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Comparative Study of In-situ Test and Laboratory Test on Material Reflectivity

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Abstract

This paper gives the theory algorithm of material reflectivity, and works out the in-situ material reflectivity combined with in-situ conditions, researches the influence rules of material's reflectivity under practical solar radiation intensity, and the feasibility of this simple in-situ test method is researched by the comparison of in-situ test result and laboratory test result.

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Keywords: Rreflective materials; Reflection; Solar radiation; In-situ

1. Introduction

Reflective materials have the optical properties of reflecting the incident light back along the incident direction [1-4]. So reflective materials can reduce the exterior surface temperature of buildings, relieve urban heat island effect, improve the indoor thermal environment, and reduce building energy consumption[5]. However, there is the spotty quality of the reflective materials quality and the wide difference for reflectivity especially in developing country such as China at present. Moreover, there are the few evaluation methods, the high cost, and expensive equipment for performance testing of reflective materials. The spectrophotometer method is the general material reflectivity testing method in the laboratory with a weighted average of the energy distribution of wavelength range for standard solar energy (air quality 2, sea level). Nevertheless, there must be a certain difference between the actual reflectivity and the laboratory result, due to the big difference of the altitude and air quality between in-situ and laboratory. Therefore, there is an urgent need to propose a simple and feasible material reflectivity testing method to gain the base data of material reflectivity more precisely.

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2. Methods

Firstly, the theoretical algorithm of integrated reflectivity is derived. In our study, the surface temperature and ambient temperature are tested continuously on the experiment model covered with reflective materials in situ and the integrated reflectivity of these materials is obtained with the derived theoretical algorithm under the actual solar radiation intensity. And then, the reflectivity for the different wavelengths is tested under the standard conditions in the laboratory and the average reflectivity is gained by the weighted computer. In the end, the feasibility of this simple in-situ test method is researched by the comparison of in-situ test result and laboratory test result.

3. Results

3.1 Theory Algorithm of Reflectivity

When calculating the heat transfer of opaque building envelope, the outdoor comprehensive temperature of building surface usually considered as a combination result of the influence of outdoor air temperature, solar radiation intensity, wind speed and absorption performance of the wall surface, etc. The calculation equation of the comprehensive temperature is as following:

$$t_e = t_w + \frac{\alpha I_t}{h_w} - \frac{\varepsilon \Delta R}{h_w} \tag{1}$$

where t_e is the measurement value of comprehensive temperature and t_w is the measurement value of outdoor air temperature, α is the solar absorption coefficient of building's exterior surface and I_t is the measurement value of total solar radiation intensity accepted by building's exterior surface, h_w is the convective heat transfer coefficient of building's exterior surface and ε is the long-wave radiation coefficient of building's exterior surface, △R is the long-wave radiant heat transfer between building's exterior surface, sky and surrounding objects. After setting up the equation (1), the reflectivity can be obtained by the following equation (2):

$$\rho = 1 - \alpha = 1 - \frac{h_w(t_e - t_w) + h_w(\varepsilon \Delta R / h_w)}{I_t} \tag{2}$$

where h_w is the convective heat transfer coefficient of building's exterior surface, in order to simplify the calculating, the value of h_w is set as 22 W/(m^2 K). △R is the the long-wave radiant heat transfer between building's exterior surface, sky and surrounding objects. While it's hard to work out △R in practical work, approximate method is often adopted as following: ①For vertical plane, △R=0； ②For horizontal plane, $\varepsilon \Delta R/h_w$=3.0~4.0°C.

3.2 Comprehensive In-situ Measurement

Combining the theory algorithm of reflectivity, for working out the comprehensive in-situ reflectivity at different time, under different solar radiation, and research the influence rules of material's reflectivity under practical solar radiation intensity, we make successive measurements of a building model, including the building model's surface temperature and environment temperature.

As shown in Fig. 1, the building model is covered by reflective materials, and the building model is built with the dimensions of 800mm×1000mm×1300mm (L×W×H), and the building envelope is made of 40mm-thick polystyrene foam board sandwiched by 0.5mm-thick stainless steel plate. Due to the thermal conductivity of stainless steel is about 100 w/(m K), the thermal conductivity of reflective material is about 20.6 W/(m K),and the thickness of reflective material is 1mm, so we think that the heat transfer resistance is only caused by polystyrene foam board, and the building model surface's temperature difference and internal space's temperature difference are only caused by the surface reflectivity's changes.

