Reduction of Reflected Heat of the Sun
by Retroreflective Materials

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ABSTRACT

It is demonstrated that the walls made of retroreflective materials can reduce the reflected heat of the sun in the directions of neighboring roads and buildings. For mitigating the urban heat island effects, the applicable area of retroreflective materials is larger than that of high-reflective paints, because retroreflective materials can be used not only as "cool roofs" but also as "cool walls." Then, the solar retroreflectances of several retroreflective materials, which cannot be measured directly by a spectrophotometer, were measured for the first time. The procedures were as follows: First, the reflectance without retroreflection was measured by using a spectrophotometer with the integrating sphere. Then, the total reflectance was deduced from the amount of temperature rise by solar irradiation. Finally, the retroreflective component was calculated by subtracting the former from the latter. The measured retroreflectances are 20 to 30 percent for the prism-array type, about 20 percent for the capsule-lens type, and about 10 percent for the bead-embedded type.

Introduction

Making a building reflective reduces the amount of solar heat it absorbs. In closely packed building areas, however, heat reflected by one building can be absorbed by the other (Fig.1, Left). To prevent this opposite effect of high-reflective materials, we propose to use retroreflective materials to reduce the reflected heat (Fig.1, Right). In retroreflection the incident light is returned back in the direction of the source (i.e., the sun), with a very small spread in the light around this particular direction (CIE 2007).

Figure 1. High Reflective (Left) and Retroreflective (Right) Materials
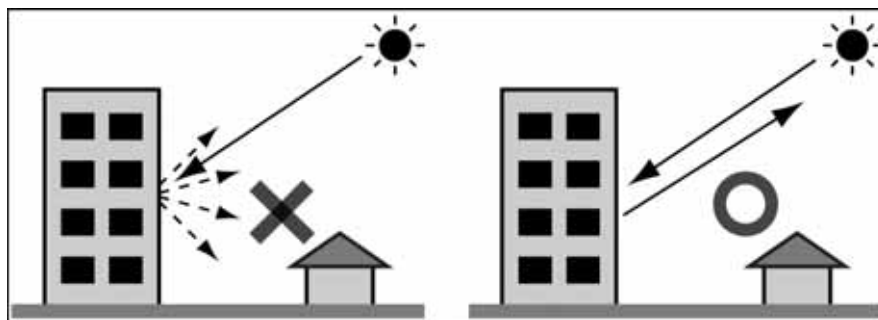
In principle, computer-controlled mirrors can also reflect sunlight upward and prevent the opposite effect in much the same way as retroreflective materials. However, mechanical moving parts are complicated and expensive, and need constant maintenance. Thus, it is a distant idea that we cover wide areas of the building exterior with these movable mirrors. In contrast, retroreflective materials have no moving parts, thus, no breakdown; they require little maintenance. This is a great advantage for building materials.

Retroreflective materials are now widely used as the road markings and signs to enhance night-time visibility (CIE 2007). Thus, they were already carefully evaluated with respect to visibility. From the viewpoint of heat transfer, however, their characteristics are unknown.

In this study, first of all, we showed experimentally that retroreflective materials reduce the heat generated by reflected sunlight. Then, we evaluated the solar reflective performance of several retroreflective materials for the first time.

Materials and Method

The experimental setup is shown in Fig.2. It is a miniature model of urban canopy consisting of an exterior wall of building, road, and the opposite building wall.

As the wall samples, three kinds of retroreflective sheets (two bead-embedded ones and a capsule-lens one), which were commercially available ones designed for traffic signs, were used. For comparison, used were four kinds of paints (high-reflective white, high-reflective gray, high-reflective black, and ordinary black) and two kinds of metallic surfaces (Galvalume and glossy aluminum). All of the samples were 75 by 70 mm in size, and were heat insulated by attaching the polystyrene foam with the thickness 60 mm on their back side.

As shown in Fig.2, each wall sample was placed vertically in the incubator maintained at temperature $T_{surrounding} = 25$ degrees centigrade, and was irradiated from above with the 60-watt infrared heat lamp (artificial sunlight E) at the incident angle of 45 degrees.

