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The Effect of Coloured Glazing on Thermal, Visual and Overall Comfort Evaluation

Giorgia Chinazzo[a]*, Jan Wienold[a] and Marilyne Andersen[a]

[a] *Laboratory of Integrated Performance in Design, School of Architecture, Civil and Environmental Engineering (ENAC), École polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland*
** Corresponding author: giorgia.chinazzo@epfl.ch*

ABSTRACT
Within the scope of a broader research project about visual and thermal interaction effects on human comfort and perception, the aim of this paper is to study the variation of thermal, visual and overall comfort votes of people exposed to blue and orange glazing. The study, conducted in a controlled test room and involving a total of 75 participants, is repeated at three temperature levels to investigate whether variations in comfort votes are affected by the thermal environment. Results show that participants changed their comfort votes for both thermal and overall comfort, beside the expected visual comfort, due to changes in glazing colour. Larger variations in thermal and overall comfort votes are observed in the close-to-comfortable temperature range (22 °C). Temperature-related effects can be seen for visual and thermal comfort evaluations. Overall comfort shows a positive correlation with both visual and thermal comfort.

Keywords: *colour, temperature, visual comfort, thermal comfort, overall comfort.*

INTRODUCTION

Colour is an essential aspect of the built environment that characterises the whole indoor ambiance, from small objects to the permeating light. Colour, besides affecting the visual perception of people, can also influence other types of perception, such as the thermal one. The specific influence of coloured stimuli on human thermal perception is referred to as the "hue-heat-hypothesis" (Bennett and Rey, 1972) and has gained attention for building design and operation due to the fascinating idea of heating and cooling with colours. A recent literature review by the authors suggests that the colour of light can have a bigger impact on the thermal perception of people compared to the colour of objects or of room surfaces (Chinazzo et al., 2018a). The colour of the incoming daylight resulting from both direct sunlight and diffuse skylight, changes its appearance due to variations of its spectrum according to weather, time of the day and season (Judd et al., 1964; Lee and Hernández-Andrés, 2005), but also because of the window's spectral transmittance properties. The role of glazing's properties (in particular, its colour) and the resulting transmitted daylight (from now on referred to as "coloured daylight") becomes therefore an important factor to study for the understanding of not only the visual perception of the indoor environment, but also of the thermal perception and the overall comfort of people.

The present study is a part of a larger research project aiming to understand the interactions between visual and thermal factors on human perception. In particular, visual (i.e., colour) and thermal interactions are investigated by means of experiments in a controlled environment that allows to set, change and monitor the indoor temperature and the coloured daylight by means of coloured glazing. The main findings about the effect of coloured daylight on thermal perception and the effect of temperature on visual evaluations can be found in Chinazzo et al. (2018b, 2018c). This paper focuses on comfort evaluation only, considering thermal, visual and overall comfort together. It first analyses the comfort vote variations according to coloured daylight (differences between blue and orange) to see if the change of glazing, other than affecting the visual comfort, has an impact on thermal and overall comfort as well. Those variations are studied at three temperature levels, to investigate whether also the thermal environment plays a role in the evaluation. Finally, the paper investigates the correlation between the three types of comfort.

EXPERIMENTS

A total of 75 people participated in the experiment conducted from November 2016 to April 2017 in a semi-controlled environment (i.e., a test room where temperature is controlled by means of a radiant system, whereas light is subjected to changes due to the time of the day, climate and season as only daylight is taken into consideration). Details are described in Chinazzo et al. (2018c). All participants experienced three types of glazing, two coloured (blue and orange) and a neutral one presented in a randomized order, and just one of the three temperature levels investigated (19 °C, 22 °C or 26 °C). Each experiment lasted three hours and participants experienced each colour condition for 30 minutes (considered as a short exposure time), while exposed to the same temperature range for the entire experiment. Thermal adaptation occurred in the first part of the experiment, when participants were exposed to electric light for 45 minutes. Participants reported their subjective evaluations about thermal, visual and overall comfort on the same five-point semantic differential scale (from very uncomfortable to very comfortable) at the end of each colour exposure. Two types of visual comfort questions were included in the investigation, referring respectively to the evaluation of the colour of the light and the general visual environment. We will refer to them as colour comfort and general visual comfort, respectively.

RESULTS AND DISCUSSION

Given the experimental design followed in this investigation and the fact that all the participants experienced the three glazing types, this paper addresses the difference in visual, thermal and overall comfort votes between the two extreme coloured daylight conditions, the blue and the orange. The following results and discussion report a comfort vote variation following equation 1, calculated for each participant.

$$\boldsymbol{comfort\ vote\ variation = comfort_{blue} - \ comfort_{orange}} \qquad (1)$$

Considering that comfort votes range from 1 (very uncomfortable) to 5 (very comfortable), the maximum difference between the two votes is 4. A comfort vote variation equal to 0 indicates that participants did not change their comfort vote under different colours. Positive values illustrate that participants rated the comfort under the blue condition more positively than under the orange, whereas negative values indicate a more comfortable condition under orange compared to blue.

