Study on the applicability of thermal comfort models considering solar effects in the design of building glazing facades

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Abstract. As a main component of the building envelopes, window plays an important role in creating comfortable indoor thermal conditions. Although the increased exterior window area can improve indoor lighting and satisfy psychological needs, it can cause severe indoor thermal problems and result in building energy consumption increasing. This paper examined the effect of short-wave radiation transmitted through exterior windows on indoor radiant temperature in office buildings and quantitatively analyzed the applicability of seven related models for assessing these impacts. It was indicated that the thermal sensations predicted by applying the six models were not significantly different. The solar-adjusted mean radiant temperature model provided a relatively reliable prediction result. The outcomes can provide a guideline for the design of the glazing façade of office buildings.

Keywords: Radiant temperature; Solar radiation; Thermal comfort.

1 Introduction

Window has always played a crucial role since it is a main component of the building envelope. It serves not only as a medium for interaction between the indoor and outdoor environment but also has an important effect on the indoor thermal environment and building energy consumption. To meet the needs of lighting and psychological health, the proportion of external windows in office building envelopes has increased. While this has brought a sense of modernity to the building, it has also resulted in issues such as deterioration of energy waste and indoor thermal environment [1].

The effect of short-wave radiation transmission on the building thermal environment has been revealed. How to accurately assess its effect on human thermal sensation has

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proposed the CPMV model to assess the human thermal sensation when they exposed to solar radiation [2]. Singh integrated the effect of solar radiation into the mean radiant temperature (MRT), which is called SMRT, and gave the related model in their study [3]. La Gennusa derived a Solar-adjusted MRT model according to the mechanism of radiant heat transfer in the enclosed space around the occupant. The additional heat load of the direct and diffuse solar radiation was included in this model [4]. Marino further modified Gennusa's mean radiant temperature modification model by considering the reflective effect of solar radiation from the indoor wall [5]. Arens developed a model for assessing the impact of solar radiation on occupants' thermal comfort based on the ERF method, which was also adopted in the new edition of ASHRAE Standard 55 [6]. Hodders and Parsons also gave a simpler Modified PMV model according to the experimental results in the artificial chamber [7]. Huang provided a Solar-corrected PMV model based on the concept of outdoor integrated temperature [8].

The effect of SSR on the building thermal environment has aroused increasing attention, and several models have been proposed to predict thermal comfort under the effect of solar radiation from different perspectives. However, most existing studies were based on theoretical but lacked field experimental verification. Owing to the lack of field human experiment data, the applicability of these models in office buildings and their differences remain elusive. Therefore, this study aims to analyse seven models mentioned above to assess their differences and applicability in evaluating the impact of exterior windows on building thermal comfort by carrying out field experiments.

2 Method

To examine the impact of exterior windows on thermal environment in office buildings and analyze the differences and limitations of the models in practice, a field experiment was accomplished in a typical office building. To facilitate the analysis, the study renumbered and named these models as shown in Table 1.

Table 1. Renumbering of seven models.

Old Name	New Name	Old Name	New Name	Old Name	New Name
Solar-adjusted MRT by Chaiyapinunt	Model 1	*Solar-adjusted* MRT by La Gennusa	Mode 2	*Solar-adjusted* MRT by Marino	Model 3
Modified-PMV model	Model 4	*CPMV* model	Model 5	ERF_{solar} model	Model 6
Solar-corrected PMV	Model 7				

The experiments were performed in a typical office rooms, located in Xi'an, China. During the test period, both rooms were unoccupied. The test parameters of indoor thermal environment included: black globe temperature, air temperature, air velocity, relative moisture, inner surface temperature of each envelope, radiant temperature asymmetry, net radiant, total solar radiation, and solar diffuse radiation. The measured data could meet the calculation requirements of the above seven models. The measurement points are closed to the glazing.