Figure 2. Experimental Setup (Miniature Model of Urban Canopy)
E: Irradiation Energy of Lamp, R_{Spe}: Specular Reflectance,
R_{Dif}: Diffuse Reflectance, R_{Ret}: Retroreflectance
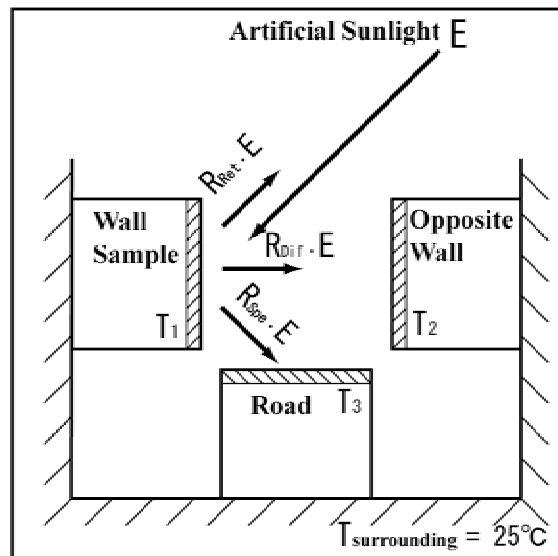
During irradiation, the sample surface temperature (T_1), the opposite wall temperature (T_2), and the road temperature (T_3) were monitored with the type T thermocouples. The lamp was continued to irradiate until these temperatures were stabilized. (It took about 40 minutes.)

The amount of rise in temperature depends on the reflectance characteristic of sample. That is, the higher the total reflectance (R_{Tot}) of sample, the lower the sample surface temperature (T_1). The higher the diffuse reflectance (R_{Dif}) of sample, the higher the opposite wall temperature (T_2). The higher the specular reflectance (R_{Spe}) of sample, the higher the road temperature (T_3). That is to say, the amount of reflected heat in each direction can be estimated by monitoring these temperatures.

Results and Discussions

The amounts of rise in temperature by 40-minute irradiation are shown in Table 1. The values of reflectance R_{Spe} and R_{Dif} of samples are also shown in the 5th column of Table 1; these values were obtained by using a spectrophotometer with the integrating sphere (RTC-060-SF, Labsphere, Inc.) at the incident angle of 45 degrees (Storm 1998).

For four paint samples, as expected, the amount of temperature rise of wall sample (ΔT_1) increased with decreasing sample reflectance. The value of ΔT_1 of high-reflective white paint, which has the highest reflectance, is smallest ($\Delta T_1 = 3.5$ K), and that of ordinary black paint, which has the lowest reflectance, is highest ($\Delta T_1 = 8.0$ K). This demonstrates that making a building reflective reduces the amount of solar heat it absorbs. In contrast, the amount of temperature rise of opposite wall (ΔT_2) and that of road (ΔT_3) decreased with decreasing sample reflectance. The values of ΔT_2 and ΔT_3 of ordinary black paint are smaller than those of high-reflective paints. This shows the opposite effect of high-reflective paints; that is, heat reflected by one building is absorbed by the other.

For two metallic samples, the values of ΔT_1 are similar or smaller than those of high-reflective paint samples, as is expected from their high reflectance. However, the values of ΔT_3 of metallic samples are larger than those of paint samples. These were caused by the intensive specular reflection of metallic surfaces. Thus, a metallic surface is good for keeping itself cool under the burning sun, like a high-reflective paint. However, its reflected heat is focused in one place (specular reflection geometry).

Table 1 Experimental Result:
The Amounts of Rise in Temperature by 40-minute Irradiation

Samples	Sample ΔT_1 [K]	Opposite ΔT_2 [K]	Road ΔT_3 [K]	Reflectance $R_{Spe} + R_{Dif}$ [%]
1: high-reflective white paint	3.5	2.7	2.6	79.5
2: high-reflective gray paint	3.7	2.7	2.6	71.1
3: high-reflective black paint	4.4	2.5	2.4	61.9
4: ordinary black paint	8.0	1.9	1.9	3.3
5: Galvalume sheet	3.6	2.6	3.3	72.6
6: Aluminum sheet (glossy)	2.3	2.5	5.4	84.0
7: retroreflective 1 (bead-embedded)	3.2	2.3	2.1	66.8
8: retroreflective 2 (bead-embedded)	3.4	2.4	2.5	69.0
9: retroreflective 3 (capsule-lens)	3.6	2.2	2.6	53.3

For three retroreflective samples, their amounts of temperature rise ΔT_1 are a bit smaller than expected from their reflectances R. For example, the value of reflectance of retroreflective sheet 1 (No.7), R = 66.8 percent, is lower than that of high-reflective gray paint (No.2), R = 71.1 percent. However, the value of ΔT_1 = 3.2 K, is smaller than that of No.2, ΔT_1 = 3.7 K. This may seem strange at the first glance, but there is no inconsistency. The point is that the retroreflectance cannot be measured by the integrating sphere measurement, because the retroreflected light escapes through the hole for the incident light (Fig.3). The actual (i.e., total) reflectance of three retroreflective samples should be higher than the measured reflectances shown in Table 1 by the amount of retroreflectance. In fact, when the retroreflective materials were used as samples, not only its surface temperature (ΔT_1), but also opposite wall (ΔT_2) and road (ΔT_3) temperatures were kept low as compared to other high-reflective samples. The reflected heats were "disappeared." (Actually, they were returned back in the direction of the light source as depicted in Fig.1, Right.)

