CHROMATIC AND LUMINOUS CHARACTERIZATION OF GLAZING PANES: CRITICAL ANALYSIS OF INTERNATIONAL STANDARDS

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ABSTRACT

In modern architecture glazed units have become a component whose diversified and complex functions shall often satisfy conflicting needs. The glazed element must be capable to modulate and control the radiant and luminous flux incoming into a room improving the quality of vision and living suitability.
The task of this study is to highlight the limits of standards in evaluating glazing units, pointing the attention on the luminous and colorimetric parameters and their influence on people satisfaction and comfort. This study analyses satisfaction and comfort levels versus the values of some "standard" and “suggested” photometric and colorimetric parameters characterising glazing units.
This research has been divided into two parts: a laboratory characterisation of a selected group of glazing units, and a subjective test investigation carried out in a scale model of an open-space office.

KEYWORDS

Glass, colour rendering, chromatic and luminous characterisation, standard.

INTRODUCTION

In architecture, light and colour have always been considered key planning elements with symbolic, esthetical or functional role. Several studies and researches have been carried out with the aim of improving the thermal, energetic and luminous behaviour of glass. A great number of products capable to satisfy different comfort and energy-saving needs are currently available on the market [1] [2]. They have different photometric and colorimetric characteristics and substantially modify the light distribution levels in the closed environment and the colour appearance of the lighted objects.

This study analyses the correlation between "standard" photometric and colorimetric parameters that physically characterise glazing units and satisfaction and visual comfort of people. The aim is to underline lacks in norms and extrapolate simple rules for evaluation and applicability of the most significant parameters from people response.

ANALISED PARAMETERS AND NORMS

The CIE (Commission Internationale de l’Eclairage) technical reports for the definition of the physical parameters characterising light-material interaction [3] [4], about colour [5] or colour rendering [6] [7], and for the specification of internal lighting requirements [8] gives a scientific background to which many International Standards refer.

The main relevant normative documents that should be considered are European CEN

(European Committee for Standardization) [9], American ASTM (American Society for Testing Materials) [10], [11] and ISO (International Standardisation Organisation) Standard [12], [13]. They specify the methods for evaluating both solar and luminous characteristics of building glass panes.

In this study the parameters considered are the glazing spectral luminous transmission (τ_λ), and the general colour rendering index (R_a).

Luminous transmittance (τ_v) is the ratio between the transmitted and the incident luminous flux.

Colour rendering index (R_i) measures the degree to which the psychophysical colour of an object (i) illuminated by a test illuminant conforms to that of the same object illuminated by the reference illuminant:

$$R_i = 100 - 4.6\, \Delta E^* \qquad (1)$$

Where ΔE^* represents the colour shift between the two above defined situations [5].

The general colour rendering index R_a is the arithmetic mean of the R_i for a specified set of 8 or 14 samples defined by CIE in 1974 [7]:

$$R_a = \frac{1}{n} \sum_n R_i \qquad n = 8 \text{ or } 14 \qquad (2)$$

The importance of the direction of the colour shifts (ΔE^*) is recognised but not included in the colour rendering indices. CIE asserts the difference in R_i of about 5 units will correspond to visually perceptible colour differences under the best conditions [7]. No such simple rule can be given for R_a, obtained as an average of R_i. This is one of the lacks of the index itself, which can be particularly important in designing lighted rooms where colour discrimination and recognition are essential requisites.

In Europe, standard EN 410 [9] is the primary reference for the determination of luminous characteristics of glazing. It would specify how to measure τ_v and calculate R_a for simple and multiple transparent or translucent glazing units.

The first step in the measurement procedure should be the definition of measurement uncertainty and instrument significant characteristics, so to be able to compare results from different laboratories. In EN 410 [9] these problems are not considered, it just asks to specify in the certificate the sample and instrument characteristics. No cross-references to specific rules for measurement execution such as [10], [11], [13] can be found.

EN 410 [9] considers spectral measurement only for normal incident and transmitted radiation. This approach is physically correct when transparent glass panes are considered but it is inadequate when diffusing, translucent or redirecting panes are characterised [14], [15], [16]. For the last sample typologies' results obtained in different laboratories are often not compatible with the declared measurement uncertainty [2], [17].

Light transmittance, τ_v, is calculate from the spectral transmittance quantity $\tau(\lambda)$, using the CIE Illuminant D_{65} as reference light source. In glazing unit typical application, the sky radiation (i.e. illuminant D_{65} [18]) illuminates the specimen diffusely, while the solar direct radiation (i.e. illuminant B [18]) illuminates the specimen in definite directions, functions of the hour of the day, day of the year and, of course, building facade orientation and position.

