By og Byg Documentation 044

Impact of coated windows on visual perception

A pilot study in scale models

Statens Byggeforskningsinstitut
Danish Building and Urban Research

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Preface

This report presents the results of a study achieved within the scope of "Projekt Vindue", a project funded by the Danish Energy Agency. The aim of "Projekt Vindue" was to contribute to energy conservation by encouraging reductions of heat losses through windows. More information about this project may be found on the Internet site: www.projekt-vindue.dk.

"Project Vindue" included a number of parallel projects with the following specific objectives:

1 Development of energy-efficient window assemblies
2 Training of glazing and window manufacturers
3 Information campaign aiming to encourage the use of energy-efficient windows. More information about this campaign may be found on the Internet site: www.energiruder.dk.

"Projekt Vindue" also permitted the establishment of a classification system and marking of energy-efficient windows, which was achieved in collaboration with window manufacturers. This classification system includes three categories: A, B or C (see www.energiruder.dk.). To ensure that the window assemblies fulfil basic environmental requirements and provide a high level of visual quality, two smaller projects within "Projekt Vindue" have also been completed. These projects concern the impact of energy-efficient windows on the environment as well as on daylight quality.

All energy-efficient windows are coated with some type of low-emissivity coatings, which affect the intensity and spectral distribution of daylight. This report describes the results of a pilot study with research subjects using scale models. The aim of this study was to develop a research method to test the impact of coated windows on daylight quality. The project was funded by the Danish Energy Agency under the law "lov om statstilskud til produktrettede energibesparelser" in the project "Daylight quality with the use of low-energy windows", j.nr. 75661/99-003. Since this study only includes experiments with scale models, it should be considered as bearing the limitations of a scale model study. There is a need for larger research projects where the impact of coated windows on room perception, light quality, colour rendering and view are investigated in full-scale buildings including a larger number of research subjects and coated windows.

The authors thank Winnie Larsen from the Danish Building and Urban Research, who organised and assisted laboratory work, as well as the research subjects, who participated in the study.

Danish Building and Urban Research
Energy and Indoor Climate Division, July 2003

Søren Aggerholm
Acting Head of Department

Introduction

The Danish Building Regulations (Danish Housing and Building Agency, 1995) require a U-value[1] below 1.8 W/m^{2}K for windows. In practice, this requirement can only be fulfilled if double-pane windows with at least one low-emissivity coating or triple-pane assemblies with argon or krypton gas fills are used. This requirement has the effect that coated windows are almost systematically used in all new constructions in Denmark.

There is also at present an architectural trend promoting the use of large glass facades in commercial and office buildings. These glass facades generate a large cooling demand and even an increase in the heating demand of buildings due to large heat losses during the winter. In these buildings, it has become common to use windows with combined solar-protective and low-emissivity coatings. The solar-protective layer reduces the cooling demand during the spring, summer and autumn while the low-emissivity layer reduces heat losses and improves thermal comfort during the winter.

Problem

A major drawback of window coatings is their impact on the intensity and spectral distribution (colour) of daylight. While a reduction of daylight intensity may result in an increase in the use of artificial lighting, a modification of the spectral distribution of daylight may affect the perception and quality of a space (Chain, Dumortier & Fontoynont, 1999).

Colour is one of the most obvious and pervasive qualities of human visual perception. While it is possible to recognise objects and perform most visual tasks without chromatic information, colour adds another dimension to perception. In modern offices, colours are often used to code or highlight different classes of information on the computer screen. In education, colour is a useful tool for reinforcing concepts, and many learning schemes adopt systems of colour coding (Thomson, 1996). The colour of light sources and objects also affect the perception of brightness[2] and the colour of surfaces modify the perceived ratio of luminances in a room. Colours also allow us to distinguish objects when luminance contrasts are too small; they thus contribute to spatial orientation and wayfinding (Yorks & Ginthner, 1987).

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[1] The U-value is the thermal transmission coefficient expressed in W/m^{2}K.

[2] Brightness is the attribute of a visual sensation according to which an area appears to emit more or less light (CIE, 1987).

Background

Previous research has shown that a modification of the spectral distribution of daylight may affect visual performance (acuity) (Berman, 1992; Simonson & Brozek, 1948; Blackwell, 1985; Krtilova & Matousek, 1980; Berman, Fein, Jewett & Ashford, 1993). In practice, a poor visual performance caused by unnatural spectral distribution of daylight may be compensated by an increase in illumination but this will result in an increase in the use of artificial lighting (and electricity use).

Some research about the effects of artificial lighting has also indicated that the spectral distribution of daylight may affect visual fatigue or discomfort (Berman, Bullimore, Bailey & Jacobs, 1996; Küller & Wetterberg, 1993). Other research has indicated that the lamps' colour rendering index CRI[3], which is directly related to the lamps' spectral power distribution (SPD), was a good predictor of mean error scores in hue discrimation tests. Note that the Danish standard DS 700 (Dansk Standard, 1997) requires a CRI above 90 for workrooms with critical colour discrimination tasks and 80 for most ordinary types of workrooms. CRIs greater than 90 characterise a very good colour rendering while CRIs greater than 80 characterise a good colour rendering. In Pilkington's catalogue (Pilkington Danmark, 1999), windows with low-emissivity coatings have CRIs greater than 95. Few window coatings for solar protection have CRIs above 90, but all solar-protective glazings have CRIs above 80, although the light transmittance can be as low as 10% and the colour of transmittance can be either grey, brown, green, blue or bronze. The variation in CRIs for glazing is surprisingly small, which may indicate that the CRI alone is not sufficient to characterise visual aspects in connection with windows.

Note, finally, that a modification of daylight spectrum and intensity may also affect health. Previous research has indicated, for instance, that a lack of daylight may induce seasonal affective disorder (SAD), which is particularly widespread in Scandinavia due to the lack of daylight during the winter (Küller & Küller, 2001). An investigation in Sweden (Küller, 1996) indicated the existence of SAD-related symptoms in approximately 20% of the individuals. It has also been shown that natural light affects mood, behaviour and sociability (Küller & Küller, 2001).

[3] The colour rendering index (CRI) is the measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation (CIE, 1987).

Project description

This report describes the results of a pilot study that investigated the impact of six coated glazings on visual perception in scale models. The study focused primarily on visual perception. Other aspects such as health, visual comfort and visual performance were excluded. This study was carried out at Danish Building and Urban Research during January and February 2002. The experiments took place between 09.30 and 15.00 hours, under overcast sky conditions and a northern orientation, in order to ensure that exterior daylight conditions were as constant as possible.

Objectives

The objectives of this pilot study were:

- to develop a method to investigate the impact of coated glazings on visual perception;
- to establish categories of coated glazings in order to simplify future full-scale studies;
- to study how coated glazings affect visual perception in a room;
- to verify whether coated glazings modify the colour of daylight to a degree that is acceptable by people with a normal colour vision.

Method

Scale models

The study was performed using scale models of an office room. The scale models made it possible to include many glazings in the study since it is easier and quicker to change the glazing in a small box than in a real office room. Two identical scale models (scale 1:7.5) of the experimental rooms of the Daylight Laboratory at Danish Building and Urban Research were thus built. These rooms measure 3.5 m (width) by 6.0 m (depth) and have a floor to ceiling height of 3.0 m. The scale models thus had the dimensions 0.47 * 0.8 * 0.4 m^3 (W * D * H). Each scale model had a unique opening for the window measuring 0.17 m (height) by 0.24 m (width) placed 0.18 m above the floor. During the experiments, the opening was covered by small samples of glazing assemblies provided by a glazing manufacturer, figure 1. The glazing samples included in the study are listed in table 1, together with their thermal and optical properties, which were provided by the glazing manufacturer. Opposite the window, a small horizontal hole was made in each box to allow observation by the research subjects, figure 2.

Table 1. Glazing assemblies and their thermal and optical properties, provided by the glazing manufacturer.

Name	Type	Description	U value (W/m^2K)	LT (%)	TST (%)
Ref	2 panes	1 iron free + 1 clear with low-e (hard) coating	1.48	77	79
A	2 panes	1 clear + 1 clear with low-e (soft) coating	1.15	79	63
B	3 panes	1 cl. with low-e (soft) + 1 cl. + 1 cl. with low-e (soft)	0.62	70	46
C	2 panes	1 solar, low-e coating + 1 clear	1.07	50	26
D	2 panes	1 clear + 1 clear with low-e (hard) coating	1.47	76	72
E	2 panes	1 solar, low-e coating + 1 clear	1.15	66	41

LT = Light transmittance (%); TST = Total solar transmittance (in Denmark called g-value) (%)

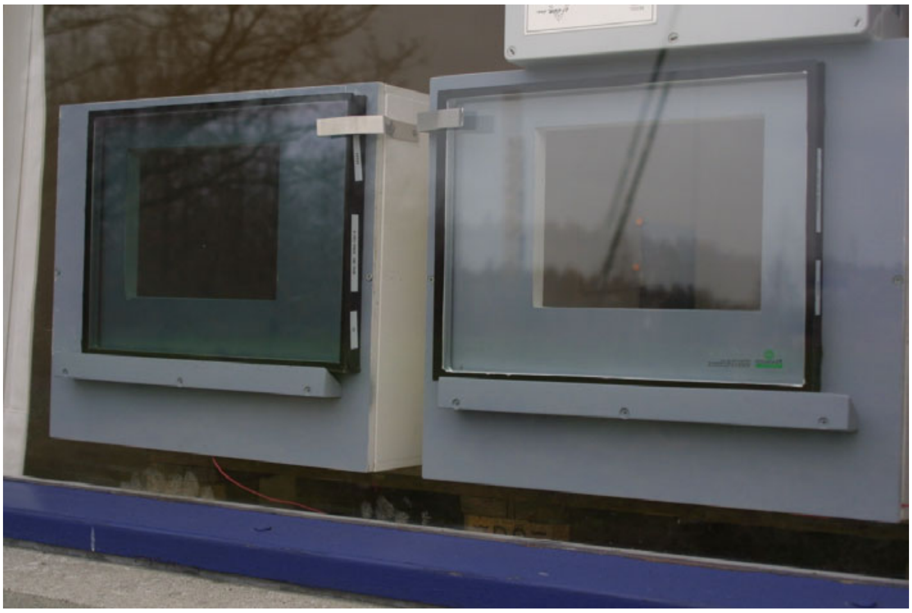


Figure 1. Photograph showing the scale models and their window opening covered by glazing sample.

