Evaluation of Solar Reflectance of Cool Materials by On-site Measurement and its Aged Deterioration

S. Kinoshita*, A. Yoshida and S. Kokawa, Osaka Prefecture University,
Sakai, Osaka, Japan,
****Corresponding author email: kinosita@me.osakafu-u.ac.jp***

ABSTRACT

As a strategy for easing the heat island phenomenon, the building exterior is constructed by the material with high solar reflectance and there is a technique for the decrease of the thermal load of the insolation origin and the thermal storage in the building frame. There is a method of covering with high reflectance paint as one of these techniques. The reflectance in the near infrared region is high compared with the general paint of the same color. Recently, the example of constructing this kind of paint increases. However, it is thought that the performance confirmation in the execution state and the establishment of technique for evaluating aged deterioration is necessary for a further spread promotion.

In this study, it is examined that a method for solar reflectance measurement of horizontal painting surface using white and black standard reference board whose performance is known, and this validity is confirmed. As analysis of the measurement error factor, the effect on solar reflectance measurements of the insolation is evaluated. The results are that measured solar reflectance tends to decrease as insolation decreases; and that solar reflectance is underestimated in the time of weak insolation. In both of cool paint surface and cool waterproof surface, the aged deterioration calms down in more than one year after execution, and the reflectance performance becomes stable. In addition, the solar reflectance can be restored to around the original value of execution by washing stain on the surface.

Introduction

In recent years, the heat island phenomenon that the air temperatures in urban area rise more than those in suburban area of the summer becomes a problem from the deterioration of the comfort, the influence on a healthy side and the energy consumption. As the strategy for easing the heat island phenomenon and the reduction in the air-conditioning load, the building exterior is constructed by the material with high solar reflectance and there is a technique for the decrease of the thermal load of the insolation origin and the thermal storage in the building frame. There is a method of covering with high reflectance paint as one of these techniques. The reflectance in the near infrared region is high compared with the general paint of the same color. Recently, the example of constructing this kind of paint increases. However, it is thought that the performance confirmation in the execution state and the establishment of technique for evaluating aged deterioration is necessary for a further spread promotion.

The reflection performance of painting materials is evaluated by multiplying the spectral solar reflectance, which is measured with spectrometer in the laboratory, with weighted factor based on a standard solar spectral distribution. The solar spectrum is different from the on-site spectrum. There is a lot of influence receiving from surroundings of the target area in the on-site measurement, and the device is necessary for the measurement.

In this study, it is examined that a method for solar reflectance measurement of horizontal painting surface using white and black board whose performance is known, and this validity is confirmed. This method is called the two point correction (Murata et. al., 2008). It is confirmed that it is suitable to use the spectral distribution of the global solar radiation at the time of the measurement. The influence of solar height is examined, and the recommended measurement condition is clarified. Field measurements are performed on the solar reflectance on-site for the high reflectance, that is cool paint and the cool waterproof sheet based on the above-mentioned results. The measurement accuracy and the aged deterioration are evaluated.

Measurement

Solar Reflectance

Solar reflectance ρ_{m} can be measured as the ratio of reflected solar radiation $S_{\uparrow}$ to global solar radiation $S_{\downarrow}$ when the object surface is sufficiently wide and uniform, as shown in the following equation.

$$\rho_{\mathrm{m}} = \frac{S_{\uparrow}}{S_{\downarrow}} \tag{1}$$

However, measuring surface is generally restricted area, and the measured value with the method includes the influence of insolation from surrounding surface. In order to eliminate the effect, the following measurement is performed. At first, global solar radiation $S_{\downarrow}$ and reflected solar radiation $S'_{\uparrow}$ are measured above the measuring area with net radiometer, which can measure four radiation components; solar radiation and infrared radiation from upper and lower side. Apparent reflectance $\rho_{\mathrm{m\text{-}app}}$ is given by calculating the ratio of $S'_{\uparrow}$ to $S_{\downarrow}$ same as eq. (1).

$$\rho_{\mathrm{m\text{-}app}} = \frac{S'_{\uparrow}}{S_{\downarrow}} \tag{2}$$

Next, standard reference board which is white or black board with known reflectance ρ_{s} is located under the net radiometer, and the apparent reflectance $\rho_{\mathrm{s\text{-}app}}$ in the condition is measured with global solar radiation $S_{\downarrow}$ and reflected solar radiation $S''_{\uparrow}$.

