DEVELOPMENT OF SELF-CLEANING TOP-COAT FOR COOL ROOF

Takeshi Sonoda[1], Yasushi Nakanishi[*1], Takahiro Hamamura[2], Hiroki Ueda[1], Taizo Aoyama[1], and Hideki Takebayashi[3]

1. Kaneka Corporation
Miyamae-cho 1-8, Takasago-cho
Takasago, Hyogo, JAPAN
* *yasushi_nakanishi@kn.kaneka.co.jp*

2. Kaneka Corporation
5-1-1 Torikai-nishi,
Settsu, Osaka, Japan

3. Kobe University
Rokkodai-cho 1-1, Nada-ku
Kobe, Hyogo, JAPAN

ABSTRACT

Our recent study has shown that the acrylic silicon polymer is useful to formulate self-cleaning topcoat which may maintain the thermal insulation effect of cool roof effectively.
A 2K self-cleaning topcoat was formulated with a water-borne type acrylic silicon polymer. Its effect to maintain high solar reflectance was confirmed by outdoor exposure test in comparison with coatings having no self-cleaning function. The solar reflectance performance was well maintained regardless of installation angle, lightness of colour or pigment type.
After outdoor exposure, drop of solar reflectance was found. It had clear correlation to change in lightness of colour for light coloured coatings. In the meantime, for dark coloured coatings, the above-mentioned correlation was relatively low. This suggests that the decline of solar reflectance was caused by dirt pick up rather than drop in the lightness of colour.
The decline of solar reflectance, that is supposed to be caused by dirt pickup, started just after installation and it was saturated in 3 to 6 months. After a 6-months exposure, the solar reflectance of the self-cleaning topcoat dropped by about 2% while the subject decline of non-self-cleaning topcoat was about 11%. A simulation study was also done to compare the electricity consumption for air conditioning, which showed that saving of electricity consumption could be 10% more with the self-cleaning topcoat.

KEYWORDS

self-cleaning, cool roof, acrylic silicon polymer, heat island, energy saving

1 INTRODUCTION

Cool Roof coating is drawing social attention worldwide, as one of solutions against “Heat Island” effect in urban area. However, it is pointed out that drop of solar reflectance of cool roof coating happens in rather short period after installation[1)]. Supposedly, the drop of the solar reflectance is due to dirt pickup.
Self-Cleaning paint is widely used for building wall coating, and effect to avoid dirt pick-up is proven. Acrylic silicon polymer is one of base resins which is useful to formulate self-cleaning paint.
In this paper, we will discuss effect of the self-cleaning technology to maintain the solar reflectance in cool roof coating application. The first part of the paper is discussing results of outdoor exposure using test specimens. The second part of the paper is discussing result of a real building installation test. In this test, temperature inside and outside of the building, electricity consumption for air conditioning, and roof surface heat balance were measured to prove effect of cool roof coating. And also, the measured data was used for simulation study of air conditioning energy saving effect based on cooling load calculation[2)].

2 EXPERIMENTS AND RESULTS

2.1 Outdoor exposure with test specimens

2.1.1 Experimental

2.1.1.1 Material

Water-borne 2K acrylic silicon polymer system was used as binder in self-cleaning paint. The binder consists of 2 parts. Part A contains base polymer emulsion with alkoxysilyl group. Part B contains hydrolysis/condensation catalyst and alkyl silicate (Table 1). Alkyl silicate is to form hydrophilic layer on the surface of the coating, and results in self-cleaning effect (Figure 1). Non-self-cleaning paint was formulated only with Part A.

To colour the paint, white and black pigments were used to formulate paints of white, black and grey of various lightness. 2 different types of titanium dioxide were chosen as white pigments.Wpg1 is large particle size type, which has average diameter around 1µm. Wpg2 is general type , of which has average diameter around 0.36µm.For black pigments, various types, BkPg1 – BkPg5, were chosen from commercially available products.