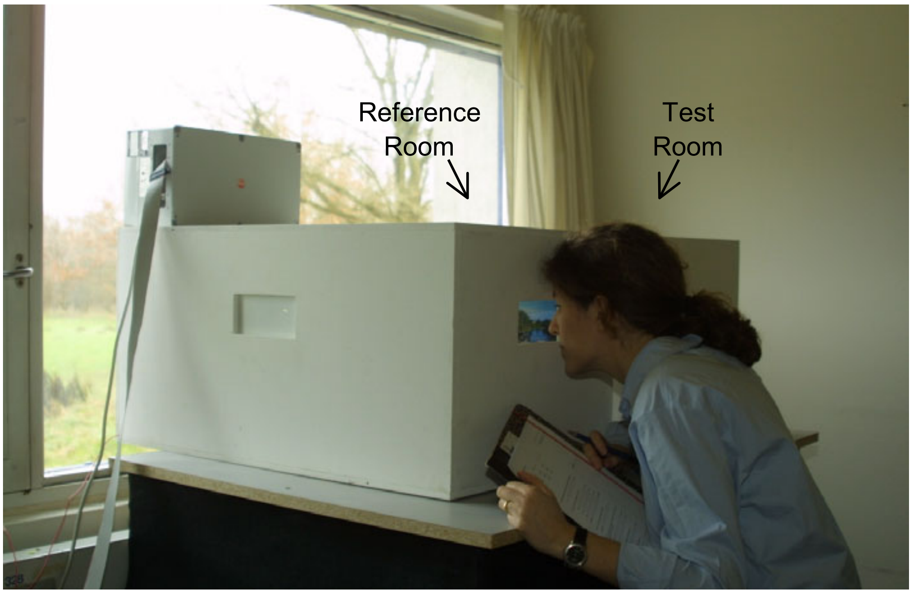


Figure 2. Picture shows how subjects looked into the scale models through the observation hole.

Each scale model was furnished with a scaled table, a silver key (on the table), a piece of broccoli, a baby tomato, a pine cone, a staple remover and a yellow tennis ball (all placed on the floor), figure 3. These objects were chosen because they offered a variety in colour (red, green, yellow, brown and black), shape and texture. The key and staple remover also had interesting shiny surfaces to look at. A coloured photograph of a castle in a landscape, figure 4 was also placed on one of the lateral walls and a black text on white background was placed on the wall next to the window.

Figure 3. Photograph showing the objects placed in each scale model: a scaled table, a key, a piece of broccoli, a baby tomato, a tennis ball, a pine cone (not visible on the picture), a staple remover, a text (next to the window) and a coloured photograph (on the right lateral wall).

Both scale models were placed behind the window of an empty office room at Danish Building and Urban Research. This room was chosen because it had a north orientation and an interesting view over a white architectonic sculpture placed on a grass lawn and surrounded by some trees and bushes, figure 5. The north orientation is preferable since it provides the most constant daylight colour under overcast conditions. The overcast, northern skylight designated CIE illuminant D75, is also the recommended light source for colour testing according to the American Society for Testing and Materials (1996).

The standard, double pane window of the office room where the experiments took place was replaced with a single, ironfree glass window. This avoided having too many layers of glass combined with the glazing samples of the scale models.

Figure 4. Coloured photograph of a castle in a landscape placed on one of the lateral walls of the scale models.

Figure 5. View seen through the windows of the scale models.

Measurements

During the experiments, the following values were recorded:

– the interior horizontal illuminance,
– the exterior global illuminance,
– the exterior vertical illuminance (on the north facade),
– the vertical spectral irradiance behind the single clear glazing of the office room.

The interior horizontal illuminance was recorded using Hagner lux meters Model SD1, which were placed inside the scale models on the scaled tables at about 0.26 m (full-scale: 1.95 m) from the window and at 0.11 m (full-scale: 0.83 m) from the floor, see figure 3. These meters have a spectral ($V(\lambda)$) response error of less than 3% and an additional cosine response error of less than 3%.

The exterior global illuminance was recorded at the meteorological station placed on the roof of the Daylight Laboratory located on the site of Danish Building and Urban Research. This value allowed the calculation of the daylight factor (DF)[4] prevailing in the room during the experiments.

The exterior vertical illuminance on the north facade was recorded using a lux meter similar to the ones used to record the interior horizontal illuminance. This meter was placed directly above the window of the office room where the experiments took place, figure 6. The exterior vertical and interior horizontal lux meters were connected to a datalogger, which was connected to a local PC.

Finally, a spectroradiometer Licor 1800, borrowed from Lund University (Sweden), was used to record the vertical spectral irradiance behind the single glazing of the office room where the experiments took place (also shown on figure 6). This value was recorded only once during each experiment (with a research subject) in order to monitor the variation in sky colour over the course of the study. The spectroradiometer was calibrated using a Licor calibration source before starting the experiments.

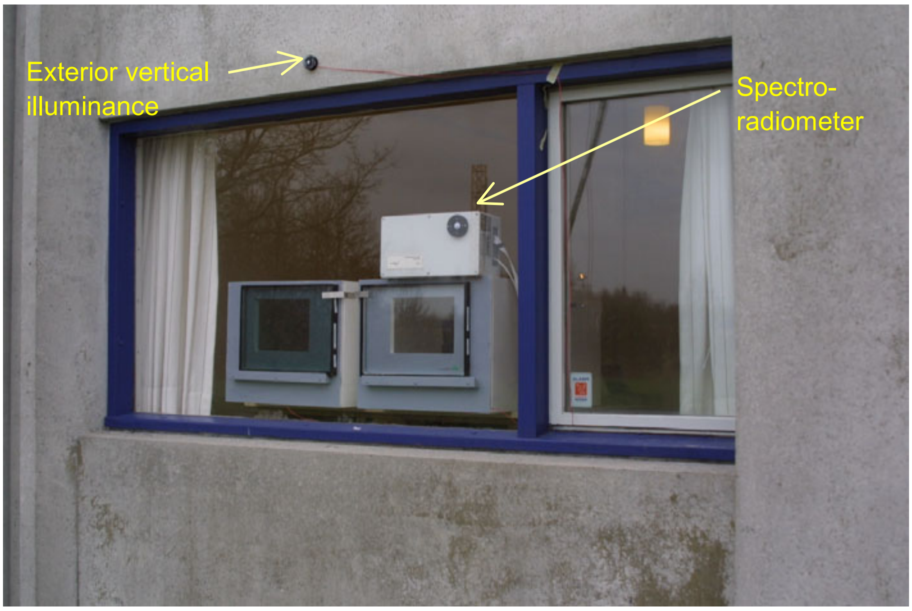


Figure 6. Photograph showing the exterior vertical lux meter placed on the north facade above the window as well as the spectroradiometer behind the single glazing of the office room where the experiments took place.

Experimental procedure

One of the scale models was used as a Reference Room and fitted with a double-pane glazing with an ironfree and a low-emissivity coated glass (glazing “Ref”, table 1). This glazing was chosen as a reference because it was the most neutral in colour among all glazings tested. The other scale model, which will be called the “Test Room” in this report, was alternately fitted with one of the other glazings (A, B, C, D or E, table 1) included in the study.

[4] The daylight factor (DF) is the ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky. The contribution of direct sunlight to both illuminances is excluded. Glazing dirt effects, etc., are included. When calculating the lighting of interiors, the contribution of direct sunlight must be considered separately. (CIE, 1987).

At the beginning of the study, it was decided that the evaluation of all the glazings should be completed using only two sessions in the laboratory. Each research subject would then have to visit the laboratory on only two occasions, each experiment requiring about 40-45 minutes. The glazings in the Test Room were thus divided into two groups:

– Group 1: A, B, C
– Group 2: C, D, E

Note that glazing C was evaluated during each experiment, to verify that the ratings were consistent from one session to the next. Note also that each session included glazings with a high light transmittance (A and D), a medium light transmittance (B and E) and a low light transmittance (C). After the second session was completed, the experimenter noticed that some subjects misunderstood some questions during the first session. After sorting out the misunderstandings, it was decided to hold a third session, which was an exact repetition of the first session.

During each visit to the lab, the subject was first asked to look into the Reference Room (figure 2) and fill in a two-page questionnaire regarding the visual conditions in this room. The subject was then asked to look into the Test Room and fill in an identical questionnaire. The subject was told that he[5] could look back into the Reference Room and at the first questionnaire to make sure that his evaluation of the second room was consistent with his previous evaluation. Once this second questionnaire was completed, the subject was asked to leave the room and wait in the adjacent room. The researcher then went into the laboratory, changed the glazing of the Test Room, and then told the subject to come back into the laboratory and evaluate the conditions in the Test Room again, filling in a third questionnaire, which was identical to the two previous ones. Note that the subject was never told that the glazing of the Test Room had been changed and that he could not see the researcher changing the glazing. Once again, the subject was told that he could look into the Reference Room and at the answers given previously for consistency in his evaluation. Once this questionnaire was filled, the subject was once again instructed to leave the room and wait in the adjacent room. The researcher then went into the laboratory, changed the glazing of the Test Room and told the subject to come back into the laboratory to fill in the last questionnaire observing the conditions in the Test Room in exactly the same way as done previously. The exact same procedure was repeated each time the subject came into the laboratory.

Balanced order of presentation

The order of presentation of the glazings in the Test Room was carefully controlled to make sure that no single order would prevail over another. There are six different ways to present three different glazings in a balanced order of presentation:

Group 1	Group 2
ABC	CDE
BCA	DEC
CAB	ECD
ACB	CED
BAC	DCE
CBA	EDC

Combining Groups 1 and 2 gives 36 (6*6) different orders of presentation of the glazings included in the study, given that the evaluation is completed

5 The masculine is used to lighten the text even though half of the subjects were females.

using two sessions. This means that in order to have all possible orders of presentation, 36 research subjects are needed. Since it was not possible to have that many subjects, the principle of Latin Squares was used to reduce the number of subjects. In a Latin Square, the different combinations of e.g. A, B, and C appear once and only once in each row and column of the 3*3 matrix. In this case, this principle was only applied to Group 1, which reduced the total number of combinations (and subjects needed) to 18 (3*6).

Group 1	Group 2
ABC	CDE
BCA	DEC
CAB	ECD
	CED
	DCE
	EDC

The 18 subjects who participated in the study were all recruited from the administrative and research staff at Danish Building and Urban Research. All the subjects were under 45 years of age and had a normal colour vision[6]. Four subjects wore glasses and three had contact lenses but none of the glasses and contact lenses were tinted[7]. Half (n=9) of the subjects were females.

Questionnaire

According to Liljefors & Ejhed (1990), light in interiors is characterised by seven dimensions: light level, light distribution, shadows, reflexes, glare, light colour and colours. A two-page questionnaire was developed to cover most of these dimensions. The questionnaire focused more specifically on daylight intensity and colour, colours in the interior and in the view out, glare, shadows and textures. The questionnaire was based on seven-grade bipolar scales (except for one question (I)) and included a comment section next to each scale. The questionnaire is reproduced in table 2 with the question numbers that will be used throughout this report (A.1 to M.5).

