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Thermal Performance Improvement of Prefab Houses by Covering Retro-reflective Materials

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Abstract

Owing to the small thermal inertia of prefab houses, indoor thermal environment is poor and occupants are tormented especially under the high solar radiation. Retro-reflective materials can make it a reasonable choice to decrease radiation heat gain due to their high reflectivity for solar radiation. Comparative results show that the indoor air temperature of the prefab house by covering retro-reflectivity materials can reduce by more than 7°C, while the reduced value is close to 10°C for the peak radiant temperature and 7°C for indoor average radiant temperature. It shows retro-reflective materials have a significant effect on thermal performance improvement of prefab houses. Through the comparative study of different walls, it is found that the top, south and east walls are the better choices and that the north wall is the worst one to cover retro-reflectivity materials.

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Keywords: Retro-reflective materials; reflection; indoor temperature

1. Introduction

Prefab houses are widely used as temporary shelters, temporary houses after a disaster and temporary offices for construction projects, due to their easy transport, rapid construction, low cost and so on [1]. In 2008, 625 thousand prefab houses were built as temporary shelters or houses after Wenchuan earthquake [2] and Fig. 1 shows one post-disaster transitional settlement of prefab houses in Wenchuan earthquake. Before the completion of permanent buildings, victims had to live in these prefab houses for 2-3 years. However, due to the low thermal resistance and

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small thermal inertia of prefab houses, indoor thermal environment was very poor, and thereby victims were tormented mentally and physically [3-5]. In-situ measurement of prefab houses shows that indoor air temperature can reach 30°C, while inner surface temperature can be up to 55°C [6] and that solar radiation affects indoor thermal environment significantly and makes indoor air temperature far higher than outdoor air temperature. Decreasing solar radiation heat gain is necessary for refining indoor thermal environment in prefab houses.

Fig. 1. One post-disaster transitional settlement of prefab houses in Wenchuan earthquake

Retro-reflective materials make it a reasonable choice for decreasing radiation heat gain and meeting the purpose of improving indoor thermal performance. Different from the specular reflection of conventional reflective materials [7], retro-reflective materials can reflect solar radiation in the opposite direction. And thereby retro-reflective materials can decrease radiation heat gain of prefab houses without increasing heat gain of other buildings. At the same time, retro-reflective materials, which have only 1mm thickness, will not change the easy transport and rapid construction of prefab houses.

At present, there is some research on conventional reflective materials. Synnefa et al. [8,9]researched reflective coatings on the effect of the urban environment and energy loads and thermal comfort in residential buildings. However, there is lack of the systemic research on retro-reflective materials. To the best knowledge of the authors, Sakai et al.[10]firstly researched these retro-reflective materials and measured their retro-reflective properties.

In this paper, a contrast experiment was done on two models of prefab houses, one of which was covered with retro-reflective materials, and the contribution of retro-reflective materials was analysed on improving indoor thermal performance.

2. Methods

To reveal the thermal performance improvement of prefab houses by covering retro-reflective materials, two prefab house models (M1 and M2) are built with the dimensions of 800mm× 1000mm× 1300mm (L ×W ×H) as shown in Fig. 2, and M2 is covered by retro-reflective materials, while M1 is a original one as a comparison object.

In addition, Fig. 2 also shows the locations of the temperature measurements. T_t, T_b, T_e, T_s, T_w and T_n measure the inner surface temperature of the top, bottom, west, south, west and north walls, while T_{in} and T_{out} measure indoor and outdoor air temperature. At last, thermocouples, whose errors are lower than 0.3°C, were selected for experimental measurement. All measurement data are recorded by JTRG-II building thermal temperature automatic tester with the data-collection interval of 60 minutes.

Fig. 3 shows the structure of M2 wall consisting of one 40mm polystyrene foam board (XPS) layer, two 0.5mm stainless steel layers and one 1mm retro-reflective material layer. There is no the retro-reflective material layer in outer surface for M1.