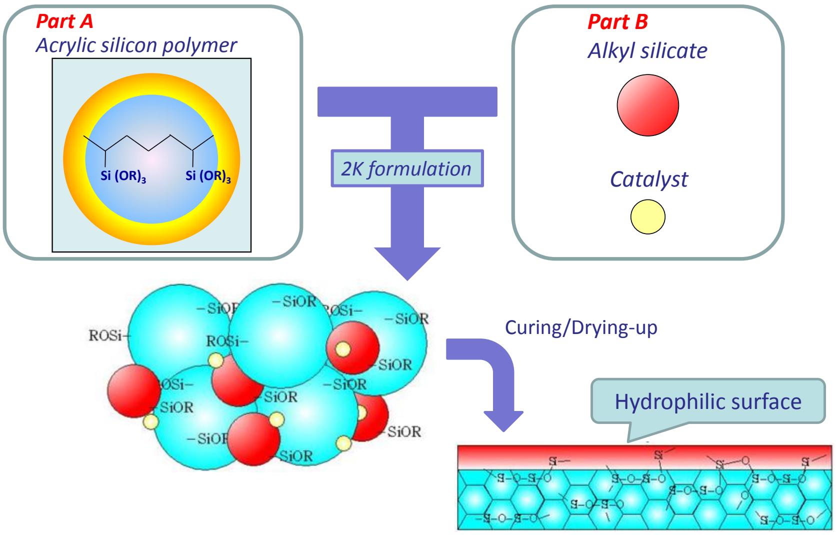

Figure 1: Image of the film-forming

. Table 1: Binder of test paint

	Part A	Part B
Main component	Acrylic silicon polymer	Alkyl silicate + Catalyst
Non-volatile content	ca. 50%	ca. 43%
Viscosity	ca. 200mPa･s	ca. 13mPa･s
pH	ca. 8	-
Minimum film formation temperature	ca. 40℃	-
Particle size	ca. 190nm	-
Surfactant	Anionic/Nonionic	-
Blend ratio	Part A : Part B = 6 : 1	

Table 2: pigments of test paint

Colour	Mark	Pigments	Concentration
White	WPg1	Titanium White (PW6) (large particle, 1µm)	100%
	WPg2	Titanium White (PW6) (general, 0.36µm)	100%
Black	BkPg1	Carbon Black (PBk6)	22%
	BkPg2	Paliogen Black (PBk31)	30%
	BkPg3	Bismuth Vanadate Yellow (PY184) / Quinacridone Violet (PV19) / Phthalocyanine Blue BGS (PB15:3) / Barium Sulfate(Synthetic) (PW21) mixture	29%
	BkPg4	Composite oxide pigment of copper and bismuth	60%

	BkPg5	Azo Methyne Black	30%

Colour Index Name is indicated in bracket.

2.1.1.2 Test paints formulation

Binder and pigments, which are mentioned above, are used to formulate test paints together with other additives. Black colour and white colour were formulated first. Then, various lightness of grey was formulated by mixing the black and white.

2.1.1.3 Test specimen

Epoxy based sealer and commercially available cool roof paint (white colour) were painted on anodic oxidized aluminium plate (70x150x0.8mm) to make base plate.

Test paints were applied on it, and cured for no shorter than 14days at room air temperature to come up with test specimen.

Photo 1: Exposure test

2.1.1.4 Outdoor exposure

All the specimens were situated at 3 different angles to horizon (0, 30, and 45degrees) facing to south in Settsu, Osaka, Japan.

In the course of the exposure test, lightness (L^*), and solar reflectance were measured periodically. The lightness was measured with Color Meter ZE2000 (Nippon Denshoku Industries). The solar reflectance was calculated with the method described on JIS K5602 (Determination of reflectance of solar radiation by paint film) based on spectral reflectance measure by Spectrophotometer SolidSpec-3700 (Shimadzu) in the wave length range of 300nm – 2500nm.

2.1.2 Results

2.1.2.1 Effect of exposure angle

Lightness and solar reflectance change after outdoor exposure were compared at different exposure angles (0, 30, and 45degrees). The comparison was made with white coloured coating. The results are shown on figure 2 and 3.

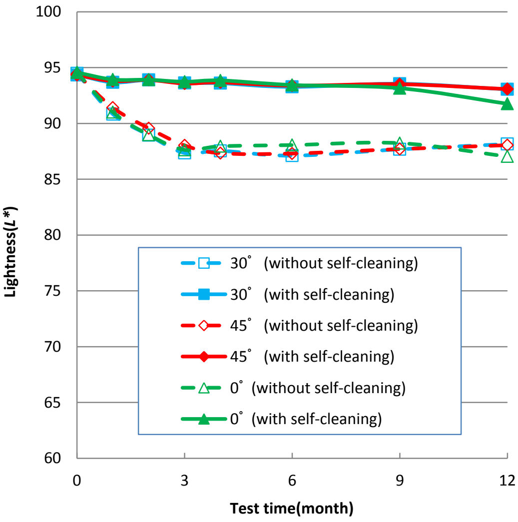

Figure 2: Effect of exposure angle on lightness (L^*)

