Actual performance of cool roof and cool facade

Tokyo Metropolitan University
Faculty of Urban Environmental Sciences
Division of Architecture and Urban Studies
Assistant Professor, Dr.Eng.

Masayuki Ichinose

ichinose@tmu.ac.jp

Abstract

The issue of global warming attracts attention worldwide, but rapid progress of the heat island phenomenon in the urban region also should be emphasized for human sustainability. Because cool roof is effective way to control the heat island phenomenon and the energy consumption despite its simple mechanism, cool roof have potential of realization of the sustainable city. However, performances of the cool roof products commercially available vary widely in actual condition regardless of desired performance, the appropriate evaluation method of actual performance is necessary.

At the beginning of this presentation, an observational study on the long-term performance evaluation of the high-reflectivity panel is presented. One set of test panels was coated with high-reflectivity paint on site or in-factory at the manufacturing stage by a newly developed heat curing paint method. Following environmental exposure, this heat curing paint method was evaluated for its long-term performance in thermal conditioning, and durability, as well as for possible performance enhancement with the addition of a photocatalyst.

In the next part, applicative study of the blocking solar radiation at the building facade so-called cool facade is discussed. The direct solar radiation irradiates mainly the roof top when low-rise buildings in the vast field are assumed. On the other hand, when the buildings in the modern urban region are studied, ratio of the building facade is increased. If cool facade is applied to urban region drastically, many considerable elements arise as compared to cool roof. These include balance of transparency and reflexivity, directional characteristics of reflection, harmonization of daylighting and solar shading, and so on. Perspective of comprehensive evaluation of the building facade is raised and discussed.

1. Long-term performance of "Cool panel" for cool envelope

Overview of Tests

Specifications of paint test specimens

Two types of paints were prepared in four colours (white, beige, grey and black): conventional paint and paint with augmented reflectivity in the near-infrared spectrum. The application and curing methods of panel painting included (1) in-factory; (2) in-factory with an additional photocatalyst coating; and (3) on site (at the testing site) (Table 1). The in-factory coated panels were mass-produced. The details of the panel coatings are as follows. The polymer binders are made of polyester. The pigments for conventional or high-reflectivity paint were: white colored with TiO_2 pigment (rutile), black colored with inorganic pigments (chrome-free pigment), and beige and grey colored with substances such as ferric oxide. Nanoparticles of the anatase phase of TiO_2 were used the photocatalyst. The pigment volume concentration had a specific gravity of 1.5, a resin to pigment ratio of 1:1, and a coating thickness of 20 μm for the primer, 30 μm for the heat shield, and several micrometers for the photocatalyst layer. The characteristics for applying the high-reflectivity coating included differences in cure temperature and time compared with that for conventional coatings. In addition, to prevent the breakdown of the organic layer, the photocatalytic coating included a pigment containing a primer and high-reflectivity component, as well as an inorganic barrier layer(Fig. 1).

Table1. Specimens for test

Color	Paint type	Application and curing method
White Beige Gray White	Conventional (Fluorine resin)	in factory
		in factory with Photocatalyst
	High-reflectivity	on site
		in factory
		in factory with Photocatalyst

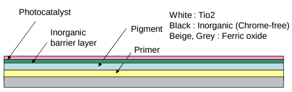

Figure1. Section of the high reflectivity with photocatalyst

Elements of measurement

The tests were carried out at a site in the suburbs of Tokyo, Japan, where the climate is moderate and wet. At the site, an inland university campus, a more focused test was carried out following the preliminary test to determine the most successful method for achieving performance in thermal conditioning and durability of painted panels.

As shown in Fig. 2, the test panels were placed on an unobstructed roof facing south at an angle of 20º to the horizontal. Each panels were 5-mm thick by 600-mm-squared and were covered with a 60-mm-thick heat insulation to eliminate any influence from heat transfer. The panel surfaces were smooth to minimize influence from air currents. Smaller samples (150 × 70 mm) were also prepared and placed on the same platform to observe spectral reflectivity.