Fig. 4 displays the magnification of retro-reflective materials with the magnifying power of *180x* and the reflectivity measurement value of retro-reflective materials by a spectrophotometer in the laboratory. It can be clearly seen the uniform distribution of glass beads on the membrane material surface. In addition, Figure 4(b) also gives the ground solar radiation energy distribution at the standard sea level with the secondary air quality. It can be found that retro-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 retro-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 retro-reflective materials can be gained as 0.543 by the weighted computation of the ground solar radiation energy distribution.

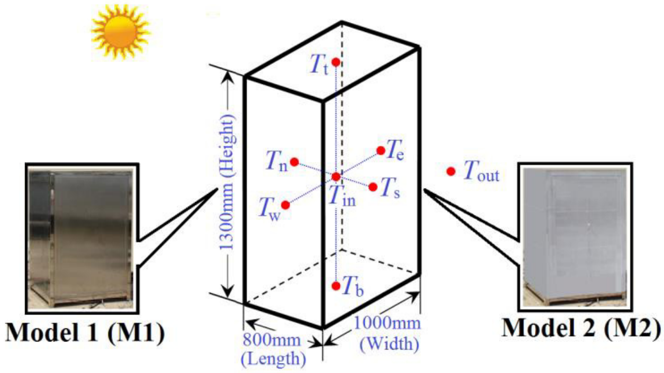

Fig. 2. The arrangement diagram of thermocouples and two models of prefab houses

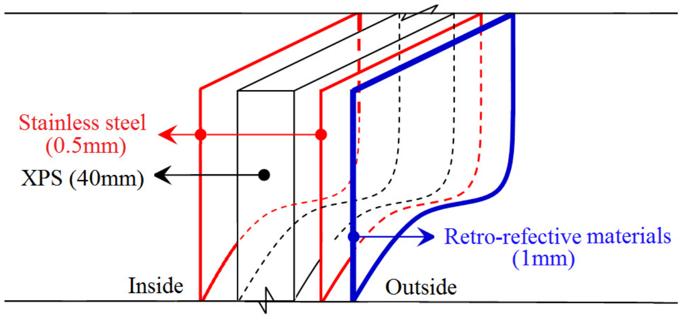

Fig. 3. A schematic diagram of wall structure for M2

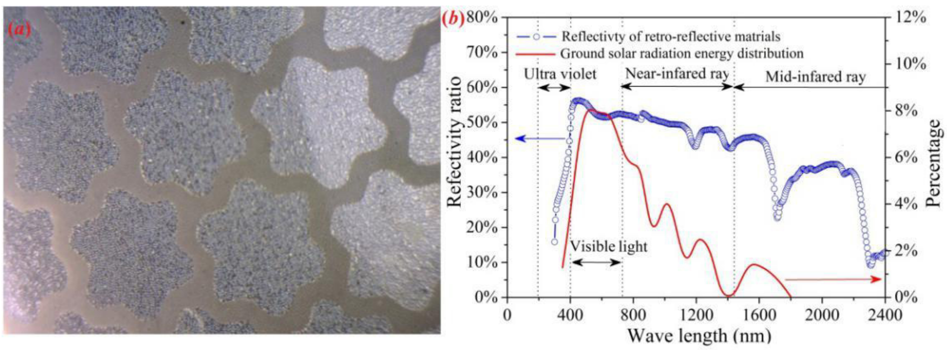

Fig. 4. (a)The magnification of retro-reflective Materials with the magnifying power of 180x and (b) reflectivity of retro-reflective materials

3. Results

The measurement experiment was carried out from 4th to 9th in August 2014 in Sichuan University of Chengdu. Fig. 5 shows outdoor air temperature and horizontal total radiation measured by a meteorological station during the test period. It is easily found that there were overcast, cloudy and sunny days during the measurement period. The maximum temperature difference can be up to 10°C in a day and solar radiation can reach 850W/m² at 14:00 during the cloudy and sunny days.