3 Result analysis

The results of the comparative analysis were shown in Figure 1. The yellow area indicated the period when there was direct solar radiation transmitted through exterior windows. All the PMV values calculated by these models could reflect the effect of solar radiation transmitted through windows on the building thermal environment. Direct solar radiation caused a rapid increase in the PMV value, indicating a decrease in indoor thermal comfort. The results of Model 1, Model 2, and Model 4 were similar. Although the results of Model 3 followed the same trend as Model 2, its PMV values were significantly higher. During the period of non-direct solar radiation, Model 5 and Model 6 produced lower PMV calculation results compared to the other models, and even lower than the PMV model. The values calculated by PMV model were lower than those by the other models. The calculations for Model 5 exhibited greater volatility. Models 5 and 6 could be used to assess the effect of solar radiation on thermal comfort. However, they were not suitable for assessing thermal comfort during periods of non-direct solar radiation.

The selection of integrated parameter values directly affected the results of Model 7 calculations. The calculations for integrated parameter values of 0.05 and 0.03 deviated by more than 13%, respectively. The integrated parameter values had no effect on the results during periods without direct solar radiation. The results of Model 7 calculations were consistent with those of Model 2. Model 7 combines the solar short-wave radiation absorption coefficient of human body, convective heat transfer coefficient, and radiant heat transfer coefficient, which determined the integrated parameter value. This value was affected by alterations in thermal environmental parameters, such as mean radiant temperature, air temperature, and air velocity, as well as subjective human factors, such as the level of human activity and the thermal resistance of clothing. To ensure accurate calculation results, the model should be limited to environmental parameters and objective factors. Determine the integrated parameter value based on experiences might decrease the result accuracy and professional expertise was required to apply the model.

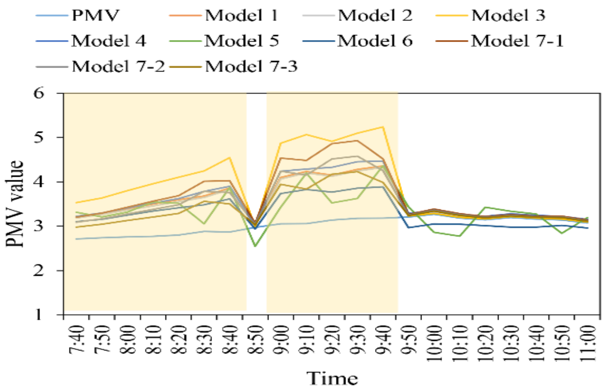
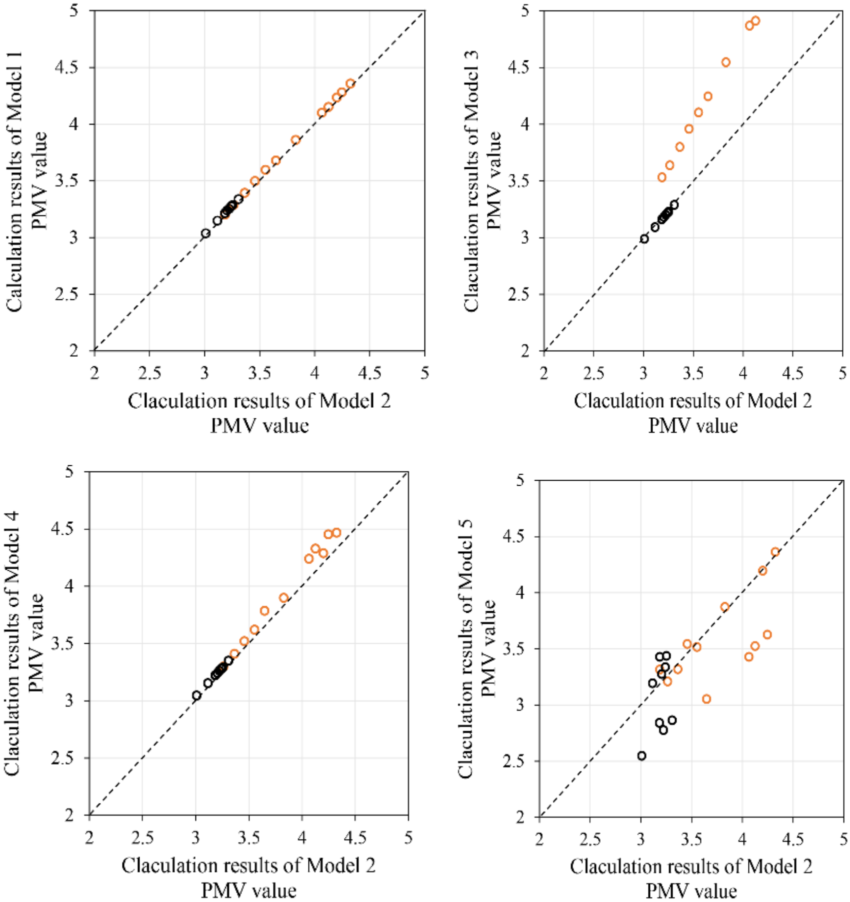