6 However, note that their colour vision was not directly tested but it was assumed normal if the subjects said it was normal.
7 However, note that even ordinary glass modifies the spectral distribution of light and many glasses have special (e.g. anti-reflective) coatings.

Table 2. Questionnaire filled by the research subjects (translated from Danish, original version in Appendix A).

#	Question		Bipolar scale (1-7)
A	Do you perceive that the room, as a whole, is bright or dark?	1	bright-dark
B	How would you describe daylight in this room?	1	cold-warm
		2	clear-tinted
		3	blurry-sharp
		4	pleasant-unpleasant
C	How easy is it for you to read the text on the paper?	1	difficult-easy
D	How would you describe the shadows on the objects (tomato, broccoli, etc.) and around them (on the floor)?	1	blurry-sharp
		2	hard-soft
E	How do you perceive the details of these objects?	1	sharp-blurry
F	How do you perceive the colours of these objects?	1	natural-unnatural
		2	tinted-not tinted
G	How would you describe the colours in the picture on the wall?	1	warm-cold
		2	natural-artificial
		3	blurry-clear
		4	lively-drab
H	Do you have the impression that daylight in this room is coloured?	1	coloured-not coloured
I	If you have the impression that daylight in the room is coloured, which colour do you perceive? (your answer may indicate more than one colour)		
J	Do you find the colour of daylight acceptable?	1	unacceptable-acceptable
K	How do you perceive the weather outside right now?	1	overcast-no clouds
		2	clear (no fog)-hazy
		3	beautiful-dull
L	What is your general impression of daylight outside right now?	1	weak-strong
		2	glary-not glary
M	How do you perceive the colours outside?	1	warm-cold
		2	blurry-clear
		3	natural-unnatural
		4	lively-drab
		5	normal-altered

Note that the adjectives in the bipolar scales were sometimes given as negative-positive (e.g. question H.1: “coloured-not coloured”) and sometimes as positive-negative (e.g. question M.4: “lively-drab”). This was done purposely in order to make sure that the subjects paid attention and thoughtfully answered each question. However, during the analysis, the scales were arranged so that positive adjectives were given high ratings (= 7) and negative adjectives were given low ratings (= 1). Note also that some questions were repeated (e.g. D.1 and D.2) in order to verify whether the subject’s answers were consistent with one another.

Results

Overview of the subjective ratings

The 18 subjective evaluations were compiled in a database and the minimum (MIN), median, average, maximum (MAX) and interquartile range (between Q(0,25) and Q(0,75)) for the subjective ratings were calculated for each question. The interquartile range comprises the ratings of 50% (n=9) of the subjects. Thus, 25% gave a rating below the interquartile range box and 25% gave a rating above the interquartile range box. The subjective ratings obtained for each question are presented in figure 7 - figure 11. In these figures, the light transmittance of the glazing is written in parentheses after the glazing's name (x-axis) and the y-axis represents the seven-grade rating scale where 1 corresponds to the box closest to the most negative rating while 7 corresponds to the box closest to the most positive rating[8]. The daylight factor measured in the scale models during the experiments is also shown in figure 7.

Do you perceive that the room, as a whole, is bright or dark? dark-bright (1-7)

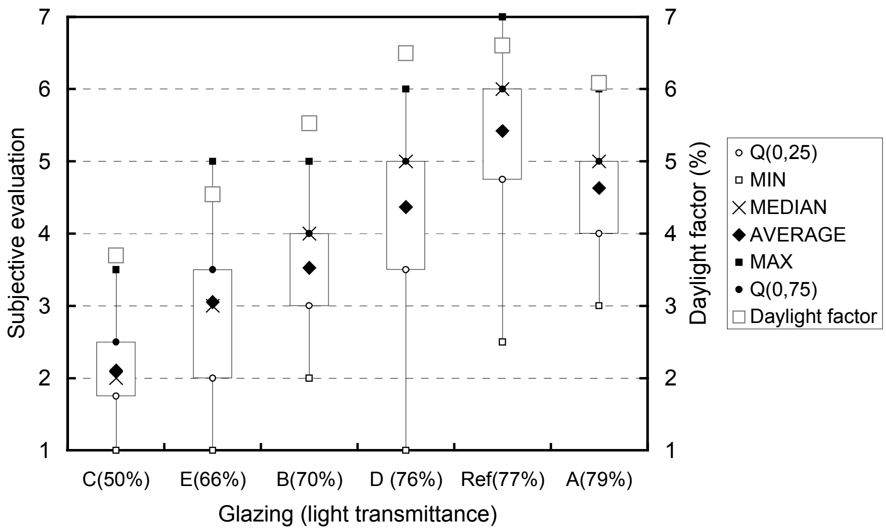


Figure 7. Subjective ratings obtained for question A: Do you perceive that the room, as a whole, is bright or dark? dark-bright (1-7). Left axis represents the subjective evaluation, right axis represents the daylight factor.

Figure 7 shows that the perception of the room being bright or dark is not a direct linear function of the light transmittance of the glazing. The Reference glazing (Ref) made the room appear significantly brighter than the other glazings, while glazing A, which had the highest light transmittance (79%), obtained a rating similar to glazing D. However, note that the higher rating obtained for the reference glazing may be due to the fact that this glazing was in the Reference Room and that the subjects *thought* that this room had a clearer glazing (although they were never told so).

Figure 7 also shows that the subjective ratings have a "curve" similar to the average daylight factor measured during the experiments, which indicates that the subjective evaluation is consistent with the conditions measured in the rooms during the experiments. However, note that the daylight

8 Note that in some cases the scale was arbitrarily assigned a negative and positive end since it was not obvious which one of the adjectives was negative or positive (e.g. the scale "cold-warm").

factor was highest with glazings D and Ref although the light transmittance in these cases was lower than for glazing A. There are a few plausible explanations for this:

The ratio of vertical to global illuminance may have been higher in the case of glazings D and Ref indicating that more daylight came from the northern region of the sky. This may have contributed to give higher daylight factors for glazings D and Ref. Note that the acceptance ratio used at Danish Building and Urban Research for an overcast sky varies between 0.36 and 0.43 and that the ideal ratio for a CIE overcast sky is 0.396.

The light transmittance of the glazing samples used in the study may have differed from the values provided by the glazing manufacturer. Note that the light transmittance was not measured by Danish Building and Urban Research and that the difference in light transmittance between glazings D, Ref and A was very small.

More daylight may have passed through glazings D and Ref because their spectral transmittance was higher in the wavelength intervals where daylight intensity was higher (the spectral distribution of daylight varied from one experiment to the next). Additionally, a larger portion of daylight may have been reflected by the inner surfaces in the scale models with glazings D and Ref because the reflectance of these surfaces was higher in the wavelength intervals where most daylight was transmitted. The accuracy of the measurement equipment (V(λ), cosine response error) may have caused errors in the daylight factor values.

The subjective ratings for the second question (B: How would you describe daylight in this room?) presented in figure 8 show similar profiles as in figure 7, except for the scale “cold-warm” (figure 8a). This indicates that the perception of cold or warm light is not necessarily related to the perception of the other scales (colouring, sharpness, and pleasantness). In this case, for example, glazing Ref provided a more pleasant, sharp and clear daylight than all the other glazings but daylight was perceived as being among the coldest compared to the other cases.

Figure 8b shows that the scale “tinted-clear” exhibits larger differences between the glazings tested, suggesting that the largest difference in perception was related to the colour of daylight. Figure 8c shows that glazings D and A provided an equally “sharp” daylight and figure 8b shows that glazings Ref and D provided an almost equally “pleasant” daylight although glazing A had a higher light transmittance than glazings D and Ref. However, the length of the interquartile range boxes in figure 8d indicates that the subjective ratings were rather spread for this question.

a) How would you describe daylight in this room? cold-warm (1-7)

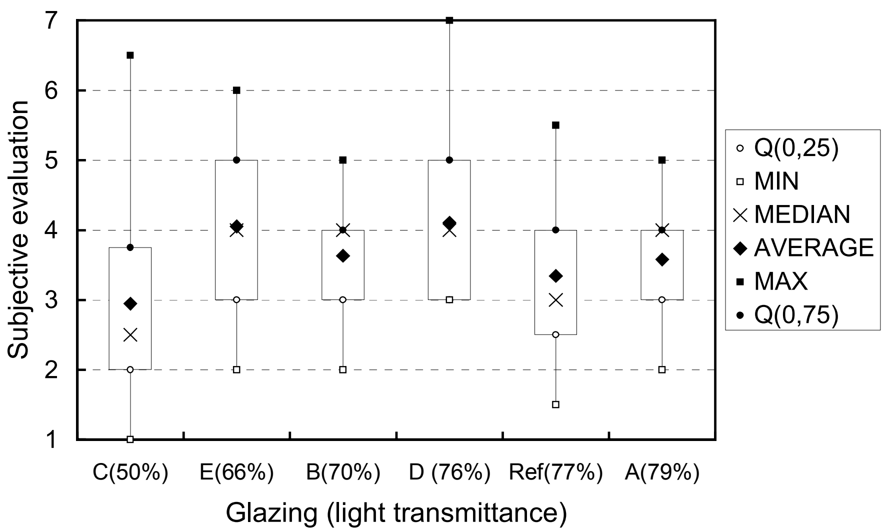
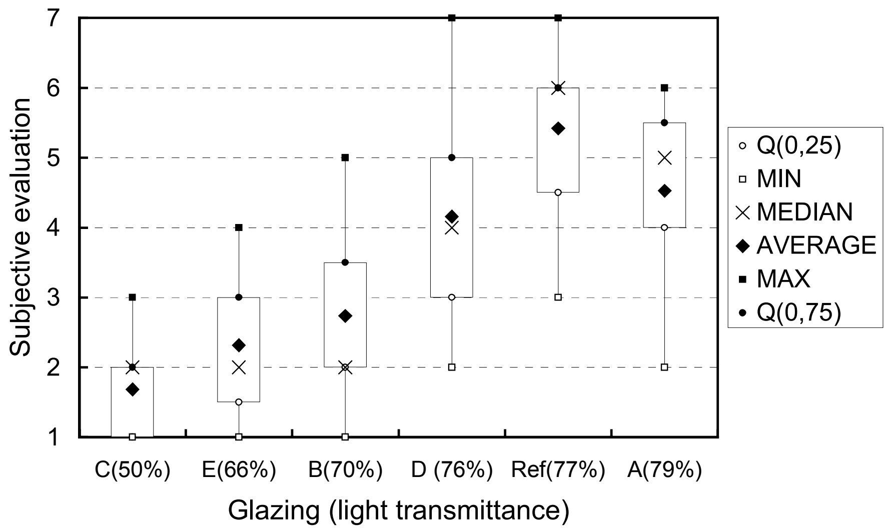
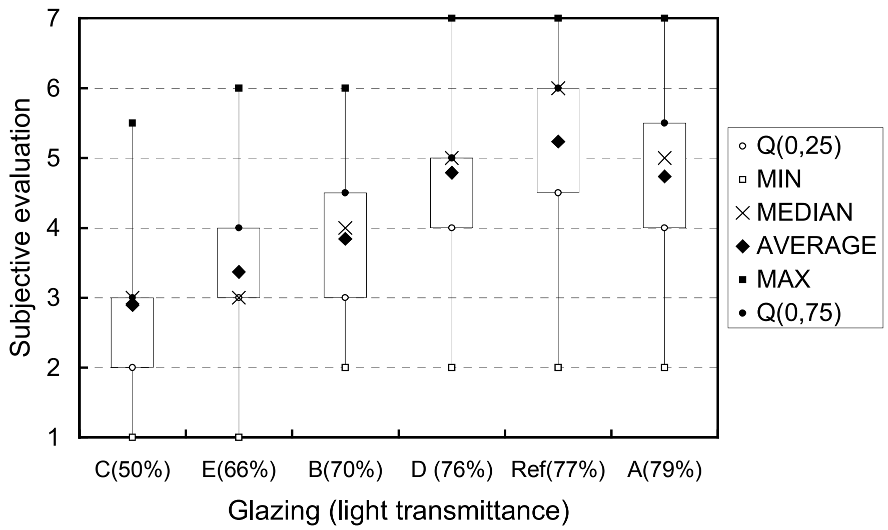


