Quantifying Solar Light-Induced Thermal Comfort Effects of Architectural Windows

Nan Wang, YanXiao Feng, and Julian Wang(✉)

Pennsylvania State University, University Park, PA 16801, USA
julian.wang@psu.edu

Abstract. Shortwave solar irradiance has an energy distribution at different wavelengths and can impact the indoor thermal comfort of humans by entering through windows and directly affecting human skin. Windows play a crucial role in this process, and the market offers a wide range of products with various technical designs and functions for selection. Thermal comfort effects induced by solar irradiance were simulated and quantified by the spectrally-resolved method, specifically focusing on different glazing options in the International Glazing Database. The thermal comfort levels with different glazing installed were also evaluated under different indoor environments. By comparing the thermal comfort levels achieved with different glazing options, it was observed that the choice of glazing system significantly influenced the solar light-induced thermal comfort levels, consequently affecting the overall indoor thermal comfort of humans in diverse indoor environments. Quantifying the solar light-induced thermal comfort effects of architectural windows can be helpful in selecting appropriate windows for buildings, ultimately improving the thermal comfort of humans and energy savings.

Keywords: Spectrally-resolved Method · Window database · Thermal comfort

1 Introduction

Thermal comfort is a crucial aspect to evaluate the human status and indispensable to maintain the productivity and well-being of human beings indoors. The prediction of the thermal comfort level provides support for evaluating and constructing a well-living and working environment. The predicted mean vote (PMV) model is widely utilized to predict human thermal comfort and serves as a fundamental model for incorporating additional factors and specific evaluation targets in the prediction [1]. The input of the PMV model to predict the thermal comfort level includes air temperature, mean radiant temperature (MRT), air velocity, relative humidity, metabolic rate, and clothing level [1]. Among them, MRT represents the longwave solar effect on human thermal comfort. To incorporate the additional shortwave solar irradiance into the model, the effect of the shortwave solar irradiance was converted into the equivalent longwave effect, acting as a supplementary variable. The variable is referred to as MRT delta [2]. The value of MRT delta depends on the presence of shortwave solar irradiance

D. Renné et al. (Eds.): ASES SOLAR 2023, SPE, pp. 21–26, 2023.
https://doi.org/10.1007/978-3-031-39147-7_3

on human skin indoors. The availability of solar irradiance is determined by several factors, including the solar irradiance that reaches the window, window transmittance, and skin absorptivity. These factors exhibit spectral power distributions, which means the energy of solar irradiance, as well as the properties of window transmittance and skin absorptivity, are distributed unequally across different wavelengths. To account for the spectral characteristics of these three key variables and other factors influencing the availability of solar irradiance, a spectrally-resolved method was proposed [3]. This method aims to enhance the accuracy of predicting human thermal comfort indoors.

The International Glazing Database (IGDB) offers optical data for a range of glazing products [4]. Manufacturers of these glazing products have measured the spectral transmittance and reflectance by a spectrophotometer, and the data has been contributed to the IGDB. Assessing the performance of the glazing products within the database is helpful for gaining a comprehensive understanding of the role of windows and their practical application in relation to the solar light-induced thermal comfort effect.

In this paper, the MRT delta and PMV values of the glazing products available in the database were calculated and compared. Additionally, the MRT delta values corresponding to the comfort PMV value were calculated under various indoor environments to investigate the combined impact of multiple influencing factors on human thermal comfort indoors.

2 Methods

2.1 MRT Delta Calculations for Windows Present in the IGDB Using the Spectrally-Resolved Method

The spectrally-resolved method was employed to calculate MRT delta values for the glazing products present in the IGDB using some default settings and assumptions. The calculation process and the settings for other variables are depicted in Fig. 1. For a more comprehensive understanding of the principles and calculation procedure, further information can be referred to our previous study [3].

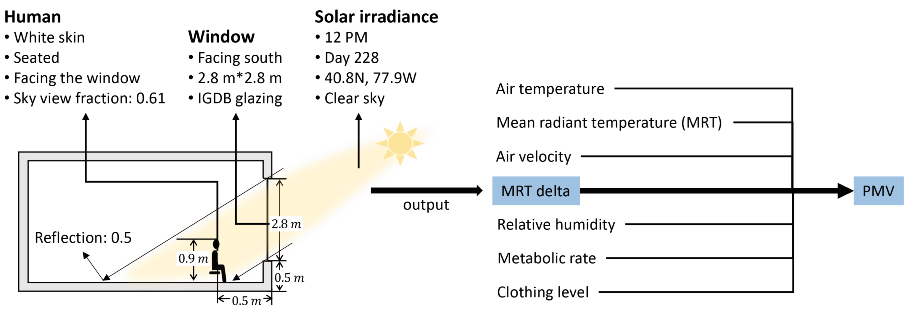


Fig. 1. A schematic diagram illustrating the solar light-induced thermal comfort effect and default settings in the calculations.