Fig. 1. Comparative analysis of PMV values based on different models.

To highlight the variations in the results from different models' calculations, this study compared the deviation degree of different models' results from Model 2's results, as shown in Figure 2. Model 2 and Model 1 had the best agreement. Model 3 provided higher results than Model 2 in terms of direct sunlight hours. However, according to the comparison results, the result of Model 3 showed 1 scale increase compared with Model 2. This increase equivalented to at least 200 W/m^2 of solar radiation landing on the human, while the maximum solar radiation entering was only 241 W/m^2 during the test. It was suggested that a possible double estimation of solar radiation reflected by the floor and wall surfaces in Model 3. Model 4 yielded higher results compared to the overall results. Model 6 produced lower results than Model 2, in both periods with and without direct solar radiation. The results of Model 7 were most similar to those of Model 2 when the integrated parameter value was 0.04.



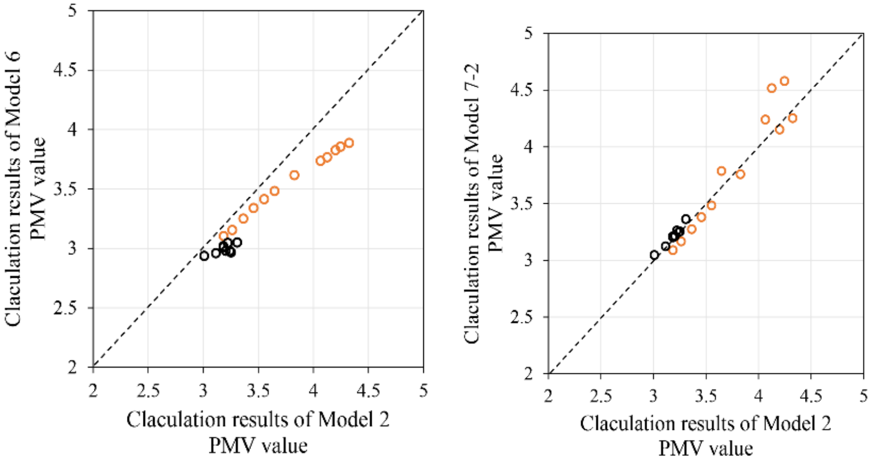


Fig. 2. The deviation degree of different models' results from Model 2's results.

4 Conclusion

Seven models were quantitatively analyzed in this study to examine their applicability for evaluating the effect of short-wave radiation transmitted through windows on indoor radiant temperature. According to the PMV values of subjective human thermal sensation acquired through field experiments, the solar-adjusted MRT model (Model 2) provides a relative accuracy of prediction of human thermal sensation under the effect of solar radiation, and other prediction models may underestimate human thermal sensation. Although Models 5 and 6 could be used to assess the effect of direct solar radiation on human thermal comfort, they were not suitable for assessing thermal comfort during periods of non-direct solar radiation. As introduced before, the calculate result by each model depends on several parameters designated by experience, the field experimental study should be carried out to verify or refine these models in future.

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