Fig. 1. The building model.

We test the total horizon solar radiation, atmospheric scattering radiation and light intensity by solar radiation observatory. And Fig. 2 shows the observations of total solar radiation and atmospheric scattering radiation on August 2. The solar radiation observatory records the atmospheric scattering radiation values every five minutes. The "section 1" in the Fig. 2 displays the atmospheric scattering radiation values; the red "section 2" displays the solar radiation values. We can see that the atmospheric scattering radiation values are equal to the solar radiation values at about 16:00, this is due to the effects of cloud covering.

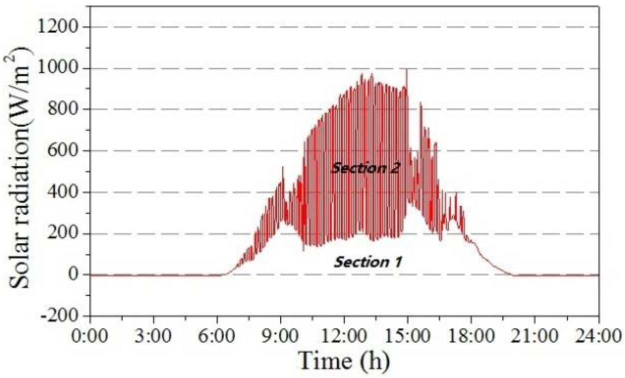

Fig. 2. The total horizon solar radiation and light intensity on August 2,2011.

We select the outer surface temperature of building model's top as the object to calculate reflectivity, the solar radiation intensity is the horizontal total radiation intensity of test points. And we assume that the absorbed heat by each building model's outer surface doesn't transfer heat to the interior space, but only causes the rise of the outer surface temperature. The Fig. 3 shows the hourly reflectivity from 10:00 to 18:00 in August 4-9, and the reflectivity values are under four different parameter conditions when $\varepsilon\Delta R/hw$ is taken as 3.5 °C, 3.7 °C, 3.8 °C and 4.0 °C respectively.

The four different-colour curves correspond to the four different long wave radiation heat exchange levels between building outer surfaces and surrounding objects. It can be seen from the Fig. 3 that the calculated reflectivity values are changing in 10:00-18:00, and the values are between 0.35 to 0.90, and the volatility don't relate to the weather conditions. The calculated reflectivity value is not only related to the surface temperature of building model, but also related to the outdoor dry-bulb temperature and horizontal total radiation, so the severe fluctuations of calculation result are due the cloud cover or the hysteresis response effect of outdoor air temperature on the changes of solar radiation intensity. From the above ,we can see that the actual reflectivity values of reflective materials are closely related to the atmosphere quality, altitude, solar radiation intensity etc.