Figures 1, 2 and 3 illustrate the distribution of thermal, visual and overall comfort vote variations between blue and orange coloured daylight, at three temperature levels.

By looking at figure 1 it appears clearly that thermal comfort of participants was affected by the coloured daylight. In particular, thermal comfort was evaluated higher under the orange condition compared to the blue one by 40% and 44% of participants exposed to 26 °C (considered "neutral" in the corresponding thermal sensation scale) and 22 °C (considered in between "slightly cool" and "neutral"), respectively. The percentage decreases under 19 °C (considered in between "cool" and "slightly cool") and it equals the one indicating more comfortable conditions under the blue light. Results suggest a temperature-related effect, with orange glazing evaluated as more comfortable under comfortable (26 °C) or close-to-comfortable (22 °C) temperatures.

For the visual comfort, we found – as expected – that the comfort related to colour of participants was affected by the coloured daylight. What is interesting to point out, by looking at figure 2, is that results are effected by the thermal environment. Orange is considered a more comfortable colour compared to blue at 19 °C (by 44% of participants) and at 22 °C (by 52% of participants), whereas the percentage of people considering blue a more comfortable colour than orange increases with temperature, with 44% at 26 °C compared with 12% at 19 °C. Also, results here suggest a temperature-related effect of colour on visual comfort evaluation, in terms of comfortable colour conditions.

The overall comfort variation (figure 3) is affected by colour but it does not show changes of votes that would have indicated a higher overall comfort under a particular colour (the negative and the positive differences are always similar), nor a temperature-related effect. On the other hand, the variation of votes is larger at 22 °C, whereas it is smaller at 19 °C and at 26 °C, in which the majority of participants did not change the overall comfort vote at different colour exposure (variation equals 0). The same observation can be done for the thermal comfort variation (figure 1). This result suggests that the effect of colour on thermal and overall comfort might be stronger in a temperature range considered as close-to-comfortable (22 °C) and the effect of temperature might predominate at temperature ranges considered as comfortable or slightly outside of the comfort zone. Regarding comfort related to colour, the variation in comfort votes is smaller in the cold temperature condition, meaning that the effect of the colour on a visual-related scale is lower if the temperature is slightly outside of a comfortable zone.

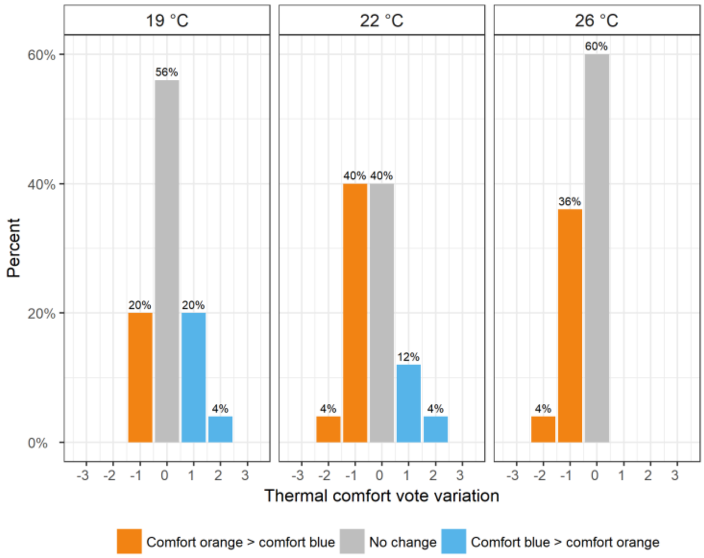

Figure 1: Thermal comfort votes variation between thermal comfort votes of participants exposed to blue daylight and the thermal comfort votes of participants exposed to orange daylight.

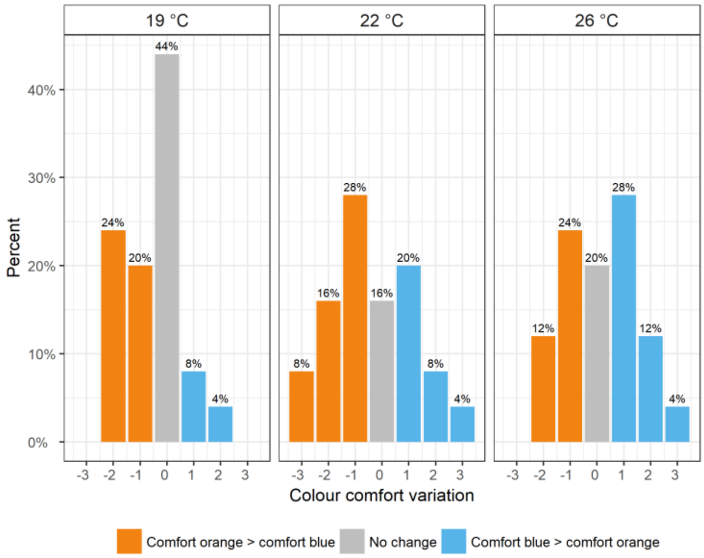

Figure 2: Visual comfort votes variation (in terms of colour evaluation) between colour comfort votes of participants exposed to blue daylight and the colour comfort votes of participants exposed to orange daylight.

