

Analysis of a Participants Experiment on the Physiological and Psychological Responses due to the Low-Emissivity Glass in a Winter Vehicle Cabin

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Low-emissivity (Low-E) glass reflects long-wave radiation and has been widely used in buildings as double glazing to reduce heat loss in the winter and solar radiation in the summer. Low-E single-glazed glass is also being introduced in vehicles to improve occupant comfort and reduce HVAC energy consumption. However, the winter performance in vehicle cabins has not been sufficiently quantified. This study evaluated how automotive Low-E glass affects the cabin thermal environment, local skin temperature, and local and whole-body thermal sensation under simulated winter conditions. The measured sensations were also compared with a previously developed psycho-sensory intensity (PSI) model.

A plug-in hybrid vehicle was placed in a climate chamber maintained at -10.0 °C, while the cabin air temperature was controlled at approximately 23.3 °C. The left rear window was covered with a low-emissivity film (emissivity 0.14), while the other windows retained normal glass (emissivity 0.84). Twelve healthy university students, six men and six women, wore standardized clothing with a thermal insulation of approximately 1.0 clo and sat alternately beside the Low-E and normal windows. The cheek and back of the hand were positioned 8 cm from the glass for five minutes. Air and globe temperatures, humidity, air velocity, glass surface temperature, long-wave radiation, and skin temperatures at 14 body parts were recorded. Participants voted local and whole-body thermal sensation and comfort on ASHRAE seven-point scales before and during exposure.

The Low-E condition reduced total heat loss through the window by approximately 38%, compared to normal glass because the reduction in radiative heat transfer significantly outweighed the increase in convective heat transfer. At a distance of 10 cm from the glass, the mean plane radiant temperature was 20.6 °C for Low-E glass and 9.6 °C for normal glass. The corresponding equivalent temperatures were 20.3 °C and 15.8 °C, respectively. The single-glazed automotive Low-E glass therefore produced a radiant environment comparable to or warmer than the environment calculated near architectural Low-E double glazing (Fig.1).

After five minutes of local exposure, the decrease in skin temperature on the cheek and the back of the hand was about 0.5 to 1.0 °C smaller next to the Low-E window. The local thermal sensation was significantly warmer under the Low-E condition, with an initial difference of approximately 0.5 scale points (Fig.2). Whole-body thermal sensation was also warmer, and the cheek condition showed a significant difference after five minutes. Women consistently voted stronger cold sensations near normal glass than men, particularly for the back of the hand, suggesting greater sensitivity to the improved radiant environment.

The PSI model represented cold-receptor responses at a depth of 0.2 mm and accounted for sensitivity of the different body parts. The calculated PSI values were 16.3 to 16.7 for the Low-E condition and 40.2 to 44.8 for normal glass. The Low-E to normal PSI ratio was approximately 0.4 for both the cheek and the back of the hand, which aligned with the experimental ratio of changes in local thermal-sensation votes. Combined environmental measurements, skin temperature data, participants votes, and model analysis indicate that automotive Low-E glass significantly reduces radiative cooling near winter windows, limits the decrease in local skin temperature, and reduces local and whole-body cold sensation. These benefits can improve cabin comfort while supporting lower HVAC loads and larger glazed areas.

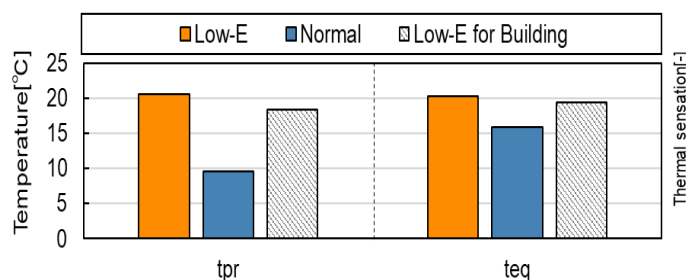


Fig.1 Mean plane radiant temperature and equivalent temperature for each glass condition

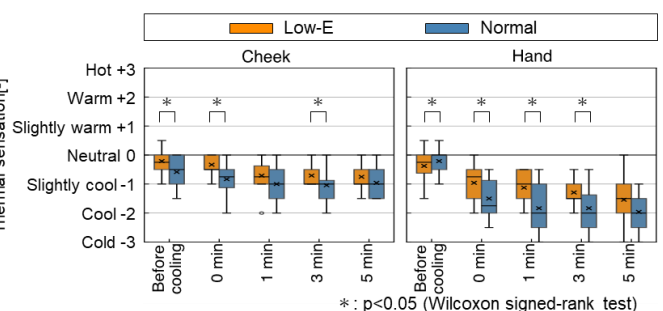


Fig.2 Local thermal sensation by cooling body part