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DEVELOPMENT OF A NEW HGMS-BASED COOL ROOF COATING AND ITS APPLICATION ANALYSIS IN BUILDINGS

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ABSTRACT

In order to reduce heat transmission into the interior building through roof surface to reduce building energy consumption, in the study a new hollow glass microsphere (HGMs)-based cool roof coating was developed and testified with high solar reflectivity of 95% in the solar visible wavelength. The building energy simulations based on various roof surface solar albedos were carried out extensively in five typical cities representative of five different thermal zones in China. The temperature difference and energy consumption of the prototype building were analyzed and the cooling load saving and heating load penalty in different cities were compared. Results showed that compared with substrate roof paint, the optimal HGMs-based cool roof coating improves the reflectivity by 7% and 23% in visible and near-infrared wavelength, respectively. For a naturally ventilated building, the HGMs-based roof coating could achieve over 30℃ cooler of rooftop surface and a more thermally comfortable room air temperature without extra energy supply when compared with low reflective roof. For an air-conditioning building, the office building with the proposed new coating achieves a higher annual cooling loading savings than the heating load penalties among five typical cities, consequently inducing the positive total energy savings. Kunming and Hong Kong are among the two largest energy saving rates, which indicate a stronger application potential of the HGMs-based cool roof coatings in the mild as well as hot summer and warm winter climate zones. The newly developed cool coating turns out to have good prospect for energy savings in building sectors of China.

Keywords: Hollow glass microsphere (HGM), Cool roof, Reflectivity, Thermal comfort, Cooling load saving, Heating load penalty

1. INTRODUCTION

Due to the skyrocketing growth in social economy and urbanization, building industry is booming, which accounts for nearly 1/3 of total energy consumption in China [1]. Moreover, the growing desire for a better indoor built environment has increased the load consumption in heating, ventilation and air-conditioning systems, which take up 65% of total energy usage in building industry [2]. Among all kinds of buildings, office building is a typical type to be a key growing area in building sectors. Energy use in office building was estimated to be 70–300 kWh/m^2, 10-20 times higher than that in residential buildings [3], which requires necessity to consider energy conservation for office building both environmentally and economically [2]. Actually, the roof surface is the main receivers of solar heat gain, which accounts for more than 40% of energy use for top floor buildings [4]. Therefore, the roof thermal insulation performance, which could affect the indoor thermal comfort and outdoor microclimate, is of great significance for the building energy savings and urban heat island alleviation [5]. The highly reflective roof is referred to as cool roof, which is capable of reducing cooling energy consumption, decreasing carbon emission owing to the passive thermal management way.

In order to improve the effectiveness of roof cool coatings, new types of materials with high solar reflectance and good thermal insulation need to be further considered. Hollow glass microsphere (HGM) is an inorganic material with a spherical morphology and hollow structure with the diameter size ranging from 10 to 100 μm. Due to the light weight, HGM is endowed with excellent properties of low density and superior thermal insulation feature [6, 7] . Owing to its bright white color, it would be a good practice to use it as an additive in the cool roof coating substrate to enhance the building energy saving performance.

The paper aims to investigate the efficacy and potential of a newly proposed HGMs-based cool roof coating for building thermal comfort and energy saving in China. Essentially, there are five climatic zones, namely

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severe cold, cold, hot summer and cold winter, hot summer and warm winter and mild zones with typical cities of Harbin, Beijing, Shanghai, Hong Kong and Kunming, respectively. The study firstly based on experimental tests to measure the spectral properties of newly fabricated coatings, then did extensive energy simulations to analyze the energy savings attainable in various climate zones by varying the roof solar reflectance on prototypes of office buildings. Heating load penalties and cooling load savings in the five Chinese climates zones were calculated and compared accordingly based on the proposed of HGMs-based roofs.