Figure continues on next page.

b) How would you describe daylight in this room? tinted-clear (1-7)



c) How would you describe daylight in this room? blurry-sharp (1-7)



d) How would you describe daylight in this room? unpleasant-pleasant (1-7)

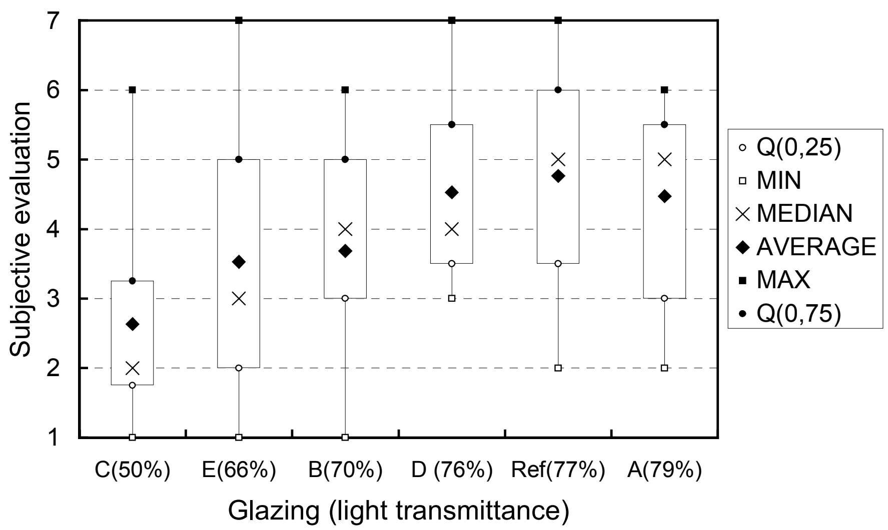


Figure 8. Subjective ratings obtained for question B: How would you describe daylight in this room? a) cold-warm (1-7), b) tinted-clear (1-7), c) blurry-sharp (1-7), d) unpleasant-pleasant (1-7).

Figure 9 shows that the differences in subjective ratings between the glazings were not as great for question C (How easy is it for you to read the text on the paper?) as for previous questions. This indicates that visual performance (to read a text on paper) may only be slightly affected by the glazing type given the range of glazings studied.

How easy is it for you to read the text on the paper? difficult-easy (1-7)

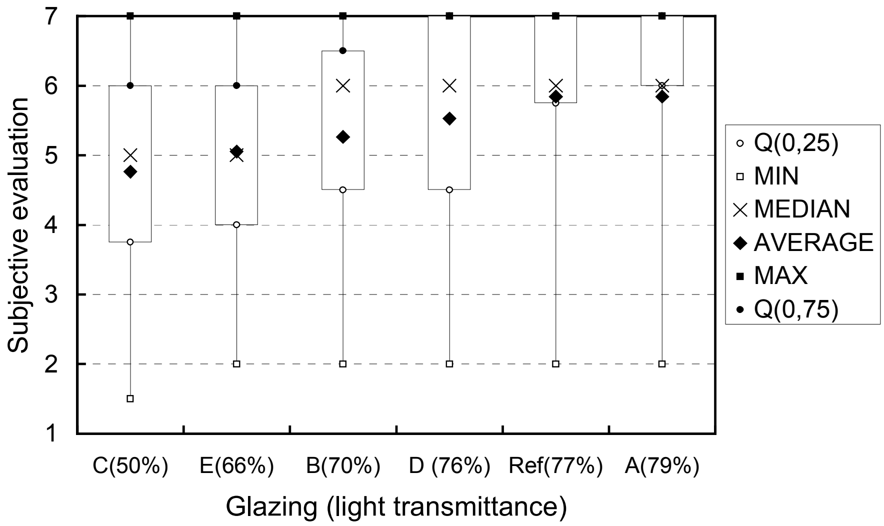


Figure 9. Subjective ratings obtained for question C: How easy is it for you to read the text on the paper? difficult-easy (1-7).

Figure 10 shows that all glazings resulted in approximately the same rating for question D (How would you describe the shadows on the objects and around them?). This indicates that the subjects were not able to perceive any significant differences regarding shadows on and around objects. The ratings were constant for both scales (figure 10a and figure 10b), which indicates that the subjects answered consistently to this question. Note, however, that glazings C and D exhibit a slightly wider interquartile range, which indicates that the ratings were slightly more spread in these cases.

a) How would you describe the shadows on the objects (tomato, broccoli, etc.) and around them (on the floor)? blurry-sharp (1-7)

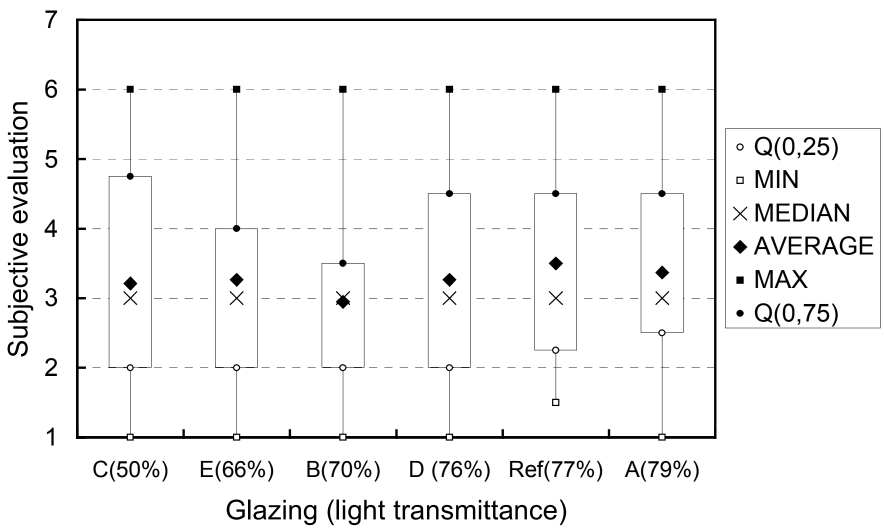


Figure continues on next page.

b) How would you describe the shadows on the objects (tomato, broccoli, etc.) and around them (on the floor)? soft-hard (1-7)

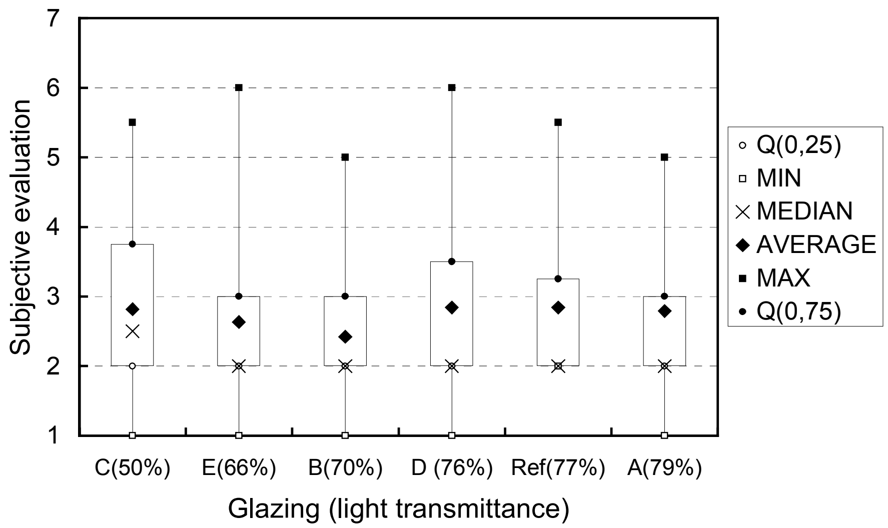


Figure 10. Subjective ratings obtained for question D: How would you describe the shadows on the objects (tomato, broccoli, etc.) and around them (on the floor) a) blurry-sharp (1-7), b) soft-hard (1-7).

The glazings do seem, however, to affect the way the details of the objects are perceived as shown by the subjective ratings obtained for question E (How do you perceive the details of these objects?), figure 11. In this case, glazings D, Ref and A obtained similar ratings, indicating that the subjects could not discern significant differences in the way they perceived the details of the objects with these three glazings. However, figure 11 shows that the perception of details was moderately affected by glazing type with glazings E and B, and more severely affected with glazing C, although there was a large spread in the ratings as indicated by the interquartile range box.