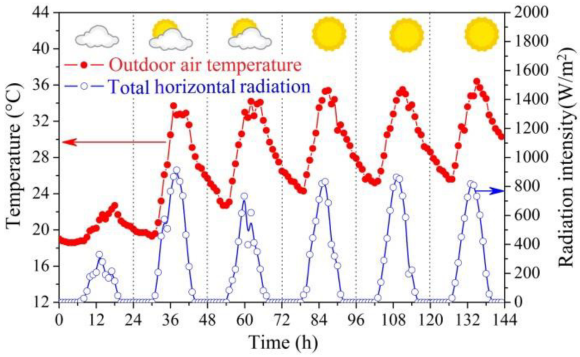

Fig. 5. Outdoor air temperature and horizontal total radiation during the test period

Fig. 6 shows indoor air temperature in M1 & M2 and outdoor air temperature during the test period. As shown in Fig. 6, compared to indoor air temperature in M1, the reduced peak air temperature is 7.1°C for the second day and 7.4°C for the fourth day in M2 by covering retro-reflective materials and it shows retro-reflective materials have a significant effect on thermal performance improvement. In addition, it can be observed that indoor air temperature is almost the same with outdoor air temperature under the lower horizontal total radiation at the first day and nights of the test period, while indoor air temperature in M1 & M2 is higher than outdoor air temperature under the higher horizontal total radiation. It shows solar radiation is a main factor causing the poor thermal environment. On the other hand, it reveals the effective cause of the retro-reflective materials on thermal performance improvement. Moreover, indoor air temperature in M1 & M2 fluctuates nearly in sync with outdoor air temperature due to the low thermal resistance and the small thermal inertia of ultrathin envelope in the prefab house.

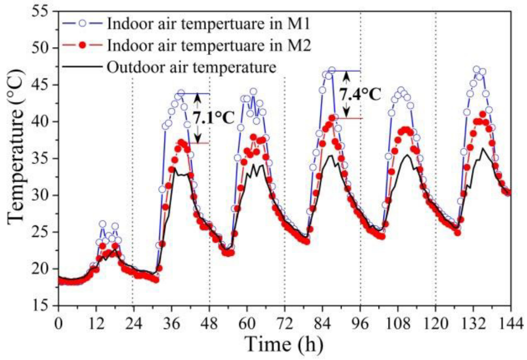

Fig. 6. Indoor air temperature in M1 & M2 and outdoor air temperature during the test period

It is generally known that radiant temperature of inner surfaces is another important parameter affecting thermal performance besides inner air temperature. And Fig. 7 shows top inner surface temperature in M1 and M2 during the test period. As shown in figure, compared to inner surface temperature of top wall in M1, the reduced peak air temperature is 9.6°C for the second day and 9.9°C for the fourth day in M2 by covering retro-reflective materials.

And retro-reflective materials have the efficient improvement on thermal performance under the higher horizontal total radiation, which is consistent with conclusion in the Fig. 6.

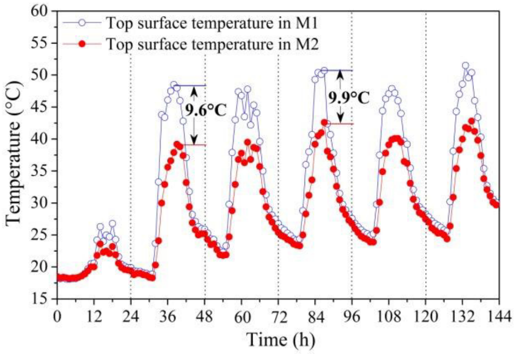

Fig. 7. Top inner surface temperature in M1 and M2 during the test period

To farther research the influence of retro-reflective materials on the radiant temperature, Fig. 8 shows inner surface temperature of the east, south, west, north walls. It can be seen clearly that when retro-reflective materials are covered on the south wall, the best effect of thermal performance has been obtained; Next is the east wall; The poorest is the north wall and no obvious refinement can be observed. It shows the walls with the different directions, on which retro-reflective materials are covered, have a different refinement effect due to that the walls with the different orientation can obtain the different solar radiation strength.