2. EXPERIMENTS

The adopted HGM samples are provided with the parameter properties as shown in Table 1. The fabrication procedures involve the materials preparation, quantities calculation, ingredients mix, coating thickness control and formation. The commercially available roof paint was used as the substrate of the coating. Before adding the HGM into the mixture, a certain amount of the DI water, dispersants, wetting agents, antifoaming agents and multifunction additives were mixed with the white roof paint and stirred with a low-speed agitator for 20 minutes. Based on the HGM mass fraction of 5.4%, the amount of HGM were dropped into the mixture with the stirrer running for another 40 minutes. The produced mixture was coated onto a metal plate by a QTG standard coater with a fixed thickness of 250 μm, then measured precisely by coating thickness gauge. The samples were finally dried in a vacuum drier before spectral properties test. The solar reflectivity of the HGMs-based coating samples was measured by an UV-Vis-NIR spectrophotometer in the wavelength between 300 nm to 2500 nm, the value of which is mainly responsible for the solar heat gain of the roof surface in a building.

Table 1 HGM parameter properties

Type	Density/ (g/cm^3)	Compressive strength/ (Mpa)	Thermal conductivity/ ($W \cdot m^{-2} \cdot K^{-1}$)
TG 20	0.20	3.5	0.0486
TG 30	0.30	12	0.0568
TG 50	0.50	55	0.0763

3. MODEL DEVELOPMENT

The building simulation model was developed using software EnergyPlus to investigate the thermal performance and evaluate energy savings of a one-story top floor office building through the application of cool roof coatings. The established three-dimensional building model is shown in Fig. 1. The energy savings are related to climatic conditions, building envelopes and HVAC control strategies. Therefore, energy savings obtained in the paper may vary from the local specific buildings.

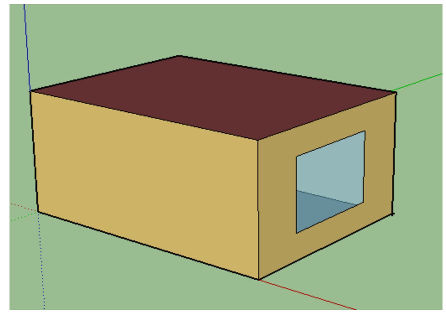


Fig. 1 Three-dimensional model of an office building

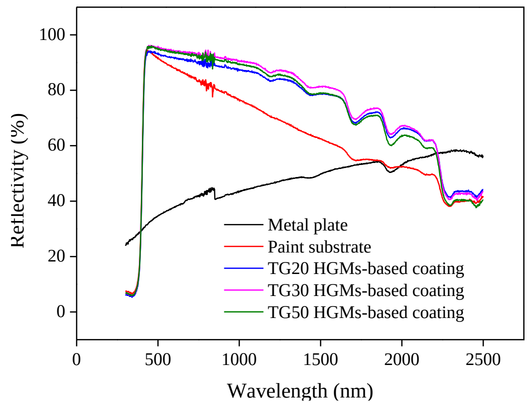
The building model has the size dimension of 8 x 6 x 3.5 m (length x width x height), which is located simultaneously in the aforementioned five different climatic zones with the typical cities of Harbin, Beijing, Shanghai, Hong Kong and Kunming in China.

4. RESULTS

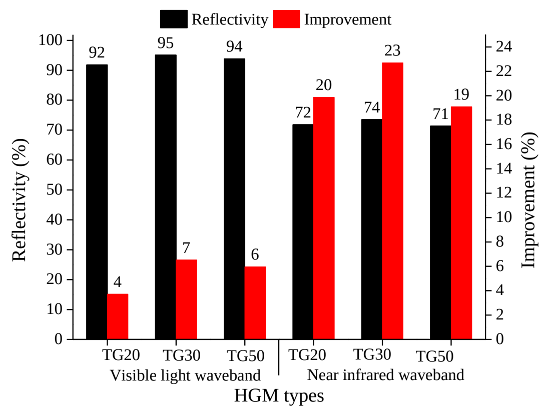
4.1 HGMs-based coating spectral properties

The measurement results of samples' reflectivity are shown in Fig. 2.

