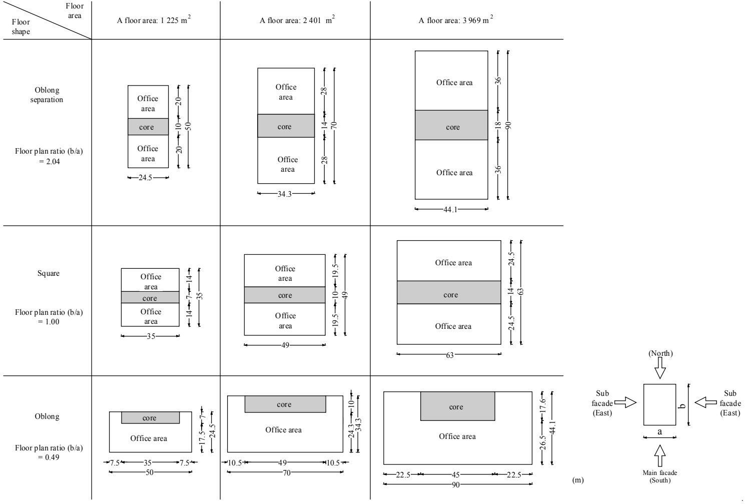
-U value: 0.86(roof), 1.99(slab), 3.39(intermediate slab)

◆ 243 (= 3^5)models were simulated.

Method

Annual energy simulation

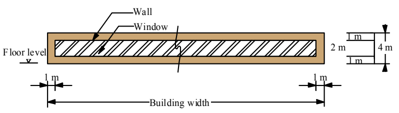
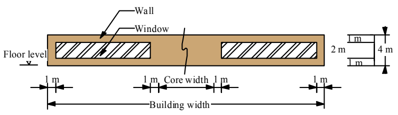
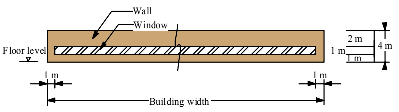
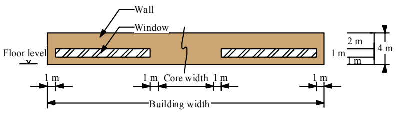
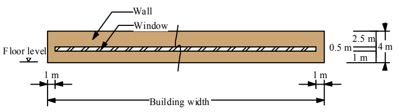
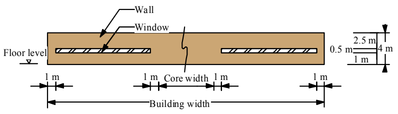
◆ A floor plan, a floor aspect ratio



Method

Annual energy simulation

◆ The ratio of window area to wall area

	Facade fenestration for office area	Facade fenestration for core side
Large window Window ratio = 0.38 - 0.42		
Medium window Window ratio = 0.18 - 0.21		
Small window Window ratio = 0.09 - 0.11		