How do you perceive the details of these objects? blurry-sharp (1-7)

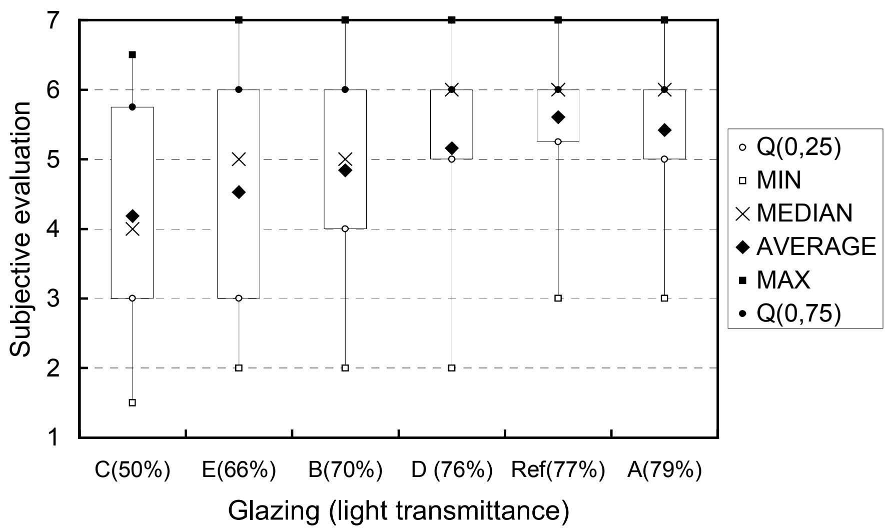
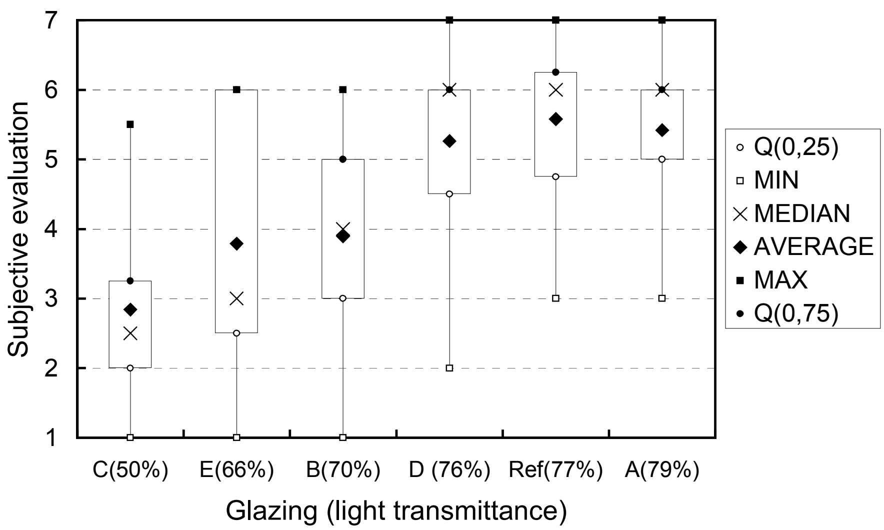


Figure 11. Subjective ratings obtained for question E: How do you perceive the details of these objects? Blurry-sharp (1-7).

The subjective ratings regarding the colour of the objects in the rooms (question F: How do you perceive the colours of these objects?) exhibited larger differences between the glazings tested as shown in figure 12. As expected, the ratings are not really a linear function of the light transmittance of the glazings. Glazings A, Ref and D obtained similar ratings for the scale “unnatural-natural” (figure 12a) although they had different light transmittances. Glazings C, E and B resulted in similar ratings for the scale “tinted-not tinted” (figure 12b) although glazing C had a much lower light transmittance than glazings E and B. Once again, the reference glazing gave slightly more positive ratings than all the other glazings, especially for the second scale (figure 12b). Note, however, that the ratings were rather spread for this scale, as indicated by the interquartile range box.

a) How do you perceive the colours of these objects? unnatural-natural (1-7)



b) How do you perceive the colours of these objects? tinted-not tinted (1-7)

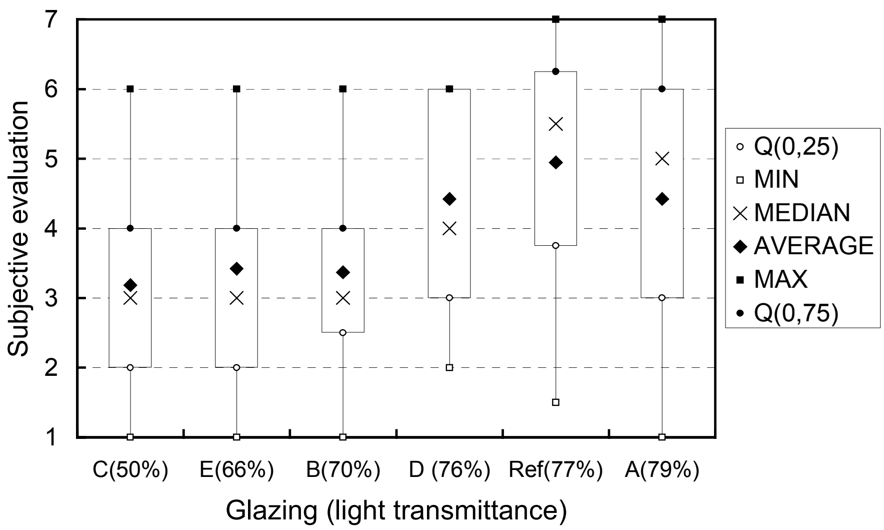
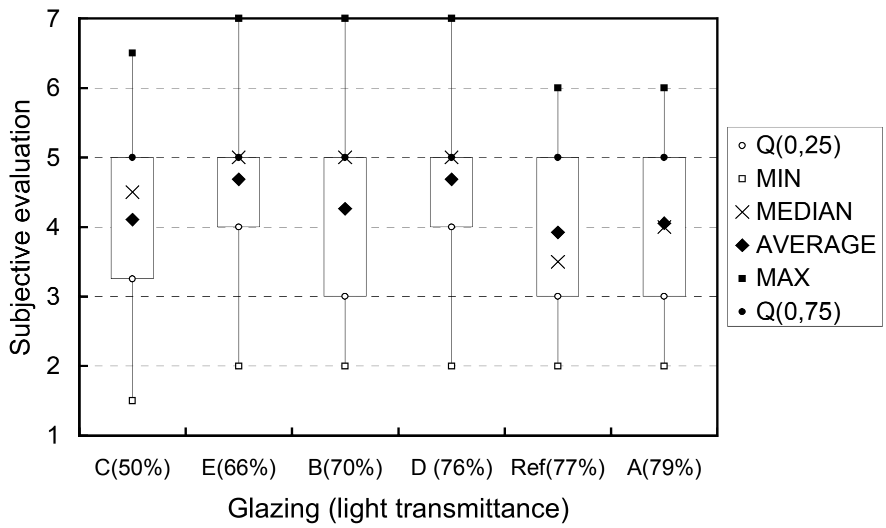


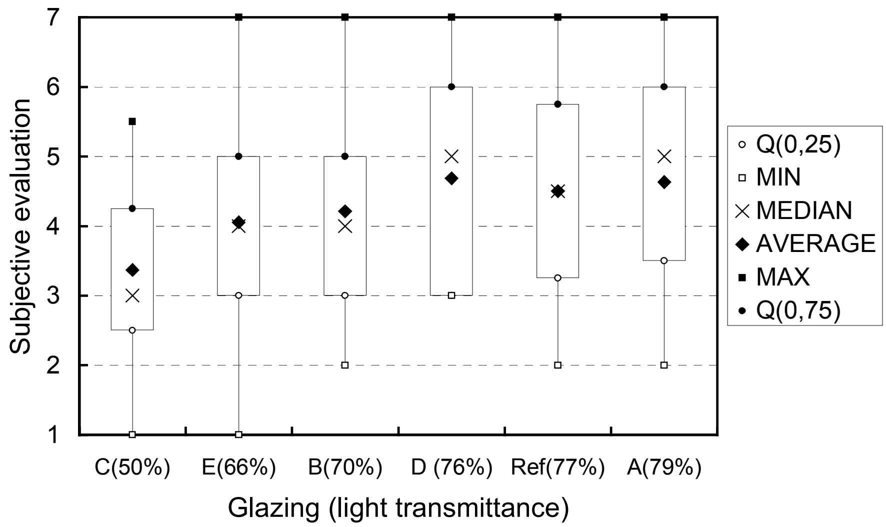
Figure 12. Subjective ratings obtained for question F: How do you perceive the colours of these objects a) unnatural-natural (1-7), b) tinted-not tinted (1-7).

There are similarities between the subjective ratings of question F (How do you perceive the colours of these objects?) and G (How would you describe the colours in the picture on the wall?) (cf figure 12 and figure 13). For example, glazing B obtains an equivalent or negative rating relative to glazings C and E (see figure 13b, c and d), although it had a higher light transmittance. However, in figure 13, the reference glazing does not exhibit the same positive peak as in figure 12. This may be due to the fact that the colours of the poster were perceived as being unnatural even under natural daylight; since the reference glazing gave a colder light (figure 13a), it made the colours of the poster look even more unnatural. Finally, note the similarity between the ratings of question B.1 (figure 8a) and question G.1 (figure 13a), which is an indication that the ratings are consistent.

a) How would you describe the colours in the picture on the wall? cold-warm (1-7)



b) How would you describe the colours in the picture on the wall? artificial-natural (1-7)



c) How would you describe the colours in the picture on the wall? blurry-clear (1-7)

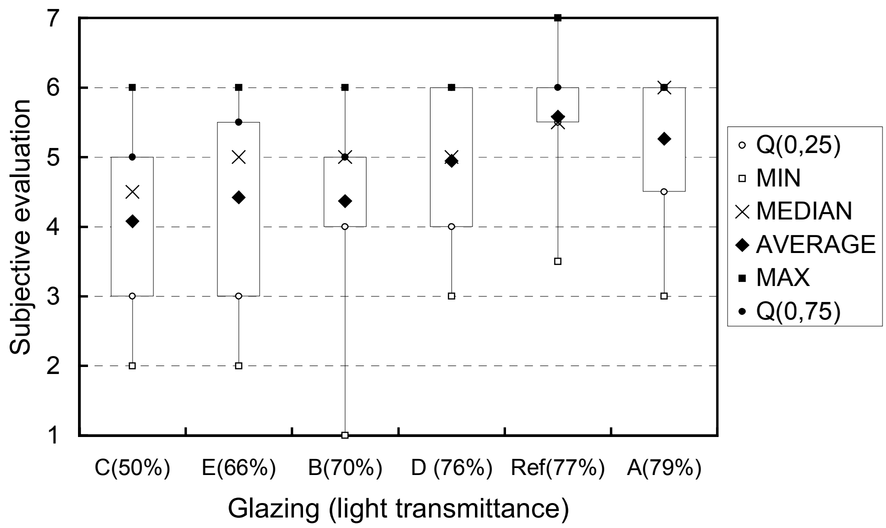


Figure continues on next page.

d) How would you describe the colours in the picture on the wall? drab-lively (1-7)