$$\rho_{\mathrm{s\text{-}app}} = \frac{S''_{\uparrow}}{S_{\downarrow}} \tag{3}$$

These apparent reflectances can be represented as following equations by using geometrical factor ϕ of the standard reference board from the view of the net radiometer on the assumption that all surfaces are perfect diffused reflection.

$$\rho_{\mathrm{m\text{-}app}} = \phi\rho_{\mathrm{m}} + (1-\phi)\rho_{\mathrm{other}} \tag{4}$$

$$\rho_{\mathrm{s\text{-}app}} = \phi\rho_{\mathrm{s}} + (1-\phi)\rho_{\mathrm{other}} \tag{5}$$

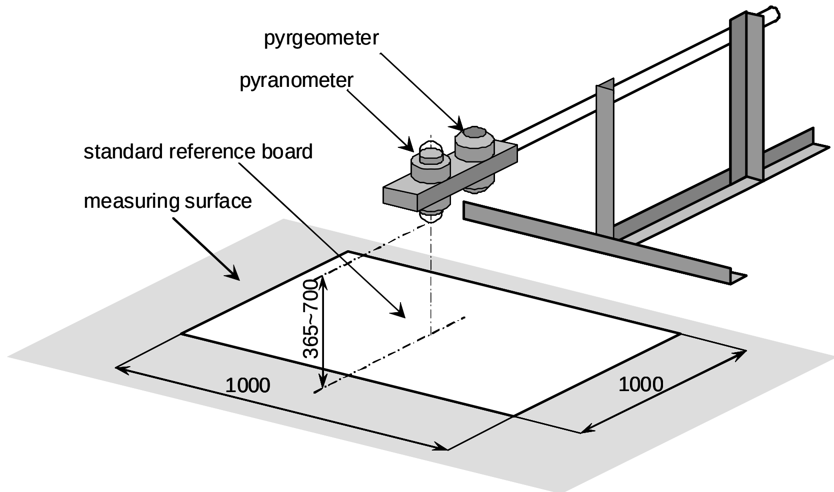

Figure 1. Measurement apparatus

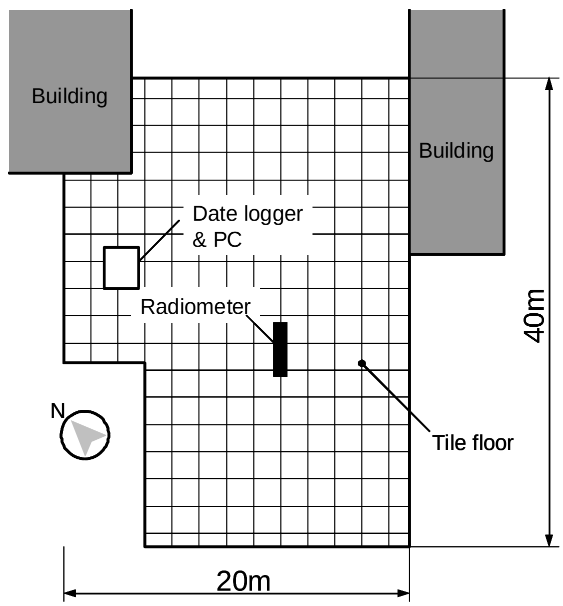

Figure 2. Schematic drawing of location of tile surface for measuring reflectivity

where $\rho_{\rm m}$; true reflectance of measuring area, $\rho_{\rm other}$; reflectance of surrounding area. The true reflectance of measuring area is calculated by eliminating the term of the influence of surrounding area with eqs. (4) and (5).

$$\rho_{\rm m} = \frac{\rho_{\rm m\text{-}app} - \rho_{\rm s\text{-}app}}{\phi} + \rho_{\rm s} \qquad (6)$$

Measuring Apparatus

Figure 1 shows the setting of measuring apparatus. Net radiometer has a pyranometer (wavelength range: 0.305 to 2.800μm) and a pyrgeometer (wavelength range: 5 to 50μm)