In the spectrally-resolved method, the solar irradiance, window transmittance, and skin absorptivity are combined by wavelength through superposition. To ensure consistency, the wavelength intervals of these three variables should be the same. To achieve this, interpolation and deletion of glazing transmittances were performed for certain wavelengths in the database. Specifically, wavelengths that were absent for more than 20 glazing products were excluded from the selected wavelength interval. Additionally, glazing with excessive missing wavelengths was also excluded to prevent excessive interpolation, which could potentially lead to inaccurate results. As a result, out of the total 5683 glazing products in the database, 5138 glazing products were selected for the calculations.

2.2 Calculations for the Preferred MRT Delta Values Under Various Indoor Environments

The original PMV is a seven-scale continuous index range from −3 to 3, which represents a scale from cold to hot [5]. People are generally regarded comfort when PMV values are in the range from −0.5 to 0.5 [5]. When other indoor environmental factors in the PMV model change, the preferred MRT delta value, which is the value of this additional factor needed to make people feel thermal comfort, would vary.

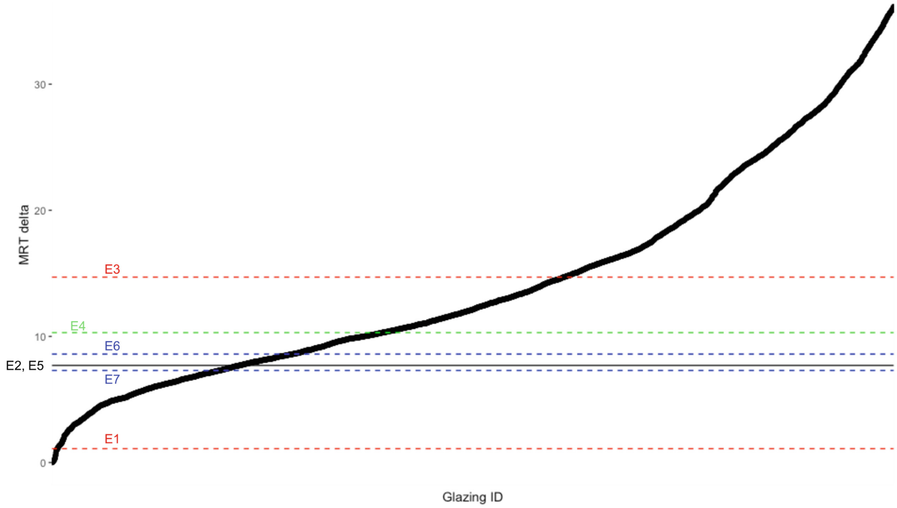
The preferred MRT delta values were calculated for specific indoor environmental settings listed in Table 1. It should be noted that air temperature and MRT were assumed the same in the analysis. The target PMV value for achieving the preferred MRT delta was set at 0. Along with the settings of the four original environmental variables in the PMV model, the metabolic rate of the human was set at 1 met and the clothing level was set at 0.6 clo during the calculation.

Table 1. Settings for the environmental variables.

Number	Air temperature (°C)	MRT (°C)	Air velocity (m/s)	Relative humidity (%)
E1	25	25	0.1	50
E2	22	22	0.1	50
E3	19	19	0.1	50
E4	22	22	0.2	50
E5	22	22	0	50
E6	22	22	0.1	30
E7	22	22	0.1	60

3 Results and Discussion

The MRT delta values of glazing products in the IGDB are shown in Fig. 2 in ascending order. The MRT delta values range from 0.0014 to 36.15, which corresponds to a difference of approximately 6.5 difference in PMV values. With the solar light-induced effect being considered and additional MRT delta value included in the model, the original PMV range is exceeded, which reflects the significant and influencing solar light-induced thermal effect of windows. In addition, the substantial variations in the glazing effects underscore the significant impact that windows have on the solar light-induced thermal comfort effect.