◆ Reflective double window: U–value 2.73, SHGC: 0.5

Method

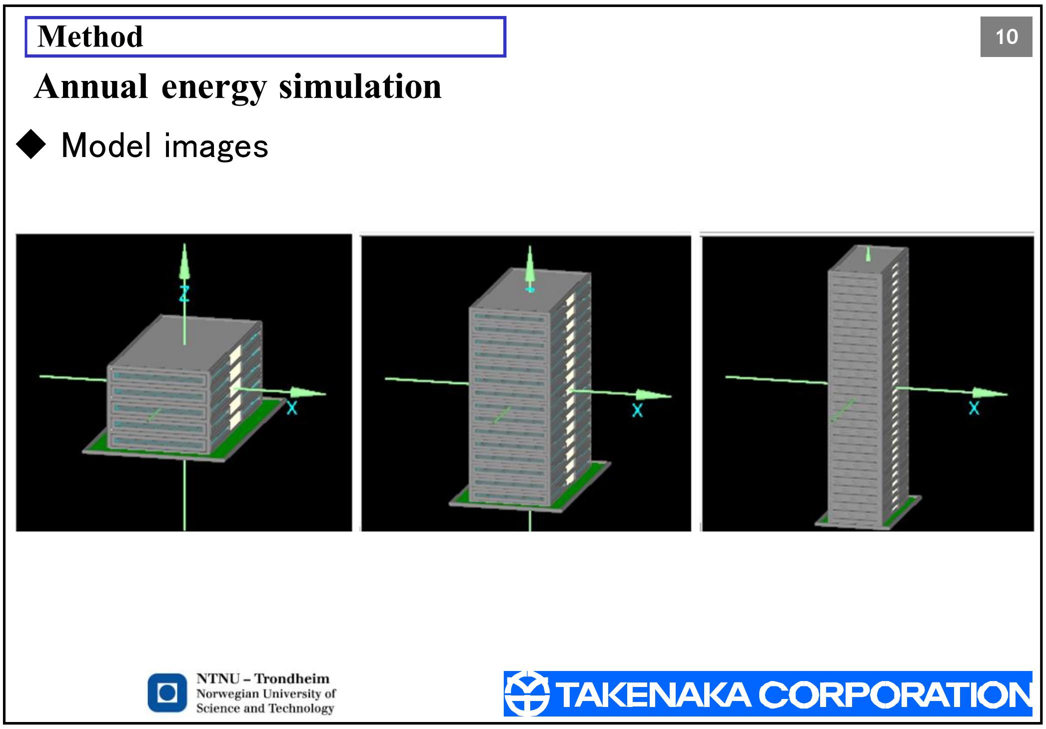
Annual energy simulation

◆ Inner loads, HVAC design for **office**

Indoor load		Weekdays		Weekends	Assumption
		09.00-17.00	17.00-21.00	09.00-17.00	
Occupant density	(person/m^2)	0.1	0.03	0.003	Adult sitting to work
Technical equipment	(W/m^2)	26	8	0.78	Lighting, computer, etc.

Indoor climate design			Assumption
Maximum temperature for cooling	(°C)	25	Constant value during 1year
Minimum temperature for heating	(°C)	22	Constant value during 1year
Maximum relative humidity for dehumidification	(% RH)	50	Constant value during 1year
Minimum humidity for humidification	(% RH)	60	Constant value during 1year
Mechanical ventilation	(m3/hr/m^2)	2.5	Natural ventilation is not assumed. Controlled with temperature.
Air change rate through infiltration	(1/hr)	0.1	—
Maximum concentration of carbon dioxide	(ppm)	1000	—

HVAC		Weekdays		Weekends	Assumption
		08.00-17.00	17.00-21.00	09.00-17.00	
Heating system, heating power	(kW/m^2)	0.110	0.036	0.110	All indoor area is heated or cooled. Time delay from zero to maximum heating power is not assumed.
Cooling system, cooling power	(kW/m^2)	0.140	0.046	0.140	
Mechanical ventilation	(m3/hr/m^2)	2.5	0.75	0.075	Efficiency of heat recovery 80%, moisture is 0%.



Method

Annual energy simulation

◆ Model images

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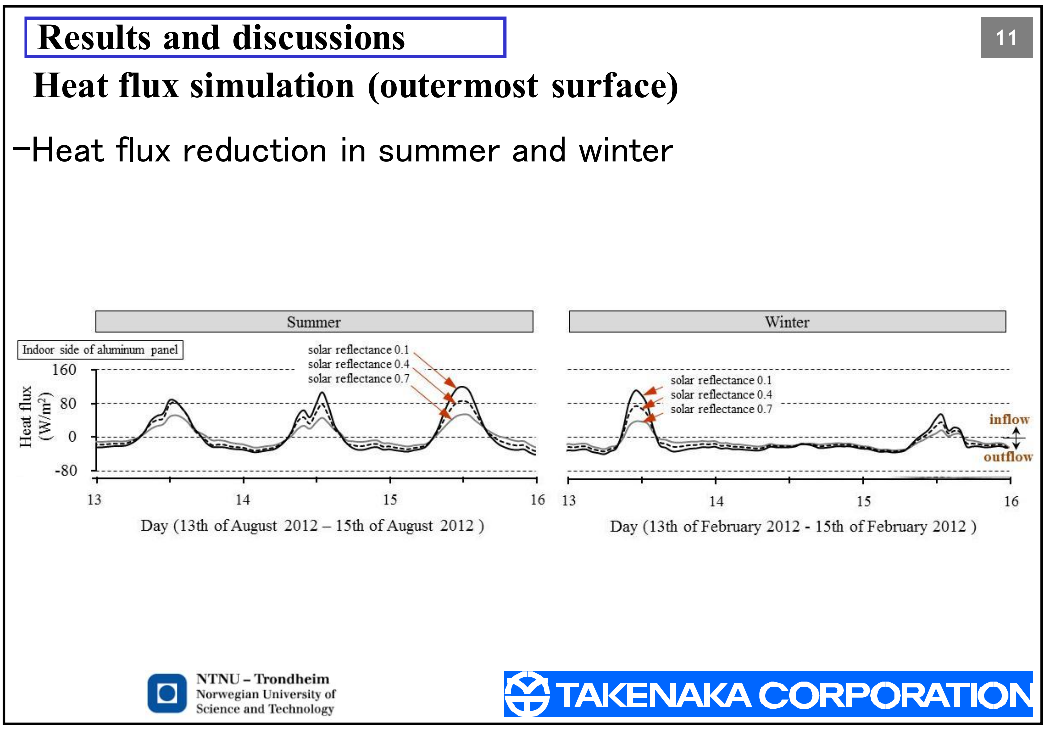