The measurement geometry and source types should follow the same principles. An hemispherical/hemispherical or, better, an hemispherical/directional measurement carried out using an illuminant D_{65} source defines the indicatrix of diffusion [18] or BDTD (bi-directional transmittance distribution) [18] and characterises the specimen for the daylight radiation. A directional/directional measurement carried out using an illuminant B (or A for simplifying the measurement procedure) source characterises the specimen for direct sun radiation. This should be more representative of the material behaviour in use.

The general colour rendering index R_a was originally used [7] to characterise artificial light chromatic behaviour. In daylighting applications, the European Standard EN 410 [9] selects correctly only one reference illuminant: the CIE D_{65}. In CIE 13.3 [7] spectral intervals of at most 5nm are recommended to characterise the illuminant, while EN 410 [9] suggests interval of 10nm, even if modern spectroradiometers for industrial measurement works on steps of at least 5 nm.

Summarising the main lacks of requirements are: a) glass response to light dependence on incident angle is not taken into consideration; b) the relation between luminous transmission, colour rendering index and people performance is not investigated; c) the measurement procedures are not always well defined, so that the data found in manufacturer literature are not easily comparable.

SUBJECTIVE AND OBJECTIVE EXPERIMENTAL ANALYSIS

The need for a deeper knowledge about glass luminous and chromatic responses induces a team made up by researchers from the Energy Department (Faculty of Architecture in Politecnico di Torino) and from the Photometry Department (Istituto Elettrotecnico Nazionale Galileo Ferraris) to an experimental investigation. This research was divided into two parts: a laboratory characterisation of a selected group of glazing units, and a subjective test investigation using a scale model of an open-space office where the already characterised glazing units were the office windows.

The investigated parameters were the luminous transmission τ_v and the general colour rendering index R_a.

Nineteen selected specimens (clear, coloured, reflective glazing and clear glass with diffusive or reflective film) have been characterised in the IEN Goniophotometric Laboratory [14][15][16][17][18][19]. Spectral measurements have been carried out using a calibrated spectrophotometer on a goniophotometer to evaluate the spectral transmittance. Then τ_v and R_a have been calculated following EN410 [9] (“standard” parameters), after that all the glazing units has been characterised for different incident angle of light beam and in diffuse-light conditions (“non-standard” parameters).

Light transmittance and colour rendering have been evaluated in several conditions. The influence of the incidence conditions varies depending on the technology used to produce the glass: as a general rule, increasing the angle of incidence the luminous transmission decreases.

For angles of incidence greater than 60° the difference with the normal luminous transmittance should be even more evident, and further tests will be done, so to verify if there is the need of a second light transmittance index, which can be representative of the ‘dynamic’ behaviour of the glazing for different angles of the incident beam or in a specified light condition [20].

R_a values are not so clearly correlated with light distribution and incident angle, but R_a varies of more than 5 units, this means that the colours inside the room, even after the chromatic adaptation, will seems different to the people (Figure 1).

CIE Publication 13.3 [7], to which EN 410 [9] refers, states that R_a depends on the choice of the reference illuminant and therefore, on the value of its correlated colour temperature (CCT). The reference illuminant is intended to have the same or nearly the same chromaticity of the source to be tested. The chromaticity difference (DC) should be smaller than $5.4*10^{-3}$. Calculating R_a for 9 coloured and/or reflective glass panes using D_{65} as reference illuminant, as EN410 [9] requires, this condition is satisfied only once (sample 6871). Table 1 shows that R_a calculated with a reference illuminant chromatically similar to the glass analysed can be significantly different from the one calculated using D_{65}.

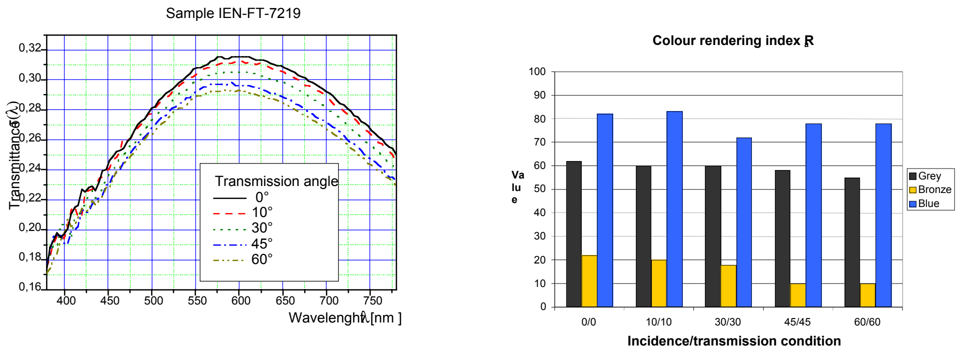
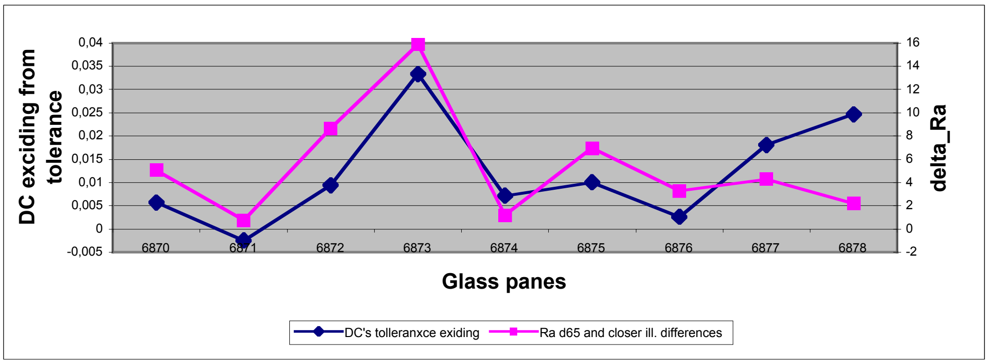