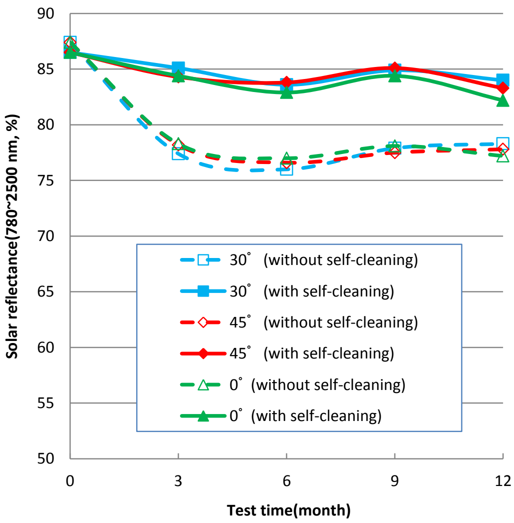

Figure 3: Effect of exposure angle on solar reflectance

No clear differences on both lightness and solar reflectance were found at different exposure angles. Self-cleaning paint maintained higher lightness and solar reflectance compared to non-self-cleaning paint.

For the case of non-self-cleaning paint both lightness and solar reflectance dropped in first 3-6 months to stay low after that.

2.1.2.2 Effect of lightness of the paint colour

In order to simulate effect of colour variation in cool roof paint, lightness and solar reflectance were compared with differently coloured specimens.

Test paints were formulated in black, white and 2 greys. The grey was adjusted to 70% and 50% lightness. White pigment was Wpg1 and black pigment was BkPg3.

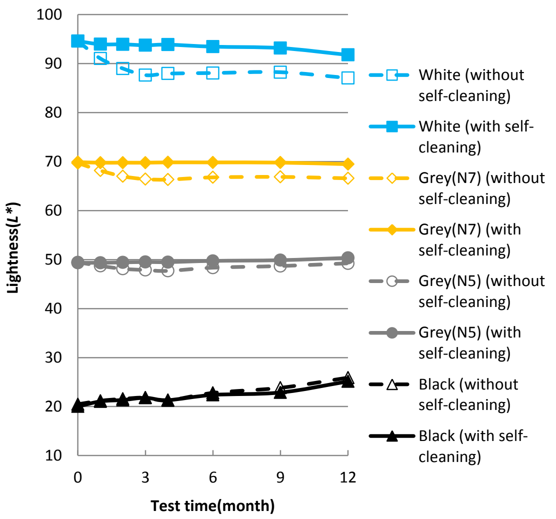

Figure 4: Effect of lightness of the paint colour on lightness (L^*)

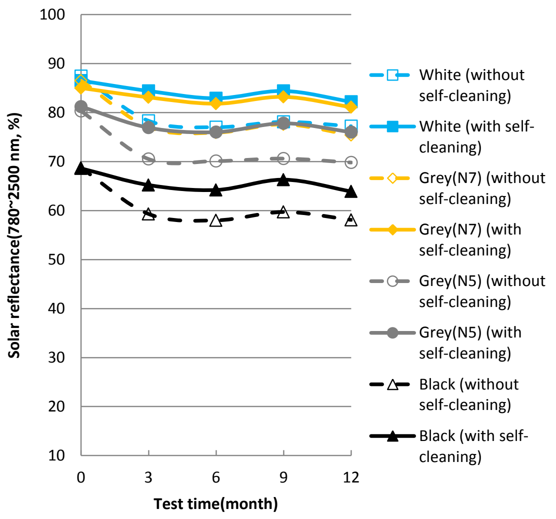

Figure 5: Effect of lightness of the paint colour on solar reflectance

On solar reflectance, effect of self-cleaning function was clearly seen even with black colour as much as white colour.

Contrary, on lightness, effect of self-cleaning function was only seen on brighter colour. The darker the colours, the less difference in lightness was found between with and without self-cleaning function. There was virtually no difference of the lightness for black coloured paint with and without self-cleaning function.

This results suggests that it is difficult to tell drop of solar reflectance by appearance for darker colours.

2.1.2.3 Effect of pigment

One of the most important aspects of cool roof paint is to maximize solar reflectance. In this aspect, choice of pigment is essential. In this section, we compared several pigments, which can be used for cool roof coating, in combination with self-cleaning technology.

