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Evaluation methods for retroreflectors and quantitative analysis of near-infrared upward reflective solar control window film—Part II: Optical properties evaluation and verification results

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ABSTRACT

In recent years, cool materials that have high solar reflectivity and thermal emittance properties have been applied for building surfaces in the urban environment. However, when such highly reflective materials reflect all or part of the solar radiation downwards or towards the ground, there are concerns that it leads to deterioration of the thermal environment of pedestrian spaces.

A newly developed near-infrared (NIR) upward reflective solar control window film (URSCF) has come to the market. The film reflects NIR upwards to the sky, and shields a building's interior from solar radiation without deteriorating the thermal environment of pedestrian spaces.

In order to quantify the reflected solar radiation, it is necessary to clarify the reflectivity and transmissivity properties of retro-reflective materials, which is desirably performed through measurement in a stable environment using artificial light sources. This required development of the evaluation methods using apparatus including an integrating sphere, allowing the measurement of directional-hemispherical spectral reflectivity at large incident polar angles, as well as the selective measurement of directional-upward spectral reflectivity from retro-reflective surfaces.

It was confirmed that these results are appropriate through verification with the results obtained from commercially available apparatus and from optical simulations. With respect to the effect of NIR URSCF, it was confirmed that downward reflectance of solar radiation at the incident polar angle of 70° and the incident azimuth angle of 0° was approximately half of that of conventional specular reflective solar control window film.

1. Introduction

In recent years, cool materials that have high solar reflectivity and thermal emittance properties have been applied for urban building surfaces. However, when such highly reflective materials reflect all or part of the solar radiation towards the ground, there are concerns that it leads to deterioration of the thermal environment of pedestrian spaces (Erell et al., 2013; Kondo et al., 2009).

A newly developed near-infrared (NIR) upward reflective solar control window film (URSCF) has been introduced to the market, which selectively reflects only NIR upwards and transmits most of the visible light so that it can create a well-lit room without impacting on visibility (Fig. 1). Reflecting NIR upwards to the sky enables the building's interior to be shielded from the solar heat without deteriorating the thermal environment of the pedestrian space (Fig. 2). The improvement of outdoor radiative environment by URSCF has been verified experimentally (Ichinose et al., 2014; Inoue et al., 2013, 2015) and the effect of solar radiation on the human body was verified based on simulation (Yoshida et al., 2014, 2015). In order to quantify the reflected solar radiation, it is indispensable to clarify the reflectivity and transmissivity

Abbreviations: BSR, bidirectional spectral reflectivity; BTR, bidirectional total reflectivity; DDSR, directional-downward spectral reflectivity; DDTR, directional-downward total reflectivity; DHSR, directional-hemispherical spectral reflectivity; DHST, directional-hemispherical spectral transmissivity; DHTR, directional-hemispherical total reflectivity; DHTT, directional-hemispherical total transmissivity; DRS, diffuse reflectance standard; DUSR, directional-upward spectral reflectivity; DUTR, directional-upward total reflectivity; FL3, 3-mm-thick float glass; NIR, near-infrared; SRSCF, specular reflective solar control window film; URSCF, upward reflective solar control window film.