Fig.2 (a) suggests that compared with the metal plate and paint substrate, the modification of the coating by adding a certain type of HGM will obviously improve the spectral reflectivity across all wavebands of solar spectrum. The comparison results show that the modified coatings with the aid of HGM have generously high reflectivity, larger than 92% in visible light waveband (400 -760 nm). The spectrally reflective effects weaken gradually in the near infrared band to the range of 70-80% (760 - 2500 nm). However, the effects of solar insulation improve evidently when compared with roof paint substrate (Fig.2 (b)). Among all the three HGMs-based coatings, the type TG30 has the most evident improvement both in visible light and near infrared waveband. Typically, near 95% of visible sunlight reflection is reached for TG30 type HGMs-based coating, which indicates a promising application on the building envelope to achieve passive cooling and energy efficiency in buildings.



(a) Spectrally reflective property



(b) Improvement comparison

Fig. 2 Spectrally reflective property and improvement comparison of HGMs-based coatings

4.2 *Thermal analysis of roof surface*

The simulation results of an office building with natural ventilation are shown in Fig.3, which illustrate the temperature variations of exterior roof surface on the day of 15 July in Hong Kong.

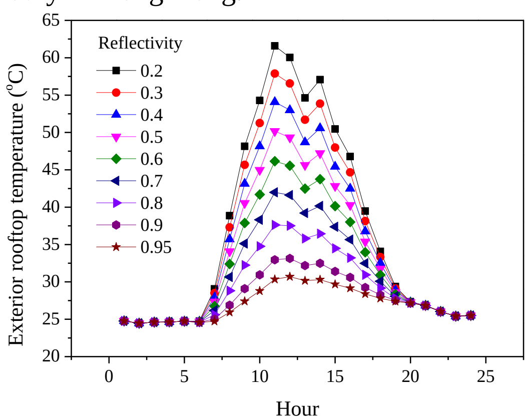


Fig. 3 Exterior roof top surface temperature

Different roof reflections exert impact greatly on thermal performance of a building. The roof top temperature varies mostly for various reflections, which reached 61.6 ℃ at the reflectivity of 0.2, while the roof top with reflectivity of 0.95 was up to 30.9 ℃ cooler, with a peak temperature of 30.7 ℃. The roof bottom with reflectivity of 0.95 was up to 2℃ cooler than that of 0.2. The obvious temperature reduction effects through a higher reflective roof surface could provide a more thermally comfortable environment for occupants.

4.3 *Energy saving analysis*

4.3.1 *Annual energy consumption.*

The total energy consumptions include heating and cooling load. All the energy consumptions in five cities decrease gradually at a higher reflectivity with a more obvious trend for Hong Kong and Kunming which belongs to hot summer and warm winter, mild climate zones respectively, where cooling load plays a dominant role in the total energy consumption, as shown in Fig. 4.

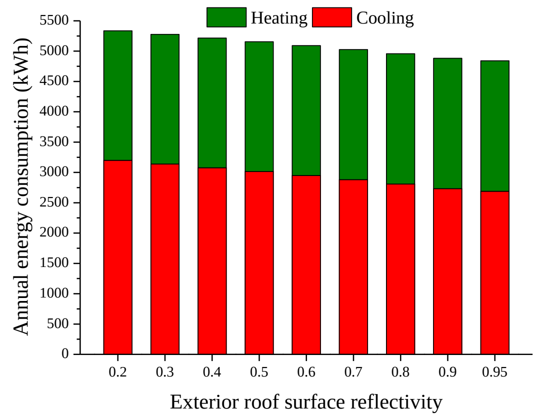


Fig. 4 Annual building energy consumption in Kunming

For severe cold, cold climate zones, like cities of Harbin and Beijing, heating loads hold a dominant position which weaken energy savings by applying high solar reflective coatings. However, the total annual energy consumptions of these two regions still turn out to decrease as solar reflectivity increases, which suggests the cool roof coatings also bring benefits to such regions.