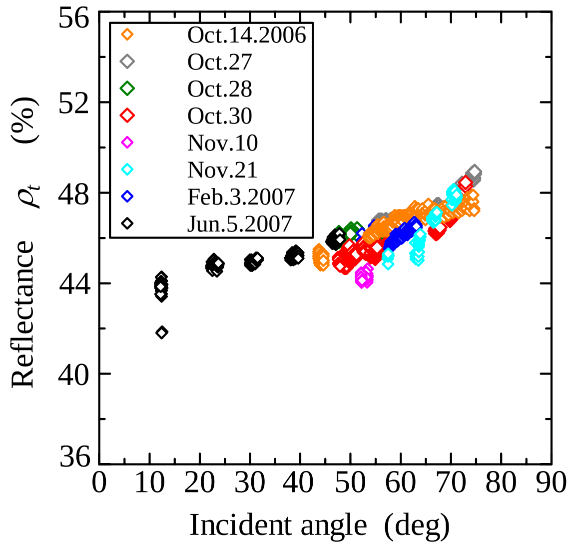

Figure 3. The influence of incident angle to reflectivity of tile surface

installed on upper and lower sides, and simultaneously measures global solar radiation and infrared atmospheric radiation from the sky and reflected solar radiation and infrared radiation from the ground. Standard reference board is used in two colors: white and black. Each reflectance based on JIS R 3106 (JISC. 2001) is 88.8% and 4.9%, respectively. The size is 100cm x 100cm. When the net radiometer is installed at 40cm height, the geometrical factor of standard reference board from the radiometer is 0.651. Data of radiations are measured in every 10 seconds for 5 to 10 minutes.

Measurement of Reflectance of Tile Surface

Reflectance of tile surface constructing on roof terrace in Osaka Prefecture University is measured in several times from October 2006 to June 2007. Figure 2 shows the shape of the terrace. As shown in the figure, net radiometer is located near the center of the terrace. It is considered that the tile surface is enough wide to be almost uniform. Consequently the reflectance of tile surface is not evaluated with calibration by use of standard reference board, but is evaluated according to eq. (1). Figure 3 shows the influence of incident angle of insolation to reflectance of tile surface. As shown in this figure, reflectance of the surface tends to be higher as the incident angle is larger, and the tendency is significant in the range over 50 degrees.

Measurement of Cool Painting Surface

Measuring Object and Conditions

Figure 4 shows a measuring object painted with several kind of cool paints, which is rooftop stage of a steel multi layer parking lot in Osaka city. Measuring solar reflectance is executed from 10 to 16 o'clock on August 6th in 2008. Color of all cool paints is uniformed in light blue. Measuring points are six areas with different cool paint in kind, and one area without painting. Symbols from I to VI in the figure corresponds to the painted surface with different kinds of cool paint, and a symbol of VII to non-painted surface. In the measuring condition, height of net radiometer from the surfaces is located at 36.5cm, and standard reference boards are two conditions: white and black. On the each cool paint surface, apparent reflectances in three conditions with white or black standard reference board and without one are measured rotationally, and the true reflectance is calculated by using these data. Measuring time for each apparent reflectance is about 5 min, and interval of data sampling for global and reflected solar

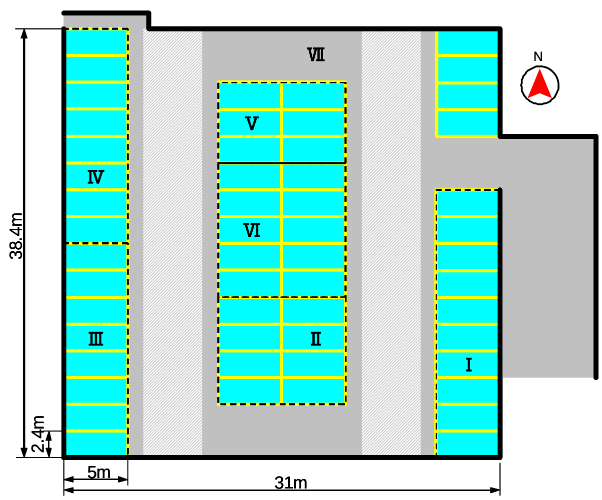

Figure 4. Schematic drawing of cool paint surface on rooftop stage of a parking lot and measuring areas