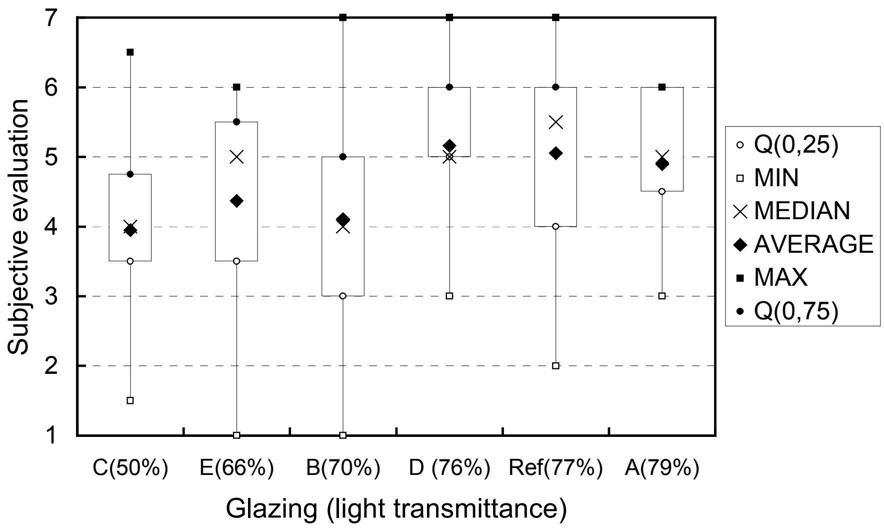


Figure 13. Subjective ratings obtained for question G: How would you describe the colours in the picture on the wall? a) cold-warm (1-7), b) artificial-natural (1-7), c) blurry-clear (1-7), d) drab-lively (1-7).

The subjective ratings obtained for questions B.2 (How would you describe daylight in this room? tinted-clear, figure 8b) and H (Do you have the impression that daylight in this room is coloured? - figure 14) are also consistent. Both questions related to the colour of daylight and the ratings are also similar and exhibit large differences between the glazings tested. Here again, the reference glazing obtained the most positive rating (“not coloured”).

Do you have the impression that daylight in this room is coloured? Coloured-not coloured (1-7)

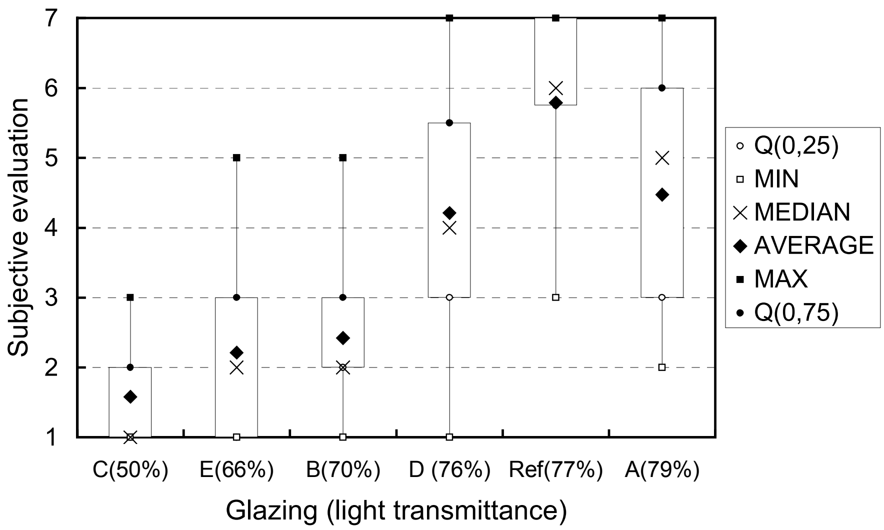


Figure 14. Subjective ratings obtained for question H: Do you have the impression that daylight in this room is coloured? Coloured-not coloured (1-7).

Regarding question J (Do you find the colour of daylight acceptable? - figure 15), it is interesting to observe that glazing C had a rating under 4, which means that the subjects crossed the boxes closer to the “unacceptable” side. This glazing coloured daylight to a degree that was judged unacceptable by the subjects. Glazings E and B obtained ratings close to 4 for the median, which indicates that half of the subjects judged that these glazings coloured daylight in a way that was unacceptable. The reference glazing (Ref) provided the most acceptable daylight colour. Finally, note that although glazing A obtained a high rating for the median, the interquartile range was large indicating that the ratings were more spread for this glazing and that some subjects judged that it coloured daylight in a way which was unacceptable.

Do you find the colour of daylight acceptable? (1-7)

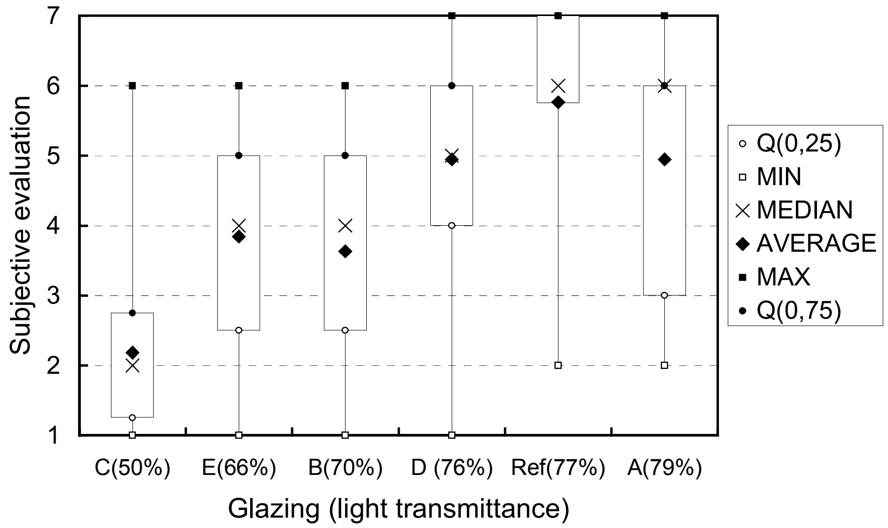


Figure 15. Subjective ratings obtained for question J: Do you find the colour of daylight acceptable? Unacceptable-acceptable (1-7).

Figure 16 shows that the ratings regarding the perception of the weather were rather consistent with the measured global illuminances. The ratings for glazing B were slightly more positive compared to the ratings obtained for the other glazings but the exterior global illuminances was higher in average when this glazing was evaluated. On the other hand, note that glazing A was also evaluated when exterior daylight intensity was high, but the ratings are not as positive as might be expected (compared with the reference glazing).

a) How do you perceive the weather outside right now? overcast-no clouds (1-7)

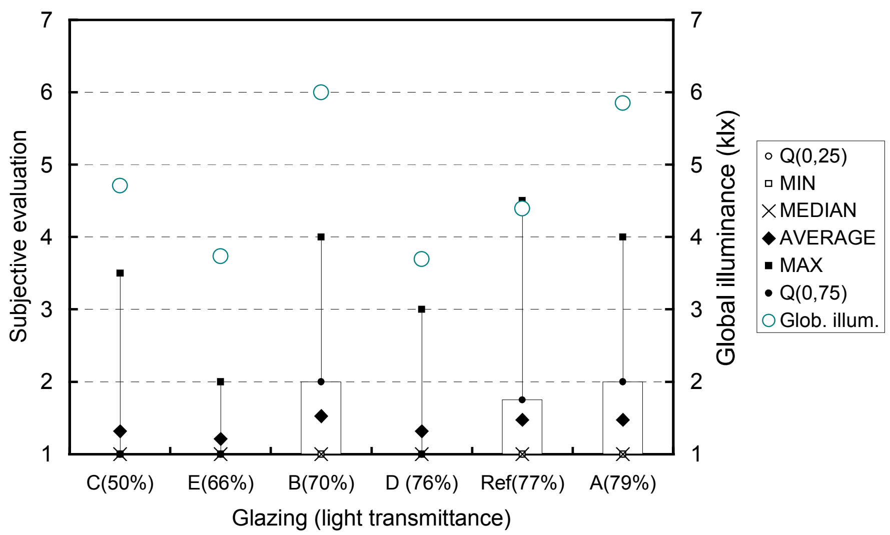
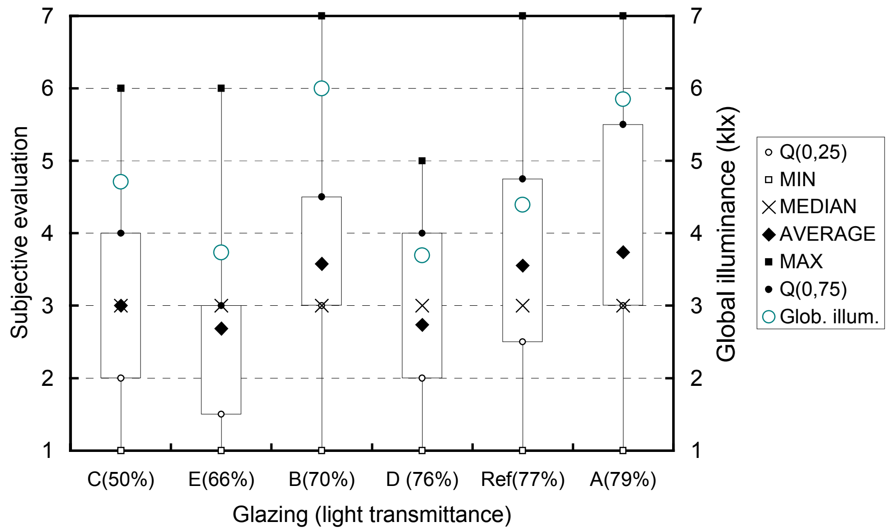


Figure continues on next page.

b) How do you perceive the weather outside right now? hazy-clear (no fog) (1-7)



c) How do you perceive the weather outside right now? dull-beautiful (1-7)

