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Effect of retro-reflecting transparent window on anthropogenic urban heat balance

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ABSTRACT

Solar heat shielding against solar radiation over the entire building envelope is one of the most effective measures for achieving air-conditioning energy savings and preventing heat-island phenomenon in warmer climate regions. For this purpose, we proposed a new heat-shielding film, which possesses a retro-reflective property and a wavelength-selection property, while having the same degree of transparency as that of transparent glass. The proposed film can be easily applied to a wide variety of buildings and architecture, including new and existing buildings. This film embodies an innovative heat-shielding technique that makes it possible to effectively return solar radiation toward the sky, while minimizing the secondary effects to other buildings, to the ground, and so on. In order to verify these effects, several aspects of quantitative evaluation are demonstrated.

The measurement results and concepts in this paper are referred to from the previous conference paper Inoue et al. [10].

1. Introduction

According to Ref. [1], the proportion of population in urban areas is over 70% for developed countries and 45% for developing countries, with the urban population of Asia increasing. Most of the capital cities in Asia are located in the warmer climate zone, where the buildings consume larger amount of energy mainly for cooling, and the Urban Heat Island (UHI) is more prevalent compared to other cities in other parts of the world. Based on the economic growth statistics, these cities are still in midst of urbanization and there will be many more high-rise buildings, resulting in higher population density. Hence, enhancing the sustainability of Asian cities in terms of energy and city environment is one of the most important issues.

One of the main UHI factors derived from buildings is anthropogenic heat balance on the surface of the urban ground. Solar radiation is absorbed on the building envelope, stored and released to the atmosphere as sensible heat flux through heat convection from the building envelope or heat released from the air conditioning system. The reflectivity of the building envelope strongly affect both energy consumption of the buildings and heat flux released from the buildings to the atmosphere. For high-rise commercial buildings in a typical Asian city, the aspect ratio of the vertical surface area (where transparent glazing is usually applied) to the horizontal opaque roof area in the total building envelope is large. Window performance strongly affects the energy efficiency of the buildings. Because of the larger demand of cooling demand in this area, daylight utilization through windows is the most efficient countermeasure for achieving energy conservation of buildings (e.g. [2,3]. To realize both daylighting and heat shielding on the window, the wavelength-selective glass that is transparent in the visible region and translucent in the near infrared (NIR) region, such as low-E glass and heat-shielding window film, is applied frequently. Optical technology, such as that for liquid crystal display, is applied to most films of this type. As an improvement in such heat-shielding films, we have devised a new film which enhances the heat-shielding performance, by reducing transmissivity in the NIR band independently of transmissivity in the visible light band, and possesses a retro-reflective property [4] due to micro-convexes and concaves formed on the transparent film surface.

On the other hand, because the window glass is on a vertical plane and has the mirror-reflecting property, the secondary effect of the reflected solar radiation that contains larger amount of NIR radiation to the ground cannot be ignored in terms of outside human environment and UHI. Therefore, the building envelope

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Nomenclature

Following solar irradiance is on the horizontal surface

I_{dh_ref} Direct component of reflected solar radiation [W/m^2]
I_{sh_ref} Diffuse component of reflected solar radiation [W/m^2]
I_{sh_sky} Global diffuse solar radiation through building [W/m^2]
I_{th_build} Total quarter sphere solar radiation from direction of the building [W/m^2]
I_{sh_build} Diffuse component of quarter sphere solar radiation from direction of the building [W/m^2]
I_{sh} Global diffuse solar radiation [W/m^2]

Following reflection is on the vertical surface

ρ_{up} Upward reflectivity [−]
I_{up_ref} Reflected radiation of incident upper side of quarter spheres [W/m^2]
I_{tv} Incoming solar radiation [W/m^2]

performance which satisfies both wavelength selectivity and directivity [5] is most highly desired. To enhance reflectivity of urban canopy while reduce secondary effect of the reflected solar radiation, several type of retro-reflective coatings are suggested and verified [6–9]. The coating have micro-structure to refract and reflect beam to the incident direction. But most of them are opaque and cannot be applied to transparent window.

For this purpose, we have developed a heat-shielding retro-reflecting film for transparent building windows [10]. This film possesses both retro-reflectivity and wavelength selectivity in the NIR band which is based on the application of thin-film production technology. This paper presents the case of reflected solar radiation around urban buildings and the effect of retro-reflecting windows on the anthropogenic urban heat balance.

2. Reflected solar radiation around glass facade buildings

2.1. Overview of measurements

To investigate the impact of solar heat shielding of a building facade on its external heat gain, actual measurements of the reflected solar radiation around a heat-shielded building facade were conducted. The measurements targeted buildings with various glass facades in the central Tokyo area, where high-rise office buildings are densely located.

An on-site spectro-radiometer capable of measuring spectral irradiance within a range of 3502500 nm was configured and used for the quantitative study. The measurement system is illustrated in Fig. 1. To extract the direct and reflected solar radiation components, a shielding hemi-sphere and shielding sphere were used, as illustrated in Fig. 2.

The shielding hemisphere blocks direct solar radiation arriving directly from the sun. The shielding ball blocks direct solar radiation arriving directly on the street, after being specularly reflected by the glazed facade. The horizontal global irradiance was measured, with and without the shields, and each component was estimated from the difference. In addition, as a reference point, a spectro-radiometer installed on the roof of a high-rise building in the measurement area was used to measure the global solar radiation. The reflected solar radiation arriving from the facade to the street I_{ref} was estimated using the following equation.

$$I_{ref} = I_{dn\_ref} + I_{sh\_ref} \quad (1)$$

Fig. 1. Appearance of on-site measuring system.

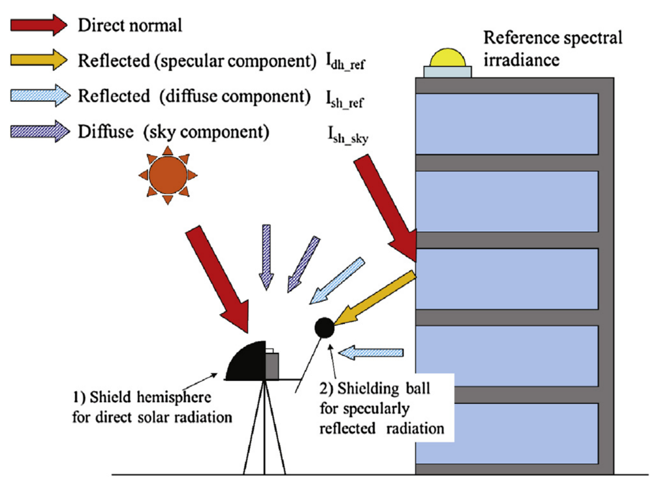

Fig. 2. Method for measuring solar radiation reflection of the facade.

$$I_{dh\_ref} = I_{th\_build} - I_{sh\_build} \quad (2)$$

$$I_{sh\_ref} = I_{sh\_build} - I_{sh\_sky} \quad (3)$$

$$I_{sh\_sky} = I_{sh} * f_{sky} \quad (4)$$

where, I_{th_build} was measured using shield hemisphere alone, and I_{sh_build} was measured using both shield hemisphere and shielding ball.

2.2. Solar irradiance of the NIR band on the street

Four points on the street in the vicinity of high-rise buildings are located in central Tokyo (Shiodome), and are equipped with different types of glass. Fig. 3 illustrates the horizontal solar irradi-

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