Table 3: Effect of the solar reflectance(780~2500nm) by change of pigment

Mark	Colour	Self-cleaning function	Change of the solar reflectancereflectance (780~2500nm)					Change of the solar reflectance retention (780~2500nm)			
			Initial	3 months	6 months	9 months	1 year	3 months	6 months	9 months	1 year
WPg1	White	Without	87.4	78.3	77.0	78.1	77.2	90	88	89	88
		With	86.5	84.4	82.9	84.4	82.2	98	96	98	95
WPg2	White	With	85.2	82.1	81.6	82.5	80.6	96	96	97	95
	Grey(N7)	With	82.2	79.2	77.7	80.5	77.5	96	95	98	94
BkPg3	Black	Without	68.7	59.3	58.0	59.7	58.1	86	84	87	85
		With	68.6	65.1	64.2	66.3	63.9	95	94	97	93
	Grey(N7)	Without	86.5	77.0	75.9	77.6	75.4	89	88	90	87
		With	85.0	83.1	81.8	83.2	81.1	98	96	98	95
BkPg2	Black	With	72.3	69.1	67.8	68.3	66.8	96	94	94	92
	Grey(N7)	With	87.1	85.6	84.5	85.1	83.8	98	97	98	96
BkPg4	Black	With	54.7	51.3	50.0	51.5	49.5	94	91	94	90
	Grey(N7)	With	81.6	79.4	78.3	77.8	78.4	97	96	95	96
BkPg5	Black	With	72.1	68.8	67.8	70.0	67.9	95	94	97	94
	Grey(N7)	With	86.8	84.3	83.4	83.6	83.0	97	96	96	96
BkPg1	Black	With	4.1	4.5	4.4	4.4	4.7	110	107	107	115
	Grey(N7)	With	33.0	32.6	32.1	32.6	32.3	99	97	99	98

Table 4: Effect of the solar reflectance(300~2500nm) by change of pigment

Mark	Colour	Self-cleaning function	Change of the solar reflectancereflectance (300~2500nm)					Change of the solar reflectance retention (300~2500nm)			
			Initial	3 months	6 months	9 months	1 year	3 months	6 months	9 months	1 year
WPg1	White	Without	85.1	74.5	73.0	74.0	72.8	88	86	87	86
		With	84.9	82.8	81.5	82.4	79.9	98	96	97	94
WPg2	White	With	87.1	83.9	83.6	83.5	82.1	96	96	96	94
	Grey(N7)	With	63.1	61.1	60.2	61.5	60.1	97	95	97	95
BkPg3	Black	Without	34.4	30.3	29.8	30.5	29.9	88	87	89	87
		With	34.3	32.9	32.5	33.4	32.6	96	95	97	95
	Grey(N7)	Without	62.8	56.0	55.4	56.3	55.0	89	88	90	88
		With	62.5	61.2	60.5	61.4	60.0	98	97	98	96
BkPg2	Black	With	41.1	39.2	38.4	38.5	37.9	95	93	94	92
	Grey(N7)	With	67.4	66.4	65.7	66.2	65.5	99	97	98	97
BkPg4	Black	With	28.0	26.7	26.2	26.9	26.2	95	94	96	94
	Grey(N7)	With	60.9	62.4	63.0	63.1	64.2	102	103	104	105
BkPg5	Black	With	36.7	35.6	35.2	36.0	35.2	97	96	98	96
	Grey(N7)	With	64.8	65.5	66.0	66.4	67.0	101	102	102	103
BkPg1	Black	With	4.2	4.6	4.6	4.5	4.9	110	110	107	117
	Grey(N7)	With	30.2	29.9	29.6	29.9	29.7	99	98	99	98

Table 5: Effect of lightness(L^*) by change of pigment

Mark	Colour	Self-cleaning function	Change of Lightness(L^*)					Change of Lightness Difference(ΔL^*)			
			Initial	3 months	6 months	9 months	1 year	3 months	6 months	9 months	1 year
WPg1	White	Without	94.6	87.6	88.1	88.2	87.0	-6.9	-6.5	-6.3	-7.5
		With	94.6	93.7	93.4	93.2	91.8	-0.8	-1.1	-1.4	-2.8
WPg2	White	With	96.6	95.0	95.6	94.2	94.5	-1.6	-1.0	-2.4	-2.2
	Grey(N7)	With	72.6	71.9	72.1	71.5	71.9	-0.8	-0.5	-1.1	-0.7
BkPg3	Black	Without	20.5	21.8	22.8	23.7	25.9	1.4	2.3	3.3	5.4
		With	20.0	21.8	22.4	22.9	25.1	1.8	2.4	2.9	5.1
	Grey(N7)	Without	69.7	66.4	66.8	66.9	66.6	-3.3	-2.9	-2.8	-3.1
		With	69.9	69.8	69.8	69.8	69.5	-0.1	-0.1	-0.1	-0.4
BkPg2	Black	With	14.0	17.0	17.4	17.8	21.0	3.0	3.4	3.8	7.0
	Grey(N7)	With	71.1	71.1	71.3	71.1	71.4	0.0	0.3	0.1	0.3
BkPg4	Black	With	17.6	21.1	21.9	22.5	24.7	3.5	4.3	4.9	7.1
	Grey(N7)	With	70.6	74.3	75.9	75.9	77.0	3.8	5.3	5.3	6.4
BkPg5	Black	With	8.8	13.2	13.9	14.7	18.0	4.4	5.1	5.9	9.2
	Grey(N7)	With	68.2	71.4	73.1	73.1	74.9	3.2	4.9	4.9	6.7
BkPg1	Black	With	5.7	11.1	12.5	13.1	16.9	5.4	6.8	7.4	11.3
	Grey(N7)	With	57.5	57.5	57.7	57.7	57.8	0.0	0.2	0.2	0.4