Results and discussions

Heat flux simulation (outermost surface)

–Heat flux reduction in summer and winter

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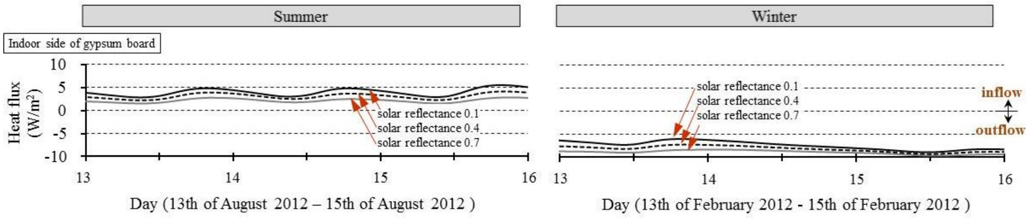
Results and discussions

Heat flux simulation (innermost surface)

–Heat flux magnitude is less

–Same phenomenon (heat flux up/down, summer/winter)



Results and discussions

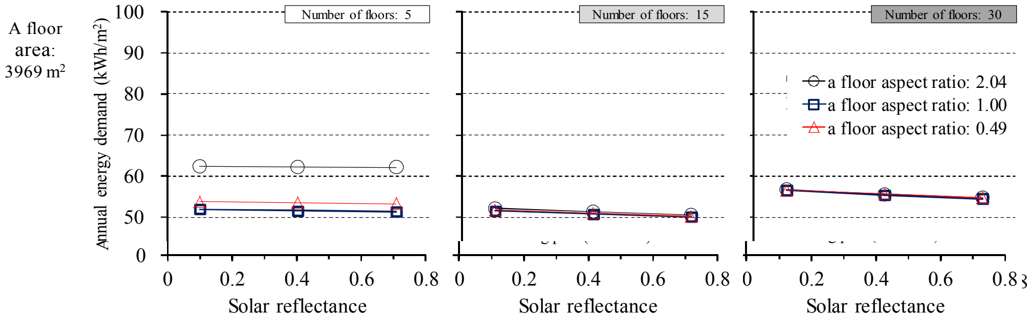
Annual energy simulations

–Similar results

–Less annual energy (decreased cooling ＞increased heating)

–Linear relationship

Window: Medium type fenetration



Results and discussions

Annual energy simulations

−When reflectance increased form 0.1 to 0.7 the annual energy was decreased.

for 5 floors: 0.3 – 2.9% down
15 floors: 1.8 – 5.1% down
30 floors: 1.8 – 6.1% down

−It was revealed that the wall area was larger, the annual energy was more affected by reflective facade.

Except for the modeled buildings, it is still unclear how the energy benefit is.

Multiple regression analysis

−The cooling energy is not able to be expressed as a polynomial expression with five variables.

−Window ratio strongly affected the cooling energy.

Dependent variable	Independent variable		Coefficient	t-value		R^2: Adjusted coefficient of determination
Cooling energy demand (kW/m^2/year)	An intercept	(-)	32.93	22.42	**	88% *
	The number of floors	(-)	0.54	15.86	**	
	A floor area	(m^2)	-0.0035	-11.14	**	
	A floor plan ratio	(-)	-0.20	-0.36		
	Window ratio	(-)	103.98	36.80	**	
	Solar reflectance	(-)	-3.34	-2.33	**	

** means p-value is less than 10%.
* means p-value is less than 5%.

Multiple regression analysis

−The heating energy is not able to be expressed as a polynomial expression with five variables.