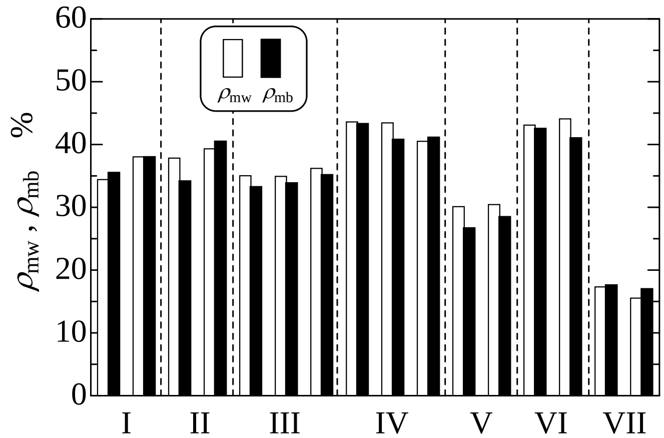

Figure 5. Measured solar reflectance of cool paints on parking lot

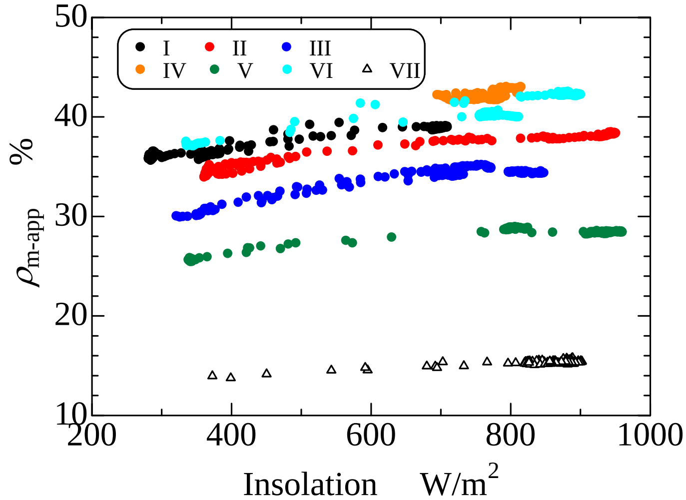

Figure 6. Effect of global insolation on instantaneous apparent solar reflectance

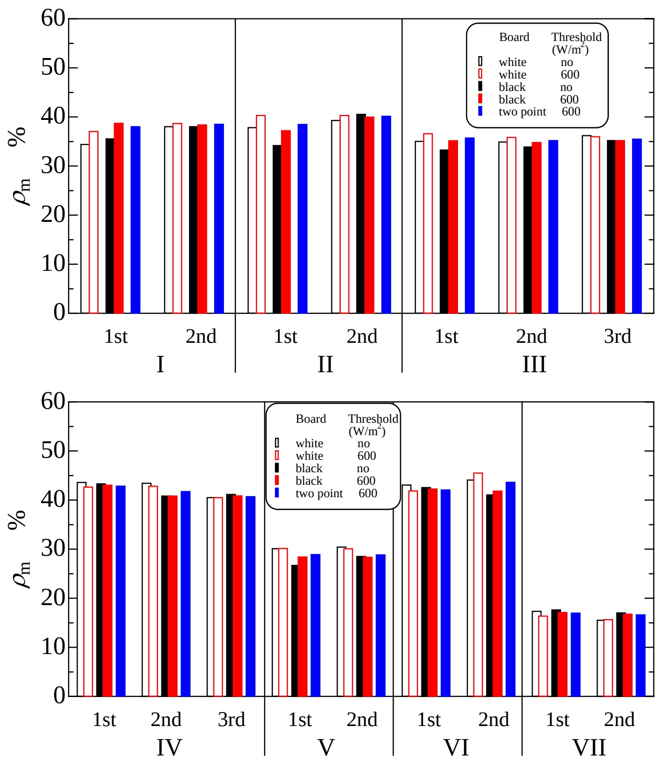

Figure 7. Effect of data selection with threshold of insolation on solar reflectance

radiation is 5 sec. Reflectance of III and IV are measured three times, and that of the others are twice during the measurement.