Figure 1 Objective analyses. Spectral transmittance of the blue magnetronic reflective glass for different angles of transmission and diffuse (hemispherical) incidence (on the left). Colour rendering index for three panes (with similar luminous transmittance factor) versus incident and transmission angles (on the right).

A second restriction in the calculation of R_a is underlined in CIE 13.3 and ignored in EN410. The luminance of the reference illuminant and of the tested source (i.e. glass, lamp,…) should be the same. Of course this is impossible in the case of glass panes, screens, etc. as the main requirement for them is the attenuation of incoming light. If we calculated the R_a without equalising the two luminances we obtain a rendering index which is mainly function of the glass luminous transmission τ_v ($R_a(\tau_v)$) as in Table 2a.

The ability of this index to describe the people response and feeling in daylight conditions has to be tested and index sensibility has to be investigated. To facilitate comparison the index has been scaled linearly so to obtain the figures between 0 and 100 of Table 2b (an approach also adopted by CIE in defining the multiplying factor of ΔE^* in equation 1).

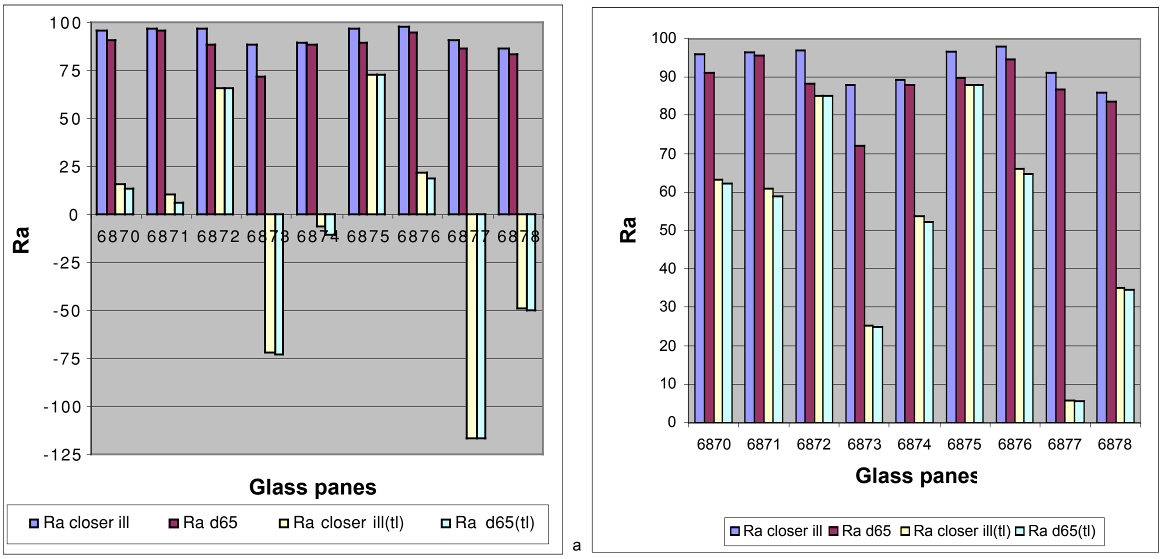
Table 1 The effect of chromatic tolerances versus reference illuminants for different glass panes



To evaluate the effect of the glazing unit on the subjective chromatic sensation and to verify the influence of luminous transmission and R_a, an experimental subjective test has been carried out using a 1:10 scale model of an office with ribbon-like glazed surfaces [21] (Figure 2).

Inside the scale model, some chromatic references and an acuity test table have been positioned. At the experiment some tens of people participated and their eventually chromatic deficiencies verified at the beginning of the tests. The questionnaire has been drawn up on the basis of previous studies and experimentation [22], [23], [21] following current psychophysical methodologies. The aim was to evaluate the subject visual sensations while the person was involved in a visual task. The parameters of investigation were glass appreciation, environment pleasantness and visual satisfaction.