As a result, it was found that self-cleaning paint kept 90% or higher solar reflectance retention after 1 year exposure, regardless of the pigment types.
One remark to be made is increase in lightness (L^*) for some pigments. All the black colour and some greys. Although there has not been precise investigation of cause of the colour change, decomposition of the pigments is suspected.

2.2 Experiments in the actual building

2.2.1 Objective material

Self-cleaning paint was formulated with 2K water borne acrylic silicon binder. 1K water borne acrylic silicon based paint, which does not have self-cleaning function, was chosen as a reference. Colour was white for both paints.

2.2.2 Outline of measurement

The measurement is being executed through 18th July 2012 and 30th September 2013 in Osaka, Japan. A cross-sectional schematic view of the roof is shown on figure 5. Data without cool roof paint was taken from 18th July to 7th Aug. 2012, then cool roof paint was applied on 8th Aug. 2012. Centre of the roof was remained un-painted, and self-cleaning and non-self-cleaning paint were applied on east side and west side of the roof.

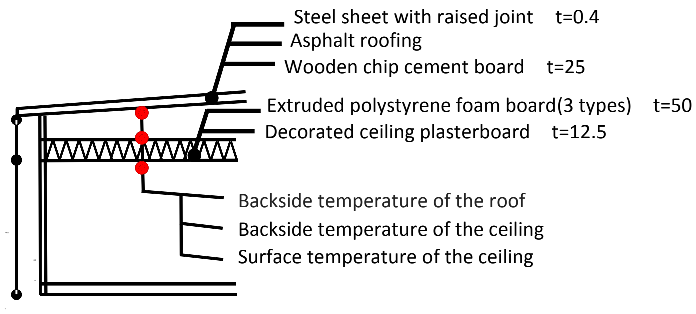

Figure 5: Cross-sectional structure of the roof and temperature measurement point

Solar reflectance measurement was done with 2 points correction method, in which black standard colour plate and white standard colour plate are used in order to remove the effect of ambient[3)]. Measurements were made at 7 positions on the roof, where self-cleaning paint (3 positions), non self-cleaning paint (3 positions), and no paint (1 position) were applied respectively. Colour measurement was also made at same positions using a handy type spectrophotometric color difference meter NF333 (Nippon Denshoku Industries).
On top of above, 3 net pyranometers and 3 infrared thermocouples were equipped to measure continuous measurement of solar reflectance and surface temperature. (Figure 6)
A sketch in the building is shown on the Figure 7. In the meeting room, air conditioner was running continuously setting point at 26°C. In the thermostatic room, air conditioner was running continuously set point at 23°C. In the office room, air conditioner was periodically running at 27°C. And there was no air conditioning in the storage room.