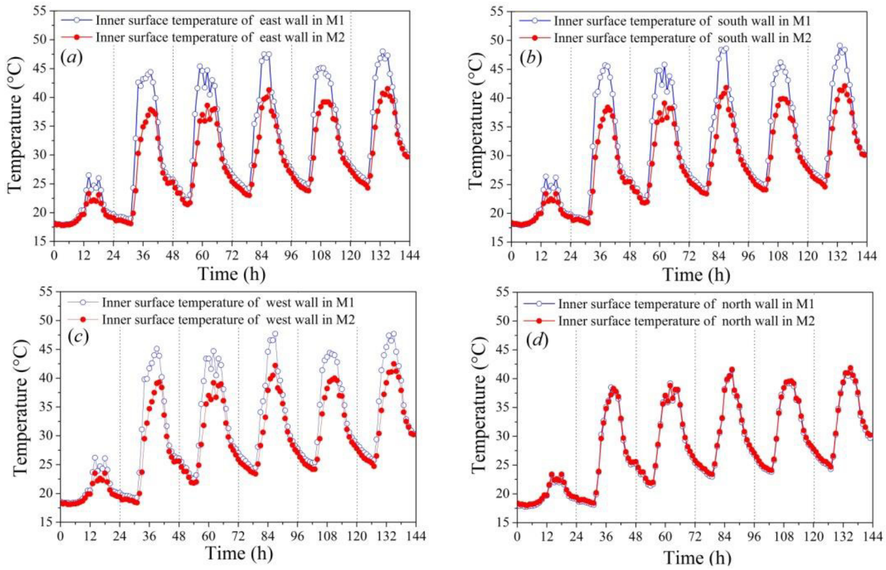

Fig. 8. Inner surface temperature in M1 and M2 during the test period: (a) East wall; (b) South wall; (c) West wall and (d) North wall

Above research on inner surface temperature of walls with the different directions shows that the top wall, the south wall and the east wall are the better choices and the north wall is the worst choice to cover retro-reflective materials.To synthesize the radiant temperature of each inner surface, indoor average radiant temperature is introduced and defined as following:

$$T_{\text{average}} = \sum_{i=1}^{N} T_i S_i \Big/ \sum_{i=1}^{N} S_i \qquad (1)$$

Where, T_i is inner surface temperature of the wall, °C; S_i is inner surface area of the wall, m^2.

Fig. 9 shows indoor average radiant temperature in M1 and M2 during the test period. It can be seen clearly that indoor average radiant temperature is 6.3°C for the second day and 6.9°C for the fourth day lower than that in M2. It shows retro-reflective materials improve thermal performance of prefab houses obviously in summer by decreasing indoor air temperature and average ambient temperature owing to their high reflectivity.

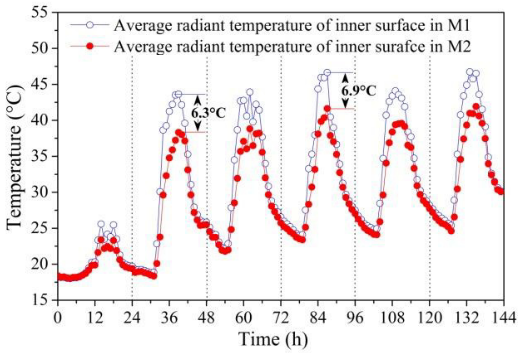

Fig. 9. Indoor average radiant temperature in M1 and M2 during the test period

4. Discussion

In our study, the thermal performance improvement of prefab house is experimentally researched by covering retro-reflective materials. Different from the conventional constructions, indoor air temperature fluctuates in sync with outdoor ambient temperature due to the low thermal resistance and the small thermal inertia of ultrathin envelope in the prefab houses. Therefore, the high solar radiation will further worse the poor thermal environment. And retro-reflective materials will increase the reflectivity of outer wall surface and decrease its absorptive correspondingly. And then the purpose of the thermal performance improvement is obtained. Experimental results show the indoor air temperature of prefab houses can be reduced by more than 7°C, while the reduced value is close to 10°C for the peak radiant temperature and 7°C for indoor average radiant temperature. It shows retro-reflective materials have a significant effect on thermal performance improvement of prefab houses. In addition, through the comparative study of walls with different directions, on which retro-reflective materials are covered, it is found that the top wall, the south wall and the east wall are the better choices and that the north wall is the worst on, which can guide the engineering application of retro-reflective materials.

5. Conclusions

Retro-reflective materials can improve the thermal performance of prefab houses significantly in the summer with the high solar intensity. And the top wall, the south wall and the east wall are the best choices to cover retro-reflective materials on in Chengdu, China.

Acknowledgements

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