For mitigating the urban heat island effects, the high-reflective paints are usually used as cool roof materials. They are not used as exterior walls, because the reflected heats from them are absorbed by surroundings. However, the retroreflective materials can be used not only as cool roofs but also as cool walls. Therefore, the applicable area of retroreflective materials is larger than that of high-reflective paints.

Figure 3. Geometry of Integrating Sphere Measurement

Retroreflectance Measurement

Finally, we will examine how to measure the retroreflectane of samples. As pointed out above, retroreflectance cannot be measured by using a spectrophotometer with the integrating sphere, because the retroreflected light escapes through the hole for the incident light (Fig.3).

Therefore, we propose the procedures as follows: First, the reflectances without retroreflection, R_{Spe} and R_{Dif}, are measured by the integrating sphere measurement (CIE 2004). Next, the total reflectance, R_{Tot}, is deduced from the amount of temperature rise by irradiation. Here, the total reflectance of sample R_{Tot} is,

$$R_{Tot} = R_{Spe} + R_{Dif} + R_{Ret} \qquad (1)$$

for non-transmissive materials. Then, the retroreflective component, R_{Ret}, can be deduced by subtracting $R_{Spe} + R_{Dif}$ from R_{Tot}.

By following the above procedures, we evaluated the solar retroreflectance of five kinds of retroreflective materials listed in Table 2. The reflectances ($R_{Spe} + R_{Dif}$) in the 2nd column of Table 2 were measured by the spectrophotometer with the integrating sphere (UV-3600, Shimadzu Scientific Instruments) at the incident angle of 7 degrees. From the 3rd to the 6th columns, the total reflectance (R_{Tot}) are shown; these values were derived from the amount of temperature rise by the outdoor exposure at the 7-degrees incident angle of direct sunlight. The experiment was repeated four times on different days and the averaged values of R_{Tot} was used to calculate the retroreflectance, R_{Ret}, which are shown in the 8th column of Table 2. The calculated retroreflectances are 29.5 percent and 23.5 percent for the prism-array retroreflective sheets, 17.8 percent for the capsule-lens retroreflective sheet, and 12.9 percent and 4.9 percent for the bead-embedded retroreflective sheets. Therefore, it seems that retroreflectance depend on the structural type.

Table 2. Reflectance by Integrating Sphere Measurement ($R_{Spe}+R_{Dif}$),
Total Reflectance Deduced from the Amount of Temperature Rise (R_{Tot}),
and the Estimated Retroreflectance (R_{Ret}) of Retroreflective Samples

Retroreflective Samples	Reflectance by integrating sphere $R_{Spe}+R_{Dif}$	Total reflectance deduced from temperature rise R_{Tot}					Retroreflecntance $R_{Ret} = R_{Tot} - R_{Spe} - R_{Dif}$
		day 1	day 2	day 3	day 4	Average	
1: Prism-array sheet 1	48.2	77.5	78.0	78.0	77.5	77.8	29.5
2: Prism-array sheet 2	47.5	70.8	71.1	70.9	71.4	71.0	23.5
3: Capsule-lens sheet	42.1	60.8	59.5	59.9	59.7	60.0	17.8
4: Bead-embedded sheet 1	55.6	68.1	68.7	68.8	68.3	68.5	12.9
5: Bead-embedded sheet 2	62.2	66.7	67.1	67.9	66.7	67.1	4.9

[%]

Conclusions

The following results have been obtained in the present study.

1) By using a miniature model of urban street, it is demonstrated that the retroreflective materials can reduce the reflected heat of the sun in the directions of neighboring roads and buildings; they have a "cool wall" effect and can be used as building materials to reduce urban heat island effect. Therefore, the applicable area of retroreflective materials is larger than that of high-reflective paints.

2) A method is proposed for measuring the solar retroreflectance, which cannot be measured directly by a spectrophotometer.

3) The solar retroreflectances of several retroreflective sheets were measured. Their reflectances generally depend on the structural type. The reflectances are 20 to 30 percent for the prism-array type, about 20 percent for the capsule-lens type, and about 10 percent for the bead-embedded type.

Acknowledgment

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