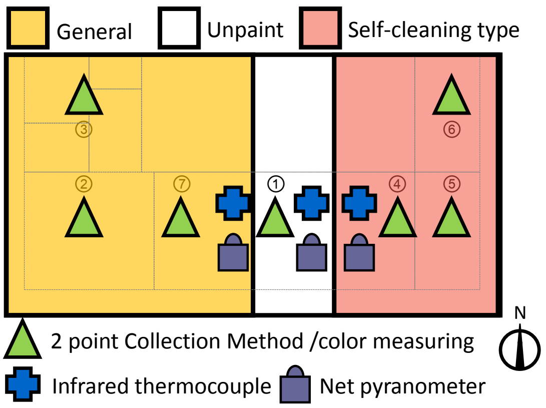

Figure 6: Measurement points on the roof

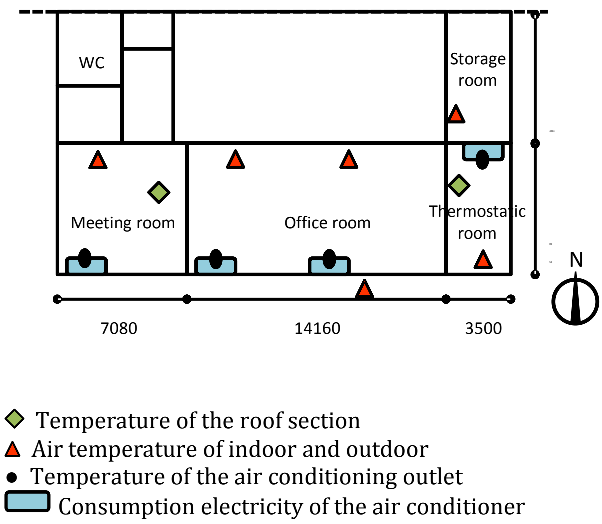

Figure 7: Measurement points in the room

2.2.3 Temporal change of solar reflectance and lightness

Change of solar reflectance with time is shown on figure 8. There are some differences according to the measurement position, however, in general, the value showed its maximum just after the paint application and gradually comes down.
Average values of solar reflectance and lightness are shown on figure 9. Average was made by measurement values from 3 positions each for self-cleaning paint and non-self-cleaning paint.
For self-cleaning paint, drop of solar reflectance in 6 months was 1.8% (82.9 → 81.1%), meanwhile it was 10.7% (84.7 → 74.0%) for non-self-cleaning paint. Besides it, lightness dropped 3.3 for self-cleaning, and 5.9 for non-self-cleaning. We suppose that the drop of the lightness is due to dirt pickup. Self-cleaning paint showed clear advantage over non-self-cleaning paint in maintenance of solar reflectance and lightness after exposure.

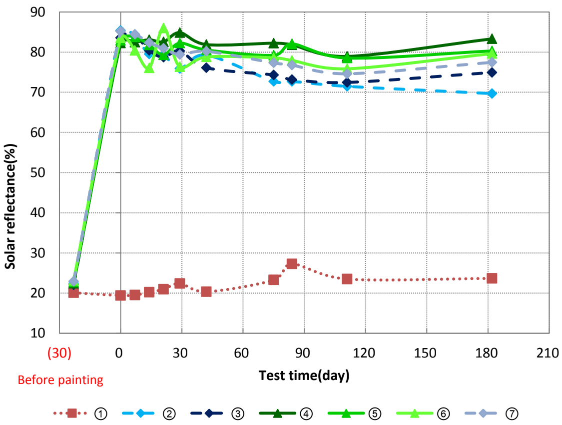

Figure 8: Temporal change of solar reflectance calculated by 2 points collection method

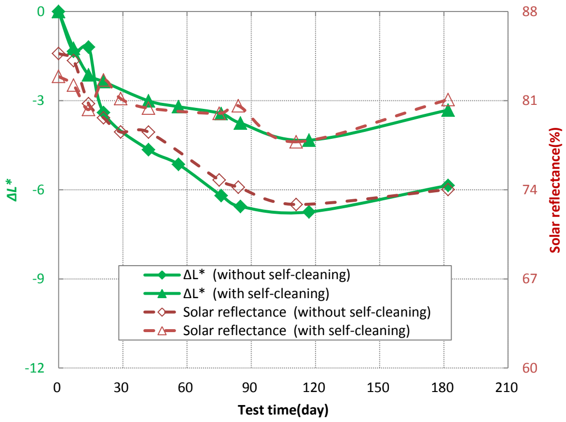

Figure 9: Temporal change of solar reflectance and lightness difference(ΔL^*) averaged in 3 measurement points

2.2.4 Room air temperature without air conditioner before and after painting

Air temperature trends in a day are compared before and after the cool roof coating installation. The comparison was made choosing typical sunny day with much solar radiation and cloudy day with less solar radiation. Outside air temperature and air temperature in the storage room (without air conditioning), before and after the cool roof paint, are shown on figure 10 and figure 11. 1-2°C drop of air temperature was observed after cool roof paint. Supposedly, it is due to decline of heat transmission by cool roof paint. It was also noticed that peak of room air temperature comes about 1hr after the peak of the outside air temperature.
The clear drop of the air temperature in the storage room and on the roof surface was only observed on fine days and not observed on cloudy days.