−A floor plan ratio affected the heating demand.

Dependent variable	Independent variable	Coefficient	t-value	R^2: Adjusted coefficient of determination
Heating energy demand (kW/m^2/year)	An intercept (-)	13.51	10.19 **	53% *
	The number of floors (-)	-0.50	-16.10 **	
	A floor area (m^2)	-0.000082	-0.29	
	A floor plan ratio (-)	1.37	2.79 **	
	Window ratio (-)	-7.18	-2.82 **	
	Solar reflectance (-)	0.67	0.52	

** means p-value is less than 10%.
* means p-value is less than 5%.

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Multiple regression analysis

−The annual energy is expressed as a polynomial expression with five variables.

− Window ratio affected the annual energy demand.

Dependent variable	Independent variable	Coefficient	t-value	R^2: Adjusted coefficient of determination
Annual energy demand (kW/m^2/year)	An intercept (-)	46.44	33.58 **	86% *
	The number of floors (-)	0.045	1.41 **	
	A floor area (m^2)	-0.0036	-12.11 **	
	A floor plan ratio (-)	1.17	2.29 **	
	Window ratio (-)	96.80	36.38 **	
	Solar reflectance (-)	-2.67	-1.98 **	

** means p-value is less than 10%.
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Multiple regression analysis

–The decreased annual energy is the energy amount difference between reflectance (0.1) and another reflectance (0.4 or 0.7).

–Solar reflectance affected the decreased annual energy demand.

Dependent variable	Independent variable		Coefficient	t-value		R^2: Adjusted coefficient of determination
The decreased annual energy demand (kW/m^2/year)	An intercept	(-)	-0.31	-3.19	**	80% *
	The number of floors	(-)	0.030	13.09	**	
	A floor area	(m^2)	-0.00013	-6.16	**	
	A floor plan ratio	(-)	-0.010	-0.28		
	Window ratio	(-)	-0.44	-2.33	**	
	Solar reflectance	(-)	2.66	27.68	**	

** means p-value is less than 10%.
* means p-value is less than 5%.

Multiple regression analysis

◆ The annual energy demand was expressed by a polynomial.

–The Annual energy demand

$$E_{annual} = 0.045\,\mathrm{N} - 0.0036\mathrm{A} + 1.17R_{plan} + 96.80R_{window} - 2.67\rho + 46.44$$

–The Annual energy demand difference caused by reflectance difference

$$\varDelta E_{annual} = E_{annual,\rho=i} - E_{annual,\rho=j}$$

- The products difference impact
- The aged reflectance impact

◆ The designer can estimate energy benefit.

◆ Those functions are limited to the simulated conditions.

Conclusion

Though simulation work

① Heat flux could be controlled by solar reflectance.
② Annual energy could be also controlled by solar reflectance.
③ When solar reflectance is increased from 0.1 to 0.7, the annual energy is decreased by 0.3 – 6.1 %

Conclusion

Through analysis work

① A polynomial with five parameters is proposed to estimate energy benefit.
② It may be possible to create similar functions through the same procedure.

Further works

- Facade details variation (U-value, window properties･･･)
- Lighting energy
- Energy details (each floor, each direction･･･)

Additional information

◆ Another my message

– Highly reflective facade may be useful in Northern countries.

An office room (h=4 m)
with a exterior wall (7 x 4m, others: adiabatic)
with a window (3 x 2m)

No.	Scenarios					Results			Annual energy reduction (kW/m^2)
	Facade surface		U value		Wether data	Cooling energy (kW/m^2)	Heating energy (kW/m^2)	Annual energy (kW/m^2)	
	Emissivity	Reflectance	Wall	Window					
1	0.8	0.9	0.64	1.99	Tokyo, Japan	59.6	5.3	64.9	2.5
2		0.3				62.9	4.4	67.3	
3		0.9	0.14	1.00	Oslo, Norway	42.5	6.7	49.2	0.5
4		0.3				43.1	6.6	49.7	

Thank you for your attention!

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