4.3.2 *Cooling load saving and heating load penalty*

Though the application of HGMs-based cool coating could effectively reduce the cooling load in buildings, it still decreases the solar heat gain through building envelopes in winter period, which inevitably increase the total heating energy. Under the circumstance, the building energy simulations base on a basic reflectivity value of 0.4, which is close to commercially available roof deck. Considering the aforementioned HGMs-based coating in section 4.1 with the visible light reflectivity of 0.95, the cooling load saving and heating load penalty and energy saving rate of the proposed HGMs-based coating are calculated on the basis of the basic reflectivity value of 0.4, as presented in Fig. 5.

With the application of HGMs-based cool roof coating in an office building, the annual cooling loading savings among five typical cities are much higher than the heating load penalty, which induce the positive total energy savings eventually. Kunming and Hong Kong have the two largest energy saving rates (7.2% and 5.5% respectively) compared with other three cities owing to the high cooling load percentage throughout the year, which indicate a much stronger application potential in the mild as well as hot summer and warm winter climate zones.

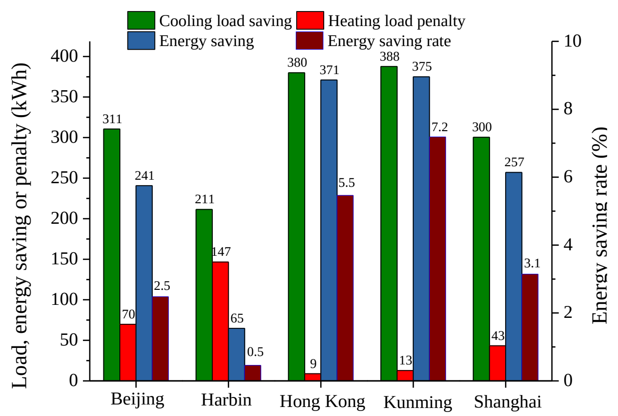


Fig. 5 Annual cooling load saving and heating load penalty

The monthly energy consumptions and energy savings between the roof reflectivity of 0.4 and 0.95 in the city of Hong Kong, is shown in Fig. 6. The energy consumptions and energy savings are more prominent in the hot months, especially in July and August when the HGMs-based cool coating could provide most potential in energy savings.

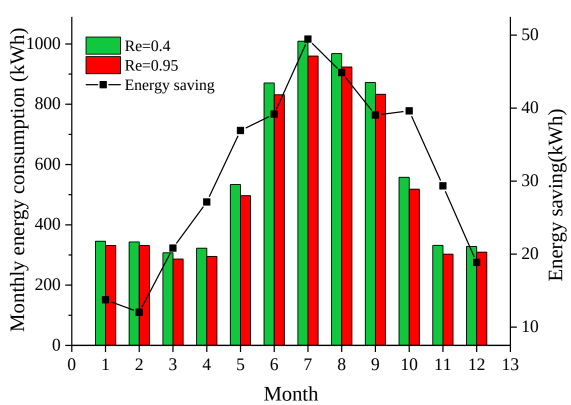


Fig. 6 Monthly energy consumption and energy saving in Hong Kong

5. CONCLUSION

The study proposed a new HGMs-based cool roof coating with excellent spectral properties and explored its energy saving potential in five typical cities representative of different thermal zones in China. The following conclusions are drawn from the paper:

1) The newly developed HGMs-based cool roof coating has highly reflective spectral properties with up to 95% of visible sunlight reflectivity.

2) For naturally ventilated building, the application of the proposed HGMs-based coating could greatly reduce the building rooftop surface temperature, thus improving the thermal comfort of the indoor environment for occupants.

3) For air conditioning building, the newly developed coating has an enormous potential to achieve energy savings, especially in warm as well as hot summer and warm winter areas, like the cities of Kunming and Hong Kong. Although its application brings the heating penalty, the larger shares of cooling load savings eventually reduce the total energy consumptions in building's air conditioning systems.

4) The future investigation should involve the structural design of the HGMs-based cool roof coating to optimize the effect of energy savings and analyze other benefits, for instance, carbon gas emission reduction and economic savings by the application of the coating.

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