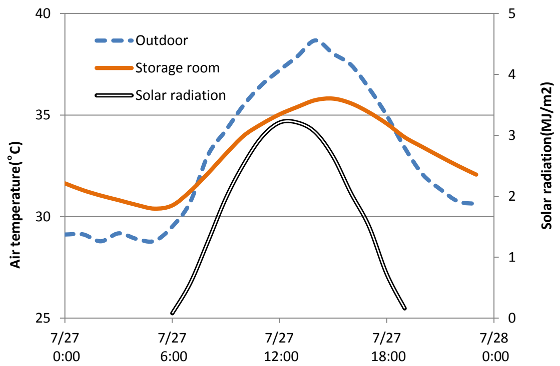

Figure 10: Room air temperature without air conditioner on sunny day **before painting**

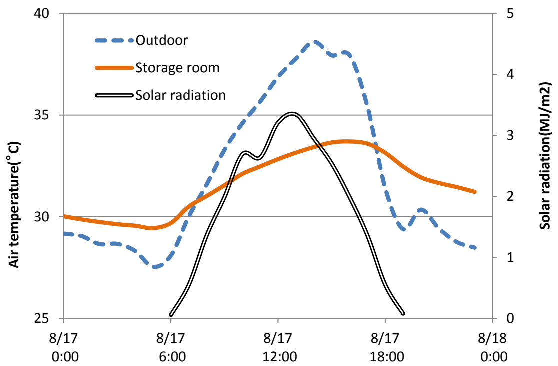

Figure 11: Room air temperature without air conditioner on sunny day **after painting**

2.2.5 Energy saving of air conditioner

In order to compare energy consumption before and after the cool roof coating installation, effect of several factors needs to be taken into account, i.e. heat of transmission, internal heat generation, temperature difference between inside and outside of the building. Because of this complexity, energy saving effect of cool roof paint was not so clear on raw data. In this section we'll discuss effect of cool roof coating on energy saving by separating effect of some factors.
Following equation is proposed to describe effect of factors on air conditioning energy consumption.

$$E = A \times I + B \times \Delta T + C$$

Here, E is a day accumulated air conditioning energy consumption (Wh/day), I is a day accumulated solar radiation (Wh/day), and ΔT is difference between outside air temperature and room air temperature a day average. A, B and C are constant coefficients which have correlation to solar radiation absorption (A), heat transmission (B), and internal heat generation (C). In this study E, I and ΔT are measured. We can assume that B and C stay unchanged before and after the cool roof paint installation.

Correlations between *E* and *ΔT* of the meeting room and the thermostatic room are shown on figure 12 and 13.

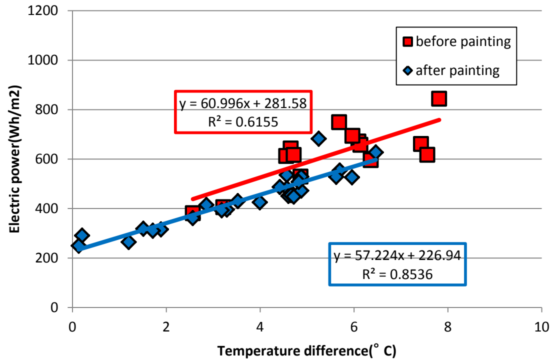

Figure 12: Relationship between daily integrated power consumption and daily averaged air temperature difference of meeting room and outdoor

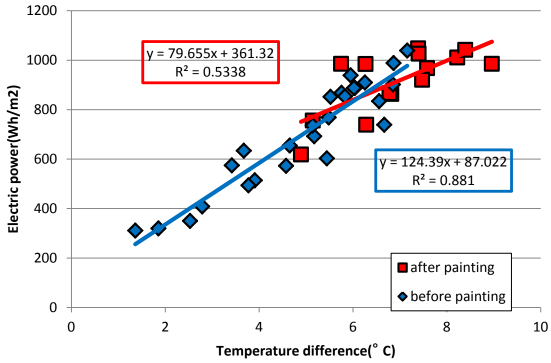

Figure 13: Relationship between daily integrated power consumption and daily averaged air temperature difference of thermostatic room and outdoor

We could see difference in energy consumption before and after the cool roof coating application in the meeting room, and we estimated the energy saving was 54.6 Wh/day/m^2. The slopes of the correlation lines (*B*) were close as assumed.

On the other hand, energy saving was not observed in the thermostatic room. It should be due to too low capacity of air conditioner in the room. It cannot maintain setting air temperature when too much load is applied. For example, data on 27th Jul. is shown on figure 14. The room air temperature went up to 25°C while setting point was 23°C. At the same time power consumption was saturating around 1100 Wh. For the reference, air conditioner's capacity was 1.13kW in the thermostatic room, and 3.31kW in the meeting room.