The following parameters were continuously measured: ambient temperature and surface temperature by a T-CC thermocouple; solar irradiance by a pyranometer (EKO, MS802); long-wave irradiance by an infrared radiometer (CGR-3, Kipp & Zonen); wind velocity by a sonic anemometer (PGWS-100, Gill, England). The following parameters were intermittently measured: infrared images by an infrared camera (TH9100MV, NEC) and spectral reflectivity by a full-range spectroradiometer (ASD FieldSpec Pro JR). The long-term continuous measurements were taken at 1-min intervals. The infrared images were taken on days with typical, clear weather. The test panels were coated by heat curing in-factory or on-site with conventional or high-reflectivity paint in one of four colours (white, beige, grey and black) with or without the additional PC coating. To obtain a comparison of the effectiveness in long-term performance of not only high-reflectivity and conventional paint, but also among other types of paint, the methods of surface finishing were observed. Specimens were prepared in black and white to observe the effectiveness of the cleaning methods.

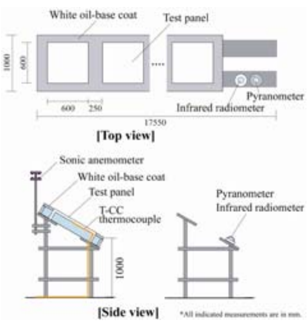

Figure2. Diagram of the test panel platform

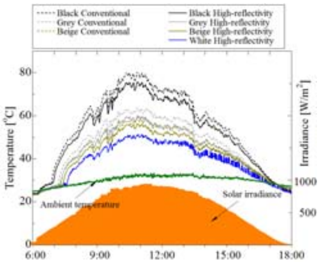

Figure3. Fluctuation of surface temperature of each test panel on day 20 with typical, clear weather.

Reflective performance relative to temperature and meteorological factors

Overview of reflectivity indicated by the theoretical relation

The test panels in decreasing order of surface temperature during a typical summer day were: conventional black, high-reflectivity black, conventional grey, high-reflectivity grey, conventional beige, high-reflectivity beige, and high-reflectivity white (Fig. 3). At peak temperatures, the surfaces were 20 – 50 K higher than ambient temperature. The temperature of conventional paint was 62 ºC, while high-reflectivity paint was 57 ºC. Therefore, high-reflectivity paint was effective at reducing the temperature of the panel.

Solar reflectivity was estimated by employing the specimen surface heat balance equation as follows,

$$\alpha_C(t_A - t_S) + \varepsilon_S \cdot R_L + (1-\rho) \cdot R_S - \varepsilon_S \cdot \sigma \cdot T_S^4 = 0 \qquad (1)$$

where t_A is ambient external temperature, t_S (T_S) is the surface temperature of the panel, R_L is the long-waveband irradiance on the panel, R_S is the solar irradiance on the panel, σ is Stefan-Boltzmann constant, α_C is the convective heat transfer coefficient of the panel, ε_S is the long-waveband emissivity of the panel, and ρ is solar reflectivity.

The value of the convective heat transfer coefficient predicted by Jurges' formula was fairly consistent with the same coefficient predicted using the static air temperature readings; therefore, the convective heat transfer coefficient could be back-calculated using Jurges' formula [7]. Long-wave radiation emissivity of each specimen was calculated inserting the radiant temperature observed by infrared images into the following equation,

$$\varepsilon_S \cdot \sigma \cdot T_S^4 + (1-\varepsilon_S) \cdot R_L = \sigma \cdot T_R^4 \qquad (2)$$

where T_R is surface radiant temperature of panel measured by infrared camera. From setting the panels up outside and then measuring with an infrared radiation camera and infrared radiometer, an emissivity of about 0.9 with minimal change over time was observed for all panels. Therefore, the value of emissivity used in Eq. (1) was set to 0.9. Thirty-minute means of temperature and meteorological data from stable meteorological periods were employed for solar reflectivity calculations. The time-based fluctuations in solar reflectivity that occurred during a typical summer day of white high-reflectivity paint (Fig. 4) indicated that stable, plausible values for reflectivity could be obtained on sunny days.