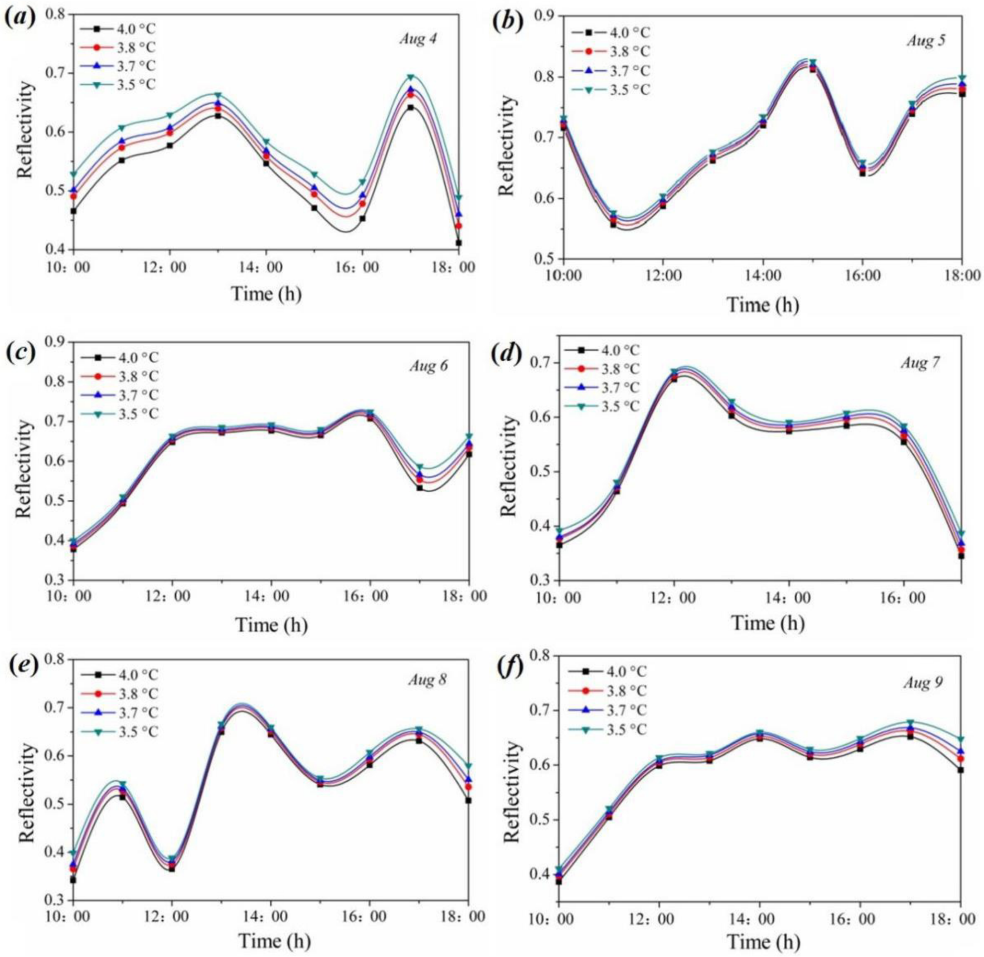

Fig. 3. The hourly reflectivity from 10:00 to 18:00 in (a)August 4; (b) August 5; (c) August 6; (d) August 7; (e) August 8; (f) August 9.

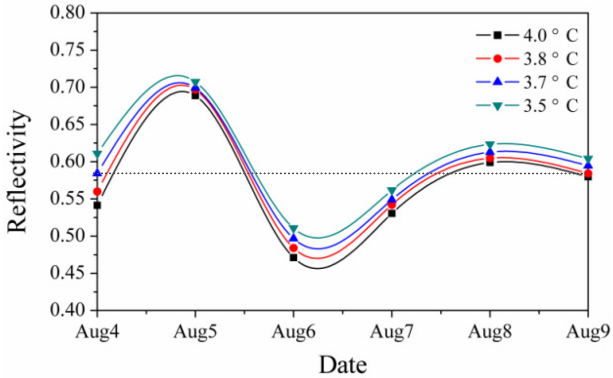

Fig. 4. The average reflectivity in August 4-9.

Fig. 4 shows the average reflectivity calculated by reflectivity theory algorithm from August 4 to August 9, and under four different ΔR levels. As can be seen, the daily average reflectivity difference is big, and from the geometrical fitting results, the average reflectivity value is 0.585 during the measurement period (August 4 to August 9).

3.3 The Laboratory Test on Material Reflectivity

Usually the optical test method is taken to test material reflectivity in the laboratory. In our laboratory tests, the test instrument is CARY 5000 ultraviolet-visible spectrophotometer produced by Varian Inc. Fig. 5 shows the magnification of reflective materials with the magnifying power of 180x, it can be clearly seen the uniform distribution of glass beads on the membrane material surface[6,7].

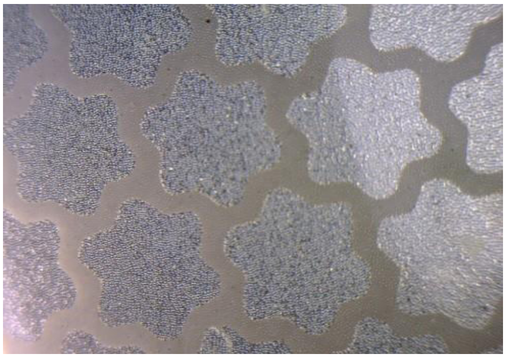

Fig. 5. The magnification of reflective Materials with the magnifying power of 180x.