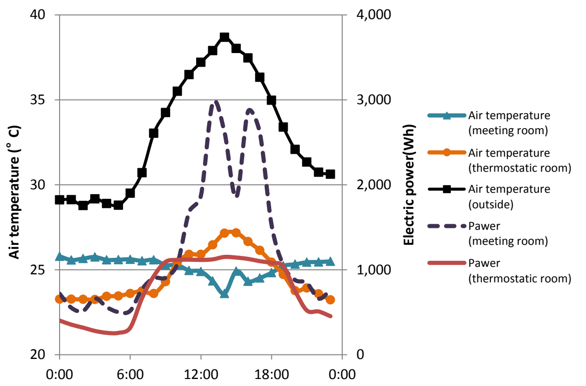

Figure 14: Air temperature and power consumption on sunny day before painting

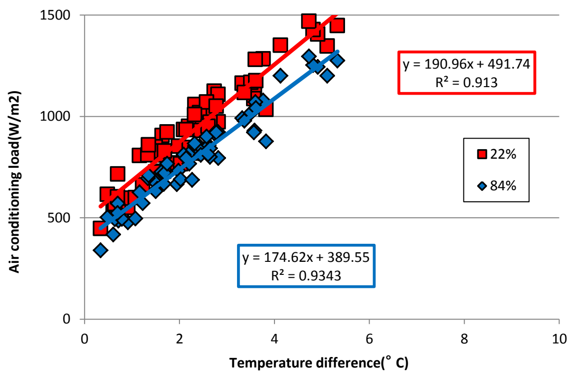

Figure 15: Relationship between daily integrated cooling load and daily averaged air temperature difference of meeting room and outdoor

2.3 Cooling load calculation

2.3.1 Outline of cooling load calculation

A cooling load calculation was carried out using computer software "SMASH". On the SMASH, a model of the building is built up with "room data", "position data" and "room relation data". Air conditioning load is calculated based on thermal circuit networks taking "area data" as boundary condition. We used average weather condition in Osaka as the "area data".

Solar reflection for the calculation was chosen based on actual measurement results. They are 22% for before painting, 84% for just after painting, 80% for self-cleaning coating after weathering, and 74% for non-self-cleaning coating after weathering.

2.3.2 Result of cooling load calculation

The calculation results for the meeting room is shown on figure 15, which compares before and after the cool roof coating installation. Energy saving effect of cool roof paint was estimated around 102.2 W/day/m^2. Energy saving effect after exposure drop was estimated 6.58 W/day/m^2 for self-cleaning coating and 16.41 W/day/m^2 for non-self-cleaning coating.

3 CONCLUSIONS

- Self-cleaning coating keeps higher solar reflectance after outdoor exposure when used for cool roof coating.
- The decline of solar reflectance, that is supposed to be caused by dirt pickup, started just after installation and it was saturated in 3 to 6 months.
- Maintenance of solar reflectance by self-cleaning function is good regardless of colour (lightness).
- It is not possible to judge visually the drop of solar reflectance of dark coloured coating.
- Drop of solar reflectance was also noticed on the coating applied on roof of actual building. It was confirmed that self-cleaning paint gives smaller drop of solar reflectance and lightness after weathering, and it resulted in slightly lower roof surface temperature.
- Temperature, electricity consumption and heat balance on the roof were measured and energy saving by the effect of cool-roof coating was estimated.
- Result of cooling load calculation was similar to the electricity consumption measurement, and also energy saving effect of self-cleaning paint over non self-cleaning paint was estimated.

4 REFERENCES

1)Daisuke Itoh, Hitoshi Takeda, Tetsuo Fujimoto, Yasushi Kondo, Yasunobu Ashie: Study on change of performance by outdoor exposure of reflective paints, *AIJ Journal of Technology and Design*. Vol.17, No. 35, pp.217-220, 2011

2) Chihiro Yamada, Hideki Takebayashi, Etsuko Ishii, Katsuo Miki: Study on the Introduction Effect of High Reflectance Paint -Part1 reduction of air conditioning load, *AIJ Journal of Summaries of Technical Papers of Annual Meeting*, D-1, 875-876, 2012

3) Yasutaka Murata, Koji Sakai, Hiroshi Kanamori, Hideki Takebayashi, Yoh Matsuo, Masakazu Moriyama, Atsumasa Nishioka, Naomichi Yano, Ryosaku Shimizu, Katsuo Miki, Toshikazu Murase, Hashem Akubari: a study on insolation reflectivity measurement of the cool painting surface : a proposal of measuring method by the 2 point correction and accuracy testing on the horizontal surface, *Journal of environmental engineering (Transaction of AIJ)*. Vol.73, No.632, pp.1209-1215, 2008-10-30