Results of Measurement and Evaluation of the Accuracy

Figure 5 shows the results of measurement of solar reflectances. In the figure, white and black bars correspond to reflectances measured with white and black standard reflectance boards,

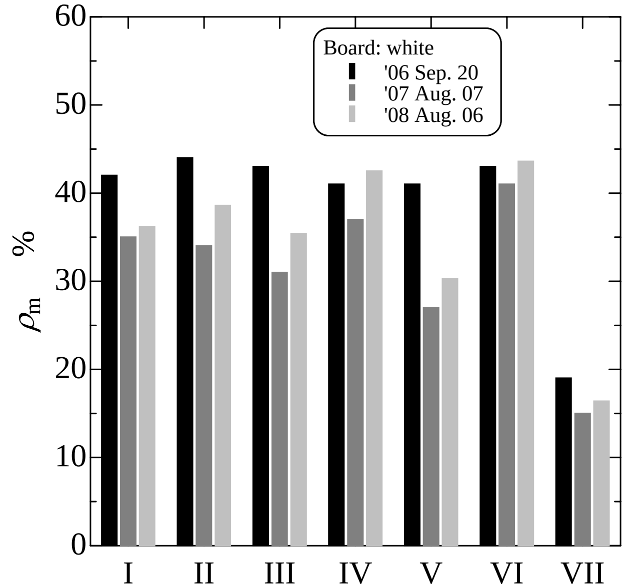

Figure 8. Aged deterioration of each cool paint surface

respectively. Solar reflectances of cool paint surface in IV and VI are relatively higher and are more than 40%. Those in I, II and III are about 35%, and that in V is about 30%. Solar reflectance of each cool paint surface is higher than that without cool paint, which is about 17%, and the effect of absorption control for solar radiation is confirmed in each cool paint surface. Difference of results between two color of standard reference boards is not so large. The maximum value is about 3% in II of the first measurement, and that in almost cases is about 1.5%.

Figure 6 shows the effect of global insolation on apparent solar reflectance without standard reference board, and is scatter plots of the instantaneous values. As shown in the figure, the solar reflectance tends to decrease as the insolation decreases, and the fact suggests that the reflectance is underestimated in the case of measuring in a period of weak insolation. Because it is desirable to measure in as uniform condition as possible, solar reflectance is evaluated with setting a threshold value on insolation and eliminating data under the threshold. Figure 7 shows the effect of the correction with threshold of insolation on measured solar reflectance. Threshold is generally set to $600W/m^2$, and is $500W/m^2$ in the case of no data over $600W/m^2$. As shown in this figure, it reveals that solar reflectances of several cool paint surfaces become higher by the data processing. In the figure, the results with two point correction (blue bar) are entered together. It reveals that the difference between methods of measurement is small.

Evaluation of Aged Deterioration

Similar measurements are also executed every one year, on September 20th in 2006 (near the time of painting) and August 7th in 2007. Figure 8 shows the past two times of results written jointly as the result in 2008. These results are evaluated with white standard reference board. The past two times of results are not processed with the correction with threshold of insolation. In the cool paint surface except IV and VI, aged deterioration is found between the results of 2006 and 2007. In paint V, about 20% decrease in solar reflectance is found. Performance deterioration of reflection in paint itself and stain including passage of vehicles and deposition of particulate matter are potential source of the aged deterioration. Compared between the results of 2007 and 2008, the change of solar reflectance during the period is smaller than that from 2006 to 2007. From these results, it is probable that the performance becomes stable.

Measurement of Cool Waterproof Sheet

Measuring Object and Conditions

Solar reflectance of waterproof sheet constructed on a building rooftop in Osaka city is measured on August 7th in 2008, and the similar measurements are executed on February 6th and August 9th in 2007. The first measurement of February 6th in 2007 is performed at the time after execution. Figure 9 shows the schematic drawing of waterproof sheet surface of a building rooftop and measuring areas. Measuring objects are two kinds of waterproof sheets: cool waterproof sheet with highly solar reflectance "Sheet1" and conventional waterproof sheet "Sheet2", and their reflectances are measured by use of two net radiometers. In the third measurement of August 7th in 2008, a square domain of one side 5m in the area of Sheet1, where is inside of dashed line in figure 9, is washed with neutral detergent in order to evaluate the effect of stain on performance deterioration, and the solar reflectance of the domain is also measured. Solar reflectances are evaluated with white and black standard reference boards. Reflectance is measured several times on each date, and is evaluated with averaging the data.