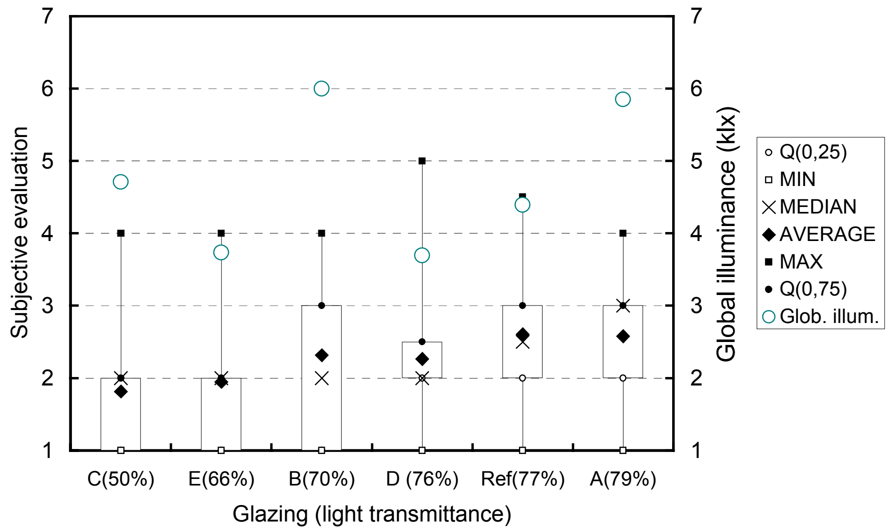
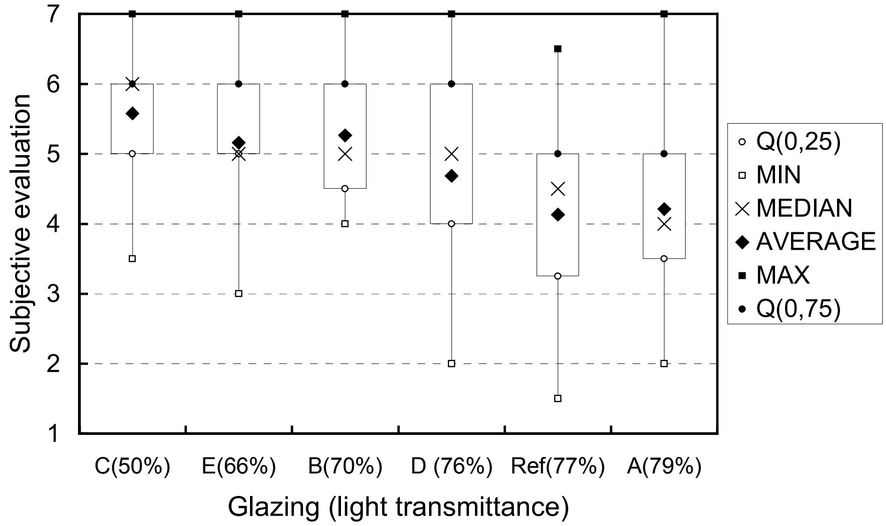


Figure 16. Subjective ratings obtained for question K: How do you perceive the weather outside right now? a) overcast-no clouds (1-7), b) hazy-clear (no fog) (1-7), c) dull-beautiful (1-7).

The subjective ratings obtained for question L (What is your general impression of daylight outside right now? - figure 17) are consistent for both scales (“strong-weak”, “glary-not glary”). Glazings Ref and A give a stronger and more glary daylight than the other glazings. However, note that the differences between the glazings are not as great as might have been expected given the differences in light transmittance, especially for the scale “glary-not glary”. This is due to the fact that as the light transmittance of the glazing is reduced, the daylight in the room is also reduced and the contrast between the inner walls and glazing remains more or less constant resulting in similar glare levels. Finally, note that the interquartile range for this question was rather narrow indicating similar subjective ratings. However, the study was carried out in January and February, a period during which the sky luminance is very low (never above 4000 cd/m^2 according to Satel-light, 2001).

a) What is your general impression of daylight outside right now? strong-weak (1-7)



b) What is your general impression of daylight outside right now? glary-not glary (1-7)

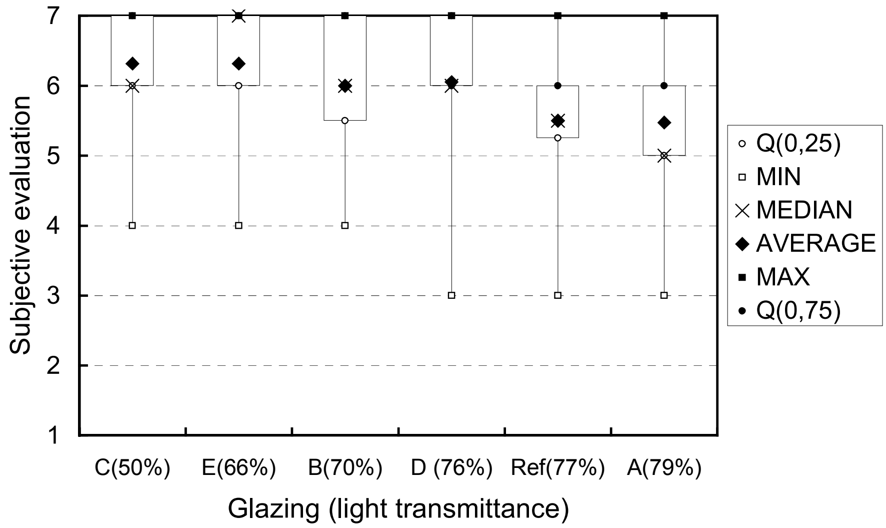
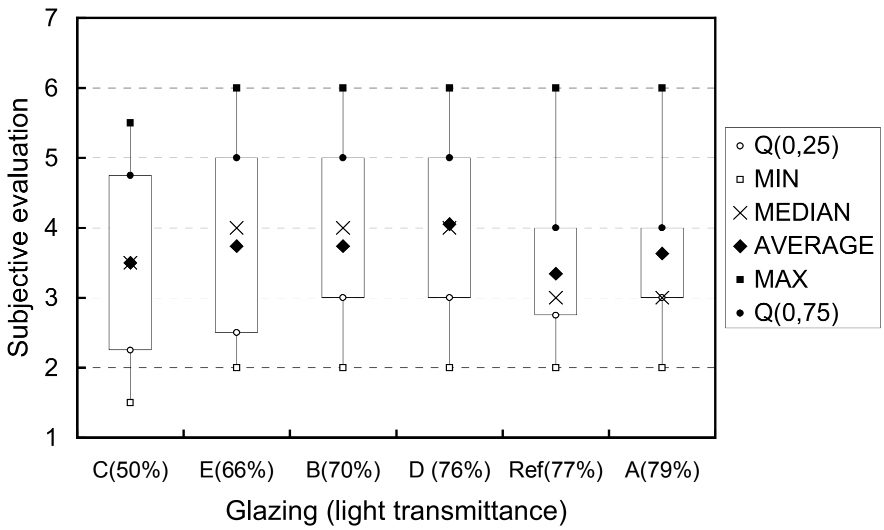


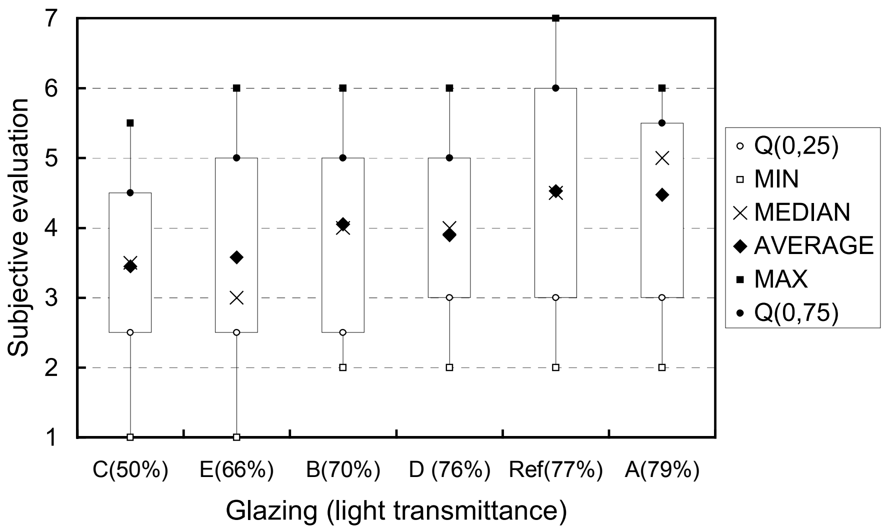
Figure 17. Subjective ratings obtained for question L: What is your general impression of daylight outside right now? a) strong-weak (1-7), b) glary-not glary (1-7).

The ratings obtained for the last question (M: How do you perceive the colours outside?, figure 18) exhibit similarities with ratings obtained for previous questions (cf figure 18a with figure 8a and figure 13a). Glazings C, Ref and A give a perception of colder colours compared with glazings E, B and D. However, glazing Ref gives a perception of more “natural” (figure 18c) and “normal” (figure 18e) colours as shown previously (figure 8b and figure 12a and b). Glazing C obtained more negative ratings indicating that the colours in the outside view looked the most “unnatural”, “drab” and “altered”.

a) How do you perceive the colours outside? cold-warm (1-7)



b) How do you perceive the colours outside? blurry-clear (1-7)



c) How do you perceive the colours outside? unnatural-natural (1-7)

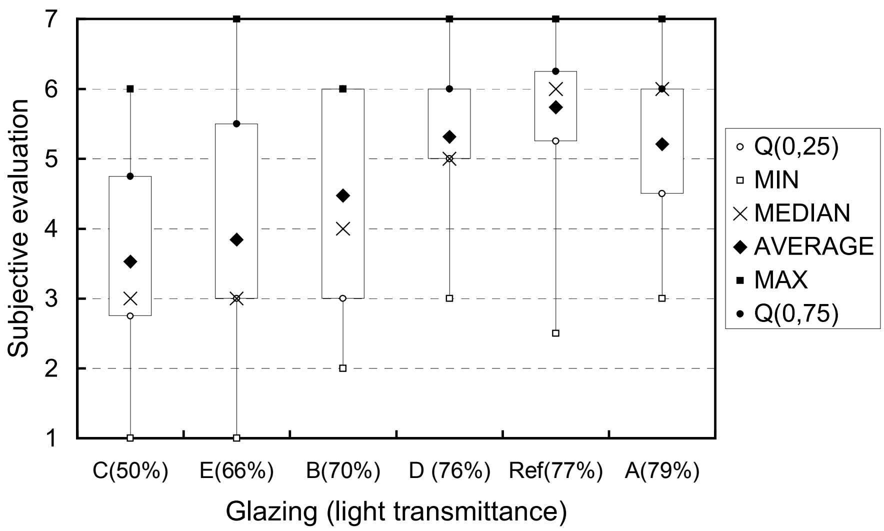
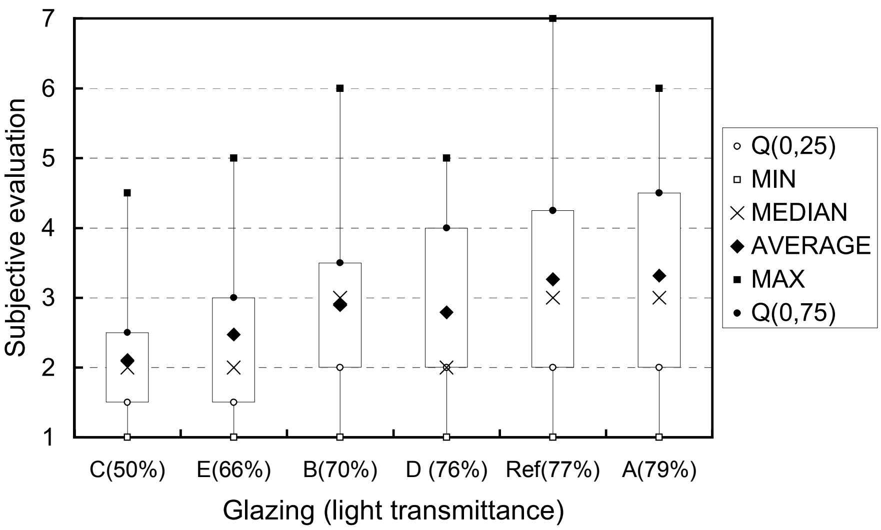