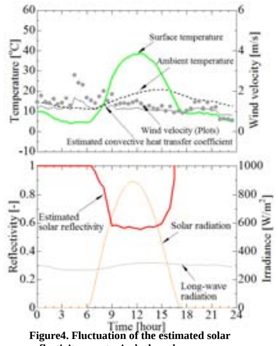

Figure4. Fluctuation of the estimated solar reflectivity on a typical, clear day

Tendency of long-term performance degradation

Figure 5 shows the long-term fluctuations observed in reflectivity. Reflectivity was calculated under the conditions described above; the mean values were used for the calculation at peak solar radiation (11:30 – 12:00). Reflectivity of black panels that dropped to zero and the larger change in reflectivity compared to that of white panels may be due to the Eq. (1) assumption that reflectivity divides the amount of reflected solar radiation. The white paint specimens in decreasing order of the initial solar reflectivity were: high-reflectivity (on site, 0.85), conventional (0.8), high-reflectivity with PC (0.7), and high-reflectivity (0.7). The intermediate coloured panels in decreasing order of the initial reflectivity were: high-reflectivity beige (0.6), conventional beige (0.5), high-reflectivity grey (0.5), and conventional grey (0.4). The difference of initial reflectivity between panels of the same colour may be due to differences in the mixture of pigments for each type of surface finishing. Here, we only focused on the decrease in reflectivity. The reflectivity values of white and intermediate coloured paints all decreased by about 0.15 within day 30 of exposure, and remained at this level of performance. Upon exposure, white high-reflectivity paint with PC showed no performance degradation with a similar level of performance as conventional white at day 15 and nearly the same level of performance as white high-reflectivity (on site) at day 30. On the other hand, reflectivity of black paint decreased by about 0.1 by day 30 of exposure.

These results indicate that performance degraded less for in-factory paint than on site paint and the addition of a photocatalyst suppresses this degradation, which implies that appropriate surface treatments provide long-term performance.

Changes caused by surface washing

The effect of washing the specimen surfaces on the degradation of reflectivity due to contamination factors was investigated. The washing process involved washing the specimens with a neutral cleanser and soft sponge to minimize damage to the coating while removing contamination. The coatings were dried after washing by pressing a cloth against them to remove water droplets. Figure 6 shows the fluctuation of solar reflectivity of the original reflectivity of panel (black bar), reflectivity after day 31 of exposure (white bar), and reflectivity after day 102 of exposure (grey bar); blue shading indicates the change in reflectivity before and after washing. After the specimens were washed on days 31 and 102 of exposure, reflectivity was restored to approximately the original level. Therefore, adhesion of contaminants after day 100 of exposure may be a major degradation factor of the coating.

Test results

A good correlation was seen between solar reflectivity estimated from the surface temperature of the paint specimens, meteorological observations and spectral reflectivity of the small paint specimens. This observation afforded an understanding of the continual variations in solar reflectivity. Thus, degradation in solar reflectivity of panel surfaces may be mainly due to contamination such as adhesion of airborne particles to the coating surface, as a particularly sharp reduction in solar reflectivity occurs after exposure of the panel surface to the first precipitation and therefore the first exposure to environmental contaminants. Panels with high-reflectivity paint were seen to lose 10 – 20% of their reflectivity within several months after exposure and the additional photocatalyst finish suppressed degradation more than the panels without it.

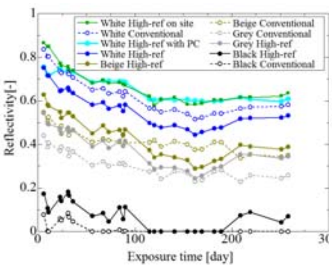

Figure5. Fluctuation of reflectivity estimated by surface temperature

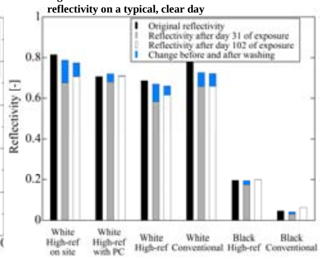

Figure6. Effects of washing on solar reflectivity

Test Conclusions

This study investigated painted panels exposed relative to actual long-term use to examine not only the effects of environmental factors, including precipitation and radiation on paint performance, but also influences of contamination. Our results reveal that the degradation of the paint surface cannot be neglected, and that this degradation is chiefly due to airborne contamination. This study also demonstrates that panels coated with high-reflectivity heat curing paint with a photocatalyst finish can preserve high reflectivity and therefore thermal conditioning effects longer than the conventional coating panels.