In addition, Fig. 6 also gives the ground solar radiation energy distribution at the standard sea level with the secondary air quality. It can be found that reflective materials have the high reflectivity for the visible light and near-infrared layer, which has the highest percentage of solar radiation energy distribution, so reflective materials can reflect the solar radiation by the reasonable choice of reflectivity wave lengths and refine the thermal performance of prefab houses. And the comprehensive reflectivity of reflective materials can be gained as 0.543 by the weighted computation of the ground solar radiation energy distribution[8].

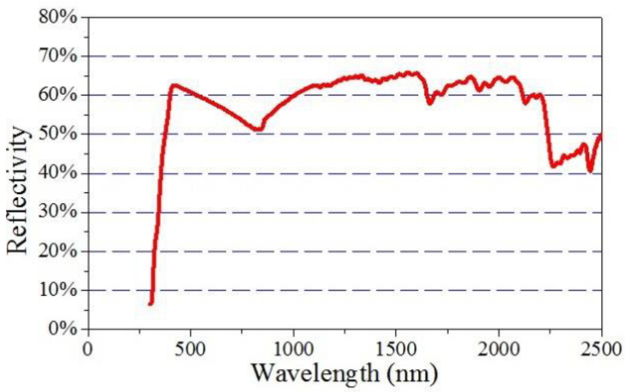

Fig. 6. The reflectivity of reflective materials.

The material reflectivity under different wavelengths can be obtained by spectrophotometer precisely. And then, we can get the intuitive reflectivity result after the weighted average calculation. The United States Material & Test Association made the flaky material solar reflectivity test standard--ASTME 424-71-424, the standard gave the formula of the flaky material solar reflectivity clearly as follows:

$$\sum_{350}^{1800} S_\lambda \cdot \Delta\lambda = 0.9756 \tag{3}$$

$$\rho_e = \frac{\int_{300}^{2500} S_\lambda \cdot \rho(\lambda) \cdot d_\lambda}{\int_{300}^{2500} S_\lambda \cdot d_\lambda} \approx \frac{\sum_{350}^{1800} S_\lambda \cdot \rho(\lambda) \cdot \Delta_\lambda}{\sum_{350}^{1800} S_\lambda \cdot \Delta_\lambda} \tag{4}$$

where $\rho(\lambda)$ is the material reflectivity measured by spectrophotometer and S_λ is the energy distribution of each wavelength under standard sunlight (air quality 2, sea level), λ *is the* wavelength and ρ_e is the average reflectivity of material.

Table 1. The energy distribution of each wavelength under standard sunlight (air quality 2, sea level)

λ (nm)	$S_\lambda \cdot \Delta\lambda$	λ (nm)	$S_\lambda \cdot \Delta\lambda$
350	0.0128	1100	0.0199
400	0.0353	1150	0.0145
450	0.0665	1200	0.0256
500	0.0813	1250	0.0247
550	0.0802	1300	0.0185
600	0.0788	1350	0.0026
650	0.0791	1400	0.0001
700	0.0694	1450	0.0016
750	0.0595	1500	0.0103
800	0.0566	1550	0.0148
850	0.0564	1600	0.0136
900	0.0303	1650	0.0118
950	0.0291	1700	0.0089
1000	0.0426	1750	0.0051
1050	0.0377	1800	0.0003

4. Conclusions

From the compare study of in-situ test and laboratory test on material reflectivity, we can see that the material reflectivity in in-situ test is 0.585; the material reflectivity in laboratory test is 0.543, the difference reaches 7.2% between the contrast of in-situ test and laboratory test on material reflectivity. The laboratory test with a weighted average of the energy distribution of wavelength range for standard solar energy (air quality 2, sea level), nevertheless, the in-situ test method is based on the in-situ conditions (atmosphere, altitude, solar radiation and illumination conditions etc. are different from the laboratory conditions). From the contrast, we can obviously see that the in-situ test method can reflect the actual situations better than the laboratory test method on testing material reflectivity. The simple in-situ test method proposed in this paper has a high reliability and is also a referenced new method for in-situ measurement of material reflectivity.

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