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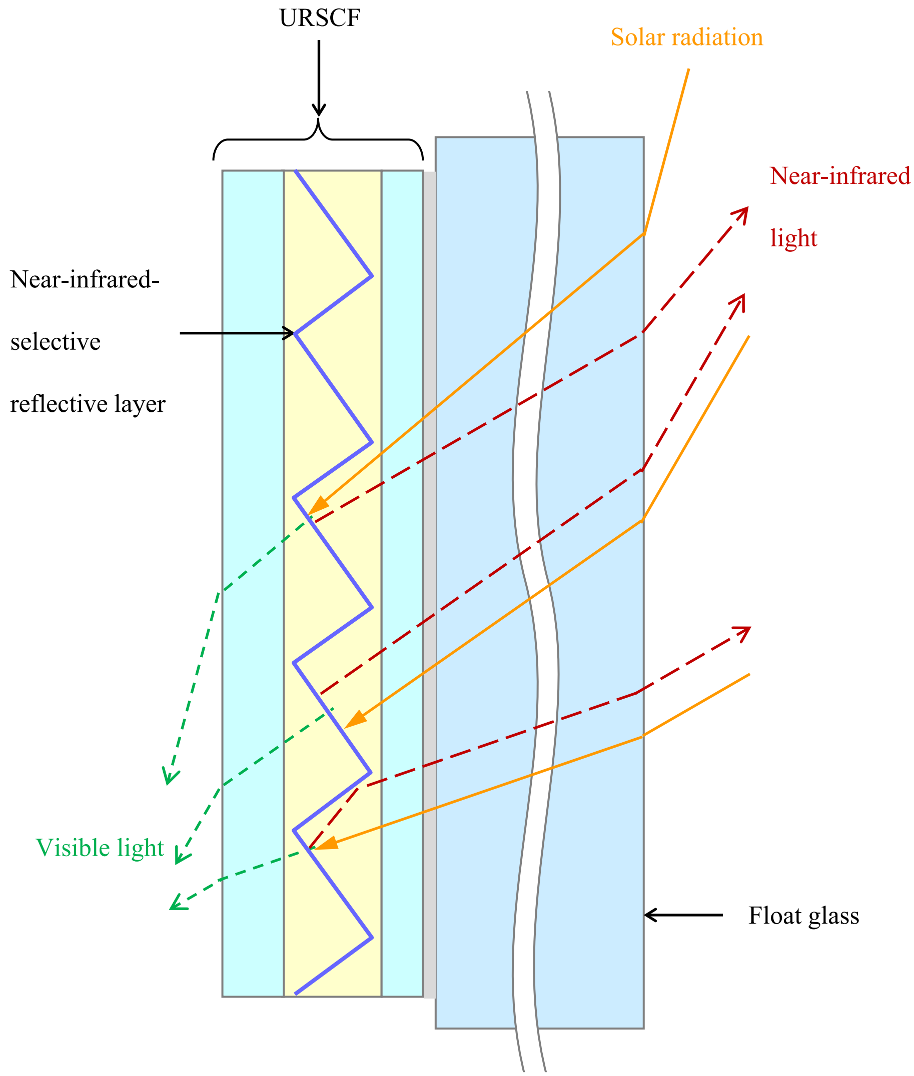

Fig. 1. Schematic showing upward reflective solar control window film (URSCF) affixed to the back of a float glass window, showing transmitted visible light and upward reflected near-infrared light.

properties of retro-reflective materials, which is desirably performed through measurement in a stable environment using artificial light sources.

In this study, the measurement and evaluation methods of directional-hemispherical spectral reflectivity (DHSR) and directional-upward spectral reflectivity (DUSR) under large incident polar angles that are equivalent to the daytime solar elevation at a south-facing vertical surface were developed, which have been enabled by development of the apparatus and measurement techniques. The measurement and evaluation methods of directional-hemispherical spectral transmissivity (DHST) were also developed in order to clarify the transmissivity properties of non-opaque materials such as window glass.

In this article, in addition to the above methods, the measurement results were verified, using a commercially available spectrophotometer, followed by an optical simulation analysis.

2. Methods of optical analysis experiment

This research aims to develop evaluation and measurement methods for the solar spectral reflectivity and transmissivity of solar radiation by retro-reflective materials, which are necessary to quantify their benefits in suppressing the deterioration of the thermal environment and mitigating the Urban Heat Island effect. In this research, URSCF was first checked to verify the presence of retro-reflectivity using a gonio-spectrophotometer and a half mirror for the measurement of bidirectional spectral reflectivity (BSR). Custom apparatus including an integrating sphere and evaluation methods were specifically designed and developed, and were then used to measure the reflectivity and transmissivity properties to clarify their correlation with the incident polar angles. Moreover, measurements using a commercially available spectrophotometer, followed by optical simulation analysis were also conducted to verify the measurement results. All the measurement apparatus used in this study was installed inside a darkroom to avoid the influence of stray light.

3-mm-thick float glass (FL3), URSCF, and specular reflective solar control window film (SRSCF) were used as evaluation specimens. URSCF and SRSCF are designed to be affixed to a window glass, and the evaluation specimens of these films are composed by integrally affixing these films to FL3 without exception. Hereinafter, the evaluation specimen of URSCF and SRSCF are simply called URSCF and SRSCF respectively in order to avoid redundant expressions.

Theory, evaluation methods, or equations concerning the evaluation that are not mentioned in this article are described in Part I of this article (Harima and Nagahama, 2017).