2. "Cool façade" An alternative for cities in hot climates

Where to paint?

Fig. 7 is a bird's-eye view of central Tokyo. Three-dimensional study was made using vector data from Google. Fig.8 is a solid body diagram drawn from infinity. i.e. it is a city as seen from the sun. It is color-coded so that, walls are blue, ground is yellow, and the roof is red. As this picture shows, for buildings that are not orderly positioned, a relatively large amount of sunlight is reaching the vertical wall surface.

Fig.9 shows the diagram of the building energy consumption and heat waste to the city. In Tokyo office buildings, even though energy conservation has progressed to some extent, air conditioning accounts for half of the total energy. In Tokyo, the status quo is that cooling is used even during winter when temperatures are relatively lower. Therefore, the cooling load in office buildings through the year can be reduced, by applying a solar shielding to whole of the building envelope. Furthermore, it is possible to reform the overall structure of inefficient cities, which is using energy to diffuse sunlight, which has high exergy, into the urban atmosphere. From these facts, adoption solar shielding to the building facade co-called cool facade can be one of the efficient alternative for hot climate city.

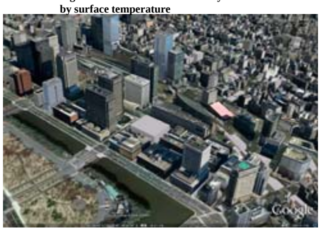

Figure7. 3D geometry of the center of Tokyo

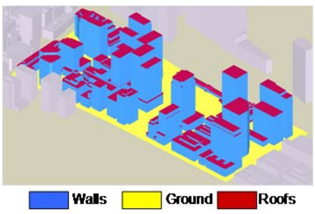

Figure8. solid body diagram drawn from infinity (it is a city as seen from the sun)

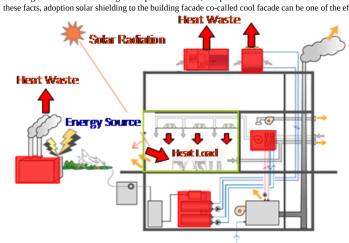

Figure9. Influence of the building on energy and environment

Performance of transparent and opaque facade

When discussing the adoption of high-ref paint to the facade, directivity of the reflection should be focused. Fig.10 shows the spectral reflectivity of high-ref paint, divided to diffuse and specular component. From this results, high-ref paint reflect Near-Infrared radiation diffusely.

On the other hand, for the transparent areas of the facade, reflection as well as transmissivity is an important point to focus on. As Fig.11 shows, by using Low-E glass with sputtering treatment or layered window film can be selectively enhanced compared to typical glass.

Influence on environment around the building

Measurement in the urban space

When we pursue solar shading and selective usage, which is beneficial for building energy and the indoor environment, reflection from the building walls onto the streets is created. In addition, when extreme spectral manipulations are carried out on building walls, exposure to a large amount of heat rays could occur, without being able to recognize it by the human eye.

Therefore, we measured whether such a phenomenon is occurring in practice, by using a Spectro radio meter. ASD's Field Spec Pro is used. This measurement used a technique, which combines a shield ball to extract the radiation from the building reflection(Fig.12).

Fig.13 shows the spectroscopic measurement of sunlight, when strong reflection from the two buildings to the streets was occurring. The reflection component from the facade is shown in orange. It is clear that the reflected sunlight from double-skin Low-E glass includes strong near-infrared energy that is not seen in natural sunlight.