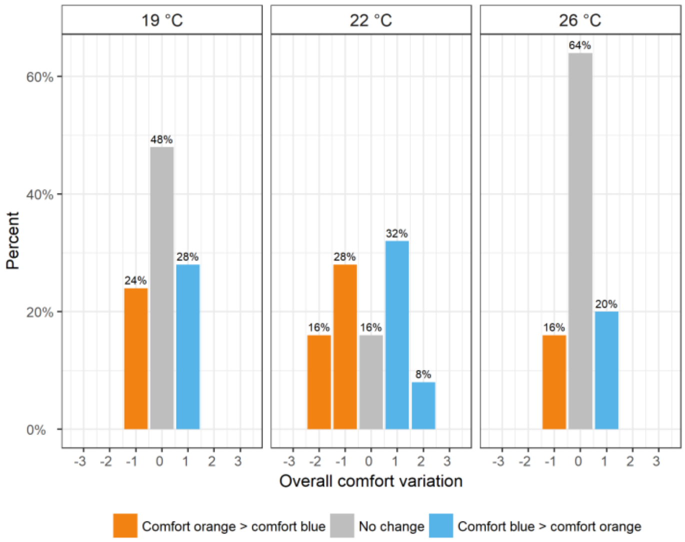

Figure 3: Overall comfort votes variation between overall comfort votes of participants exposed to blue daylight and the overall comfort votes of participants exposed to orange daylight.

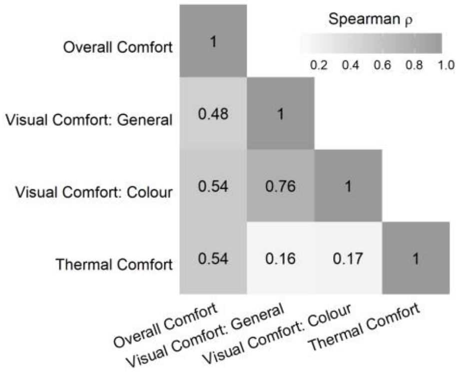

Figure 4: Correlation matrix between overall, visual (general and colour) and thermal comfort.

Figure 4 illustrates the correlation matrix with the Spearman correlation between the three investigated comfort votes: overall, visual (general and colour) and thermal. This time, all the votes at all temperature levels for all three coloured glazing (neutral, blue and orange) are included in the analysis. It is possible to see that the overall comfort positively correlates with both thermal and colour comfort in a comparable way, a result that seems in contrast with previous studies, where overall comfort was mainly related to thermal comfort (Buratti et al., 2018; Frontczak and Wargocki, 2011; Kim and de Dear, 2012). A possible explanation for the contrasting results is the nature of the experiment, in which both thermal and visual parameters were the only factors varied across participants, resulting in the two principal factors strongly correlated with the overall evaluation. Thermal and visual comfort do not correlate and only 76% of the variation in colour explains the variation in the general visual environment, highlighting that colour, despite being a strong attribute of the visual environment, was considered along with other factors in the general visual comfort evaluation.

CONCLUSION

This paper illustrates that changes of coloured glazing resulted in changes of thermal and overall comfort, other than of foreseeable changes of visual comfort. Moreover, results show temperature-related colour effects regarding visual and thermal comfort evaluations. In particular, orange glazing led to more comfortable thermal conditions than blue glazing, especially at comfortable (26 °C) or close-to-comfortable (22 °C) temperatures. Orange glazing also led to higher colour comfort compared to blue glazing at slightly uncomfortable (19 °C) and close-to-comfortable (22 °C) thermal conditions, and preferences with blue daylight over orange daylight increased with temperature (from 12% at 19 °C to 44% at 26 °C). Despite changes in colours led to changes in overall comfort, neither blue nor orange resulted in more comfortable overall conditions. Variations in thermal and overall comfort votes between the blue and the orange conditions were larger in the close-to-comfortable thermal condition (22 °C), highlighting a stronger influence of temperature in the other thermal conditions. Variations in colour comfort votes were larger at comfortable (26 °C) and close-to-comfortable (22 °C) thermal conditions, meaning that the effect of colour on a visual-related scale is lower if the temperature is slightly outside of a comfortable zone.

Overall comfort positively correlated to both visual and thermal comfort in a comparable way, due to the experimental design and the fact that colour was a strong attribute of the indoor environment.

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