Number	E1	E2	E3	E4	E5	E6	E7
MRT delta	1.1	7.7	14.7	10.3	7.7	8.6	7.3

Fig. 2. The MRT delta values for glazing products present in the IGDB and the preferred MRT delta values for various indoor environments. The MRT delta values for the 5138 glazing products are arranged in ascending order. The ascending order of the MRT delta values, along with their large quantity, results in the accumulation of data points forming an ascending line (depicted in black). This line serves to visually represent distribution of MRT delta values for glazing products. The preferred MRT delta values for conditions E1 to E7, which are defined in Table 1, are indicated by horizontal dashed lines. Different colors are utilized to distinguish conditions with various settings: E2, serving as the baseline condition, is represented in black; E1 and E3 have different air temperature settings compared to E2, indicated in red; E4 and E5 have different air velocity settings, shown in green (since the MRT delta value of E5 is the same as E2, the line remains black); E6 and E7 have different Relative humidity settings, denoted by blue. The MRT values for these conditions are also summarized and listed at the bottom of the figure.

The preferred MRT delta values differ across various indoor environmental conditions, as shown in Fig. 2. E2 is the baseline condition with air temperature of 22°C, air velocity of 0.1 m/s, and relative humidity of 50%. With the increment of air temperature, the preferred MRT delta decreases. Conversely, an increase in air velocity leads to an increase in the preferred MRT delta. However, when the air velocity decreases from 0.1 m/s to 0 m/s, the preferred MRT delta remains unchanged. This indicates that low air velocity may counteract the additional solar effect. Regarding relative humidity, higher humidity results in a smaller preferred MRT delta, although the influence of relative humidity tends to be smaller compared to the other two variables.

The variations in the preferred MRT delta values across different indoor environments necessitate the selection of appropriate windows to achieve thermal comfort. Conversely, selecting different windows would require different indoor environment conditions, thereby offering the potential for energy savings when employing active strategies to maintain a comfortable indoor environment.

4 Conclusions

Glazing products available in the IGDB offer a diverse range of MRT delta values, reflecting the substantial role that windows have in solar light-induced thermal comfort effects. This effect can influence the requirements of other indoor environmental variables that are typically controlled by active strategies such as air conditioning systems in modern society. Therefore, a careful selection of window systems to use the solar light-induced thermal comfort effect in a more practical way will improve human thermal comfort indoors and enhance energy savings.

This study also presents a workflow and knowledge that can assist stakeholders and customers to evaluate and select window systems. The spectrally-resolved method, introduced in this paper and our previous publications, for calculating MRT delta values can be applied more broadly to evaluate target windows under specific solar, environmental, building, and human conditions. Furthermore, it would be beneficial if a thermal effect index for the windows in the IGDB could be developed and integrated in the National Fenestration Rating Council (NFRC) window rating system. This would offer customers direct information when choosing a glazing product in the market, as the thermal effect index would be displayed on the NFRC label. A higher index value would indicate a higher MRT delta value, implying that the glazing product allows more sunlight entering indoor spaces. Customers could then make informed decisions based on their specific needs and preferences. Through the generalization of the method and potentially incorporation of the index in the NFRC rating system, guidance related to the thermal effect of the windows could be provided to relavant organizations and customers. With that being said, ongoing research is still needed to gain a deeper understanding of the role of windows in the solar light-induced thermal comfort effects. Future research should explore more aspects to develop a more comprehensive and systematic rating system.

Acknowledgment. This project is supported by the NSF award: # 2001207: CAREER: Understanding the Thermal and Optical Behaviors of the Near Infrared (NIR)-Selective Dynamic Glazing Structures.

References

1. Zhao, Q., Lian, Z., Lai, D.: Thermal comfort models and their developments: a review. Energy Built Environ. **2**(1), 21–33 (2021)
2. Arens, E., Hoyt, T., Zhou, X., Huang, L., Zhang, H., Schiavon, S.: Modeling the comfort effects of short-wave solar radiation indoors. Build. Environ. **88**, 3–9 (2015)

3. Wang, N., Wang, J.: A spectrally-resolved method for evaluating the solar effect on user thermal comfort in the near-window zone. Build. Environ. **202**, 108044 (2021)
4. Berkeley Lab Homepage. https://windows.lbl.gov/software/igdb. Accessed 11 Apr 2023
5. Yau, Y., Chew, B.: A review on predicted mean vote and adaptive thermal comfort models. Build. Serv. Eng. Res. Technol. **35**(1), 23–35 (2014)