What is the ideal cool façade?

The current composition of wavelength selection technology is as follows. Selective transmission of visible light that benefits the building interior, and NIR shielding required for the interior and exterior of the building is being performed. However, there is a side effect, which is the deterioration of the street environment. How far such a phenomenon is acceptable, for the purpose of energy conservation and for suppressing the heat island effect, may be a matter of debate.

Desirable function for cool façade is described as Fig.14. It would be very convenient, if wavelength selection and control of reflection direction were possible, as shown in this schematic. In terms of returning solar energy directly to the sky, it can have the same functionality as a cool roof.

A Japanese technology can achieve wavelength selection and directed reflection at the same time(Fig.15).

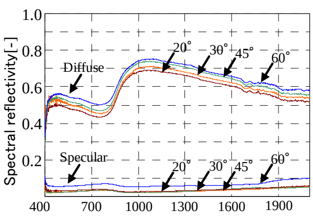

Figure10. Spectral reflectivity (diffuse and specular component) of the high-ref paint

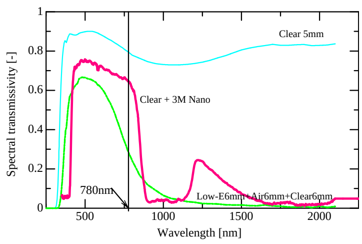

Figure11. Spectral transmissivity of typical glass

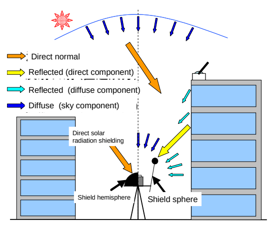

Figure12. Method for measuring solar radiation reflection off the facade

Comprehensive evaluation of the facade

Fig.16 shows comparison of the buildings with different type of facade. Using the most common transparent glass as a benchmark, film application, Low-E glass, double skin, and exterior shielding are evaluated. The three graphs are shown in MJ, but they cannot be combined. From left to right, we have primary energy associated with air conditioning and lighting equipment operations, sensible heat flux emitted into the atmosphere from the façade, and the amount of sunlight reflected from the facade to the street. In Tokyo, even though air conditioning is often used during the winter, some heating load is also produced. Therefore, Low-E-glass which has high-performance in both Solar shielding and insulation is excellent in terms of energy. From these results alone, it cannot be stated as to which is most appropriate for the outdoor street environment or suppression of the heat island, While a trade-off relationship can be seen, between energy consumption and environmental impact to the exterior; in comparison to other methods, methods such as external shielding and Recursive film can change this balance.

Conclusion

The effectiveness of Solar shielding technology for the Asia region, while considering the city geometry and the way the buildings are used, was presented. A perspective for optimizing the building interior and exterior together, in regard to the deployment of Solar shielding technology, using cool façade, was presented. There may still be some incomplete points, and I would appreciate your opinions

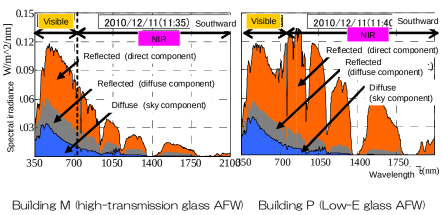

Figure13. Solar radiation reflection off the facade

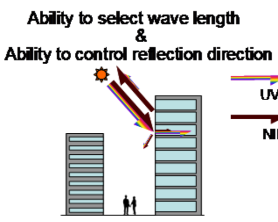

Figure14. Desirable performance of cool facade

Figure15. How Japanese technology realize ideal façade?

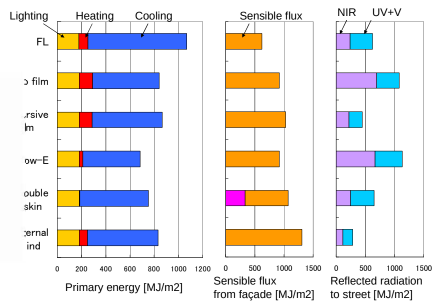

Figure16. Facade performance for the entire year