Results of Measurement and Evaluation of Aged Deterioration

Table 1 shows the measured results of solar reflectances of waterproof sheets in each

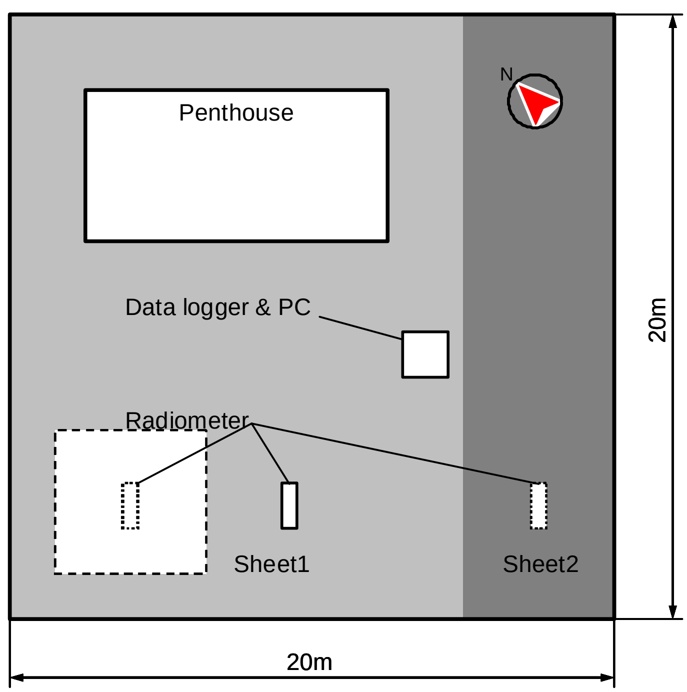

Figure 9. Schematic drawing of waterproof sheet surface of a building rooftop and measuring areas

Table 1. Solar reflectance of waterproof sheets in each measuring condition

Object	Method	Solar reflectance (%)		
		1st Feb. 6 2007	2nd Aug. 9 2007	3rd Aug. 7 2008
Sheet1 (unwashed)	White	59.8	44.9	42.1
	Black	59.1	43.4	43.7
	2 point correction	59.3	---	42.9
Sheet1 (washed)	White	---	---	54.0
	Black	---	---	55.2
Sheet2 (unwashed)	White	40.3	24.9	25.8
	Black	37.4	27.1	27.2

measuring condition. Evaluation with two point correction is applied to unwashed area of Sheet1 in the first and third measurement. Measurement on the washed area surface is performed in the last condition. As shown in the table, difference between evaluation methods is not so large; from 1 to 3%. Solar reflectance of Sheet1 is larger than that of Sheet2 in all measuring condition, and cool waterproof sheet maintains higher solar reflectance performance compared with conventional sheet. About aged deterioration, solar reflectance significantly decreases for a half year from execution, but it hardly changes in the next one year. The solar reflectance of Sheet1 is restored to around the original value of execution by washing. Thus, it is reasonable to suppose that the decrease of solar reflectance of waterproof sheet is caused by the effect of stain deposited on the surface. Similar aged deterioration is found in Sheet2.

Conclusions

In this study, it is examined that a method for solar reflectance measurement of horizontal surfaces painted with high reflectance paint and covered with cool waterproof sheet using white and black standard reference board whose reflectance is known, and the validity is clarified. Field measurements are performed on the solar reflectance on-site for the high reflectance materials which are the cool paint and the cool waterproof sheet. In addition, the aged deterioration of these materials is evaluated.

As analysis of the measurement error factor, the effect on solar reflectance measurements of the quantity of insolation is evaluated. The results are that measured solar reflectance tends to decrease as insolation decreases; and that solar reflectance is underestimated in the time of weak insolation. In both of cool paint surface and cool waterproof surface, the aged deterioration calms down in more than one year after execution, and the reflectance performance becomes stable. In addition, the solar reflectance can be restored to around the original value of execution by washing stain on the surface.

Acknowledgments

In performing this study, Daikin Industries, Ltd. which offered the standard reference boards and measured their reflectance and the people concerned who offered measurement places are sincerely acknowledged.

References

Murata, Y., Sakai, K., Kanamori, H., Takebayashi, H., Matsuo, Y., Moriyama, M., Yoshida A., Nishioka, M., Yano N., Shimizu, R., Miki, K., Murase, T., Akbari, H., 2008. “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 -” J. Environ. Eng., AIJ, Vol. 73, pp.1209-1216.

JISC (Japanese Industrial Standards Committee). 1998. “JIS R 3106: Testing method on transmittance, reflectance and emittance of flat glasses and evaluation of solar heat gain coefficient”.