Table 2 Figures of R_a.



It's interesting to verify the relationship between luminous transmission, colour rendering indices and appreciation at different illuminance levels: the answer trend of the subjects is steady for different levels of glazing luminous transmission - room illuminance, while in absolute the appreciation is higher with the raising of the illuminance level. People appreciate differences in colour rendering, but is more sensible to illuminance variations (Figure 2).

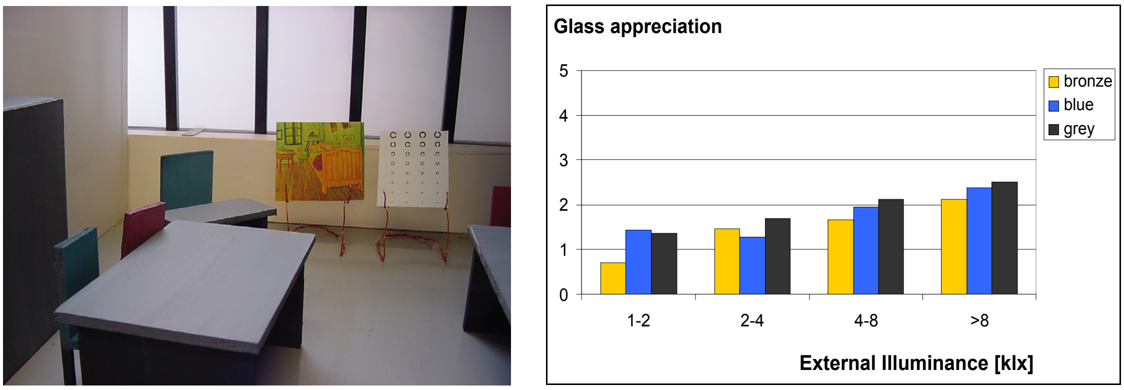
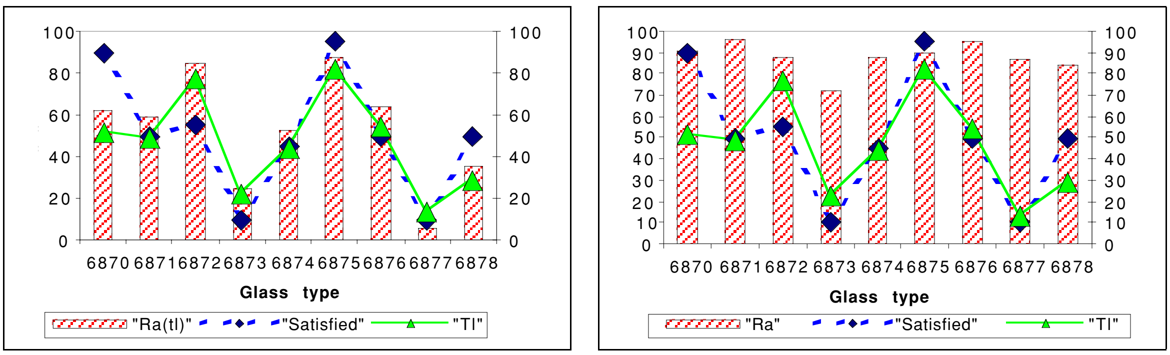


Figure 2 Subjective analyses. Close up view of the model used during the subjective tests (on the left). Subjective glass appreciation (semantic scale) versus external illuminance for three different panes (on the right).

Table 3 τv and Ra(τv) (on the left) or τv and Ra (on the right) compared with the people satisfaction. In both conditions the reference illuminant for Ra was D65.



In Table 3 the results of some of the examined glasses are shown: the correlation between environment pleasantness and $R_a(\tau_v)$ is very satisfying (on the left), while people satisfaction cannot be evaluated throughout standard R_a.

It is interesting to compare the results of Table 2 and Table 3: the absolute values of people preferences and $R_a(\tau_v)$ are different but if the order of appraisal of glass panes is considered the correlation is perfect. If further investigations will confirm this trend the definition and adjustment of an index taking into consideration both parameters (R_a and $\_{v}$) can be significant for quantify people indoor lighting condition appreciation and could be considered an useful index for design.

CONCLUSIONS

In this work authors outline how luminous and colorimetric parameters characterising glazing panes depends on measurements procedures and instruments and the fact that people is strictly sensible to these parameters.

In conclusion we underline the need for standards that should define product indexes (comprehensive of the relevant measurement and calculation procedures) and environment requirements in compliance with the real subjective chromatic perception, as already happened for thermal and acoustic performances parameters. In particular we highlight the need of improve the colour rendering index, originally developed for artificial light, so to be more efficient in daylighting evaluation.

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