Figure continues on next page.

d) How do you perceive the colours outside? drab-lively (1-7)



e) How do you perceive the colours outside? altered-normal (1-7)

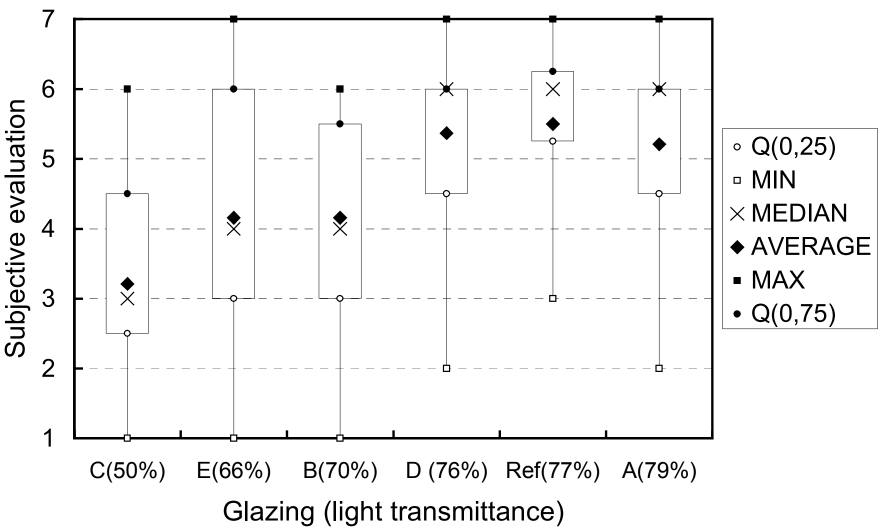


Figure 18. Subjective ratings obtained for question M: How do you perceive the colours outside? a) cold-warm (1-7), b) blurry-clear (1-7), c) unnatural-natural (1-7), d) drab-lively (1-7), e) altered-normal (1-7).

Vertical spectral irradiance distribution

A measurement was made of the vertical spectral irradiance behind the single glazing of the office room where the experiments took place. This measurement was made in order to verify whether daylight colour shifted significantly from one experiment to the next. These spectral data were converted to CIE*Lab co-ordinates and are presented in figure 19. This figure also shows the CIE*Lab co-ordinates for the transmittance of the glazings tested in the study. This data was provided by the glazing manufacturer who provided the glazing samples used in the experiments.

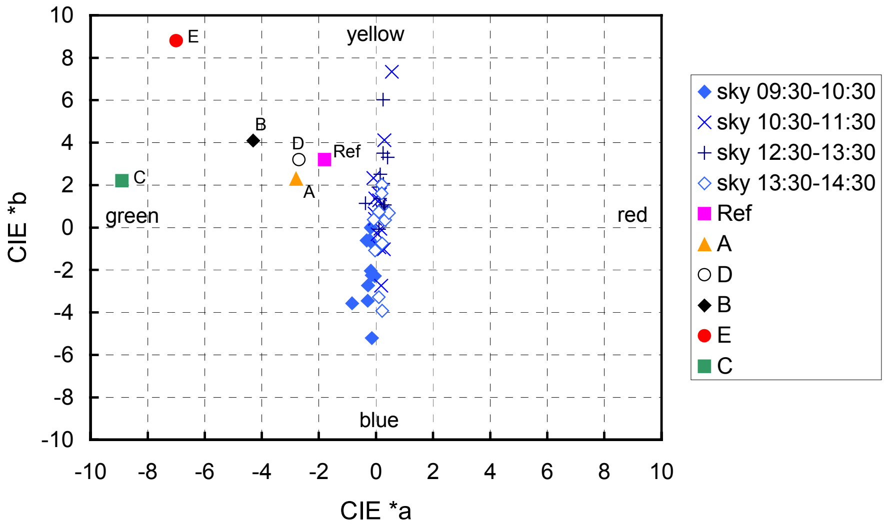


Figure 19. CIE*Lab co-ordinates representing the sky colour for different periods of measurement (one point corresponds to one experiment with a subject) superposed to the transmittance co-ordinates for the glazings tested (provided by the glazing manufacturer).

Figure 19 shows that the colour of daylight did not changed significantly along the green-red axis but changed significantly along the blue-yellow axis. The sky was generally bluer in the morning and at the end of the afternoon than around noon time, in which case the points are closer to the yellow end of the axis.

The interesting feature of this diagram is that it shows that the variation in sky colour along the blue-yellow axis was greater than the variation in colour along that axis between the glazings tested. This means that if two glazings were evaluated on different days and at different times, the difference in subjective ratings cannot be entirely attributed to the properties of the glazings: they might be due to the shifting sky colour from one day to the next. Fortunately, a reference case was used throughout this study and all the subjective evaluations were made *in relation to* this reference case. This means that the subjects were chromatically adapted to the reference case, which probably compensated for the variation in sky colour between the experiments.

Figure 19 also shows that the glazings that are the furthest away from the origin of the diagram (glazings C, E) were also generally rated more negatively compared with the other glazings. For example, glazing E was rated much more negatively in comparison with glazing B although its light transmittance was only lower by 4%. The negative rating might be due to the fact that this glazing is much further away from the origin (thus more coloured) than glazing B.

Discussion and conclusions

In this study, five coated glazings were evaluated by 18 subjects and compared with a reference glazing, which was a double assembly with one iron-free and one low-emissivity coated glass. The reference glazing (Ref) provided a colder but brighter, clearer (less tinted), sharper and more pleasant daylight than all the other glazings tested. Also, it was found that this glazing coloured daylight to a degree that was judged the most acceptable among all glazings tested. The question should be raised, however, whether the more positive ratings obtained for this glazing are a result of the fact that it was used as a reference case. It is possible that the subjects gave a more positive rating because they *supposed* that the glazing in the reference room was better than all the other glazings tested, although they were never told so.

Overall, glazings A and D obtained slightly more negative ratings than the reference glazing although the difference between these glazings and the reference glazing was often small, and sometimes negligible. Glazing A was perceived as more glary and providing stronger light than glazing D. Overall, the differences in subjective ratings between these two glazings were small although glazing A had a slightly higher light transmittance than glazing D. Note, however, that the light transmittance of the samples used in the experiments was never measured by Danish Building and Urban Research and the values presented in this report are the ones provided by the glazing manufacturer. It is possible that there was a slight discrepancy between the actual transmittance of the samples used and the transmittance values provided by the glazing manufacturer.

Glazings E and B obtained ratings that were most often on the negative side of the scale (i.e. below 4). Glazing B obtained slightly more positive ratings than glazing E indicating that daylight and the colours inside and outside were perceived as slightly clearer, sharper, more pleasant, natural, less coloured and less glary. The difference in subjective ratings between these two glazings was perhaps greater than expected given the small difference in light transmittance (4%). This suggests that, together with the light transmittance, the colour of the transmitted light may affect visual perception. Finally, glazing C obtained the most negative ratings among all glazings tested and the subjects felt that it coloured daylight to a degree that was unacceptable by most subjects.

The evaluation leads us to propose the following categories for the glazings tested in this study:

Daylight quality	Glazing	Comments
Excellent	Ref	
Good	A, D	
Moderate	B, E	Colour daylight to a degree that is judged unacceptable by some subjects
Poor	C	Colours daylight to a degree that is judged unacceptable by most subjects

Apart from these observations, this pilot study permitted to establish the following facts:

- The perception of the *colour* of daylight and of the *colour* of objects in the room and of the view is the parameter most significantly affected by glazing type (which varied in light transmittance and colour).
- The perception of *brightness* is also significantly affected by glazing type and is not a linear function of the light transmittance of the glazing, but appears to be a complex function of the light transmittance of the glazing and colour of the transmitted light.
- The perception of *details* of objects in the room and the ability to read a text are moderately affected by glazing type.
- The perception of *glare* is only slightly affected by glazing type.
- The perception of *shadows* on and around objects in the room is not affected by glazing type.

The study also permitted to establish the following conclusions regarding the methodology:

- The scale "cold-warm" used to describe the colour of daylight or objects does not necessarily correlate with scales like "unpleasant-pleasant", "tinted-clear", "blurry-sharp", etc. For example, the reference glazing (Ref) provided a colder daylight colour but daylight obtained with this glazing was also judged more "pleasant", "sharp", "natural", "acceptable", etc.

The sky colour varies significantly from one day to the next and from morning to afternoon, even under a northern, fully overcast sky. Thus, any study with a real sky must either be achieved so quickly that all glazings are evaluated in the same time period and under similar sky conditions, or include a reference case to ensure that the subjects' chromatic adaptation to the reference case compensates for the variation in sky colour. An alternative is to use a simulated sky, but this solution makes it difficult to simulate the view through the window.

In conclusion, this study indicated that coated glazings (of variable transmittance) significantly affect the perception of brightness and colours in a space, moderately affect the perception of details, slightly affect the perception of glare from window and do not seem to affect the perception of shadows on and around objects in the room. The study also suggests that the perception of brightness and other visual aspects such as sharpness, details, character, etc., seem to be a complex function of the intensity *and* colour of the transmitted light and is not solely and linearly dependent on the light transmittance of the glazing. However, more research—including many more glazing samples—is needed before clear and precise relationships between daylight quality or visual perception and glazing properties may be established.

The method used in this study (small scale models) has proved to be rather efficient and reliable to approach this problem and should be used in future research before carrying out full-scale investigations. However, the questionnaire may be slightly improved, by removing and adding a few questions. Also, some details of the lab installation need to be changed and the order of presentation of the samples may require re-thinking in order to avoid the bias of the reference case. For example, a session may be included where the reference glazing is placed in the Test Room or where a different glazing is used in the Reference Room in order to verify whether the positive rating obtained for the reference glazing is due to a real difference in visual perception.

Resumé (in Danish)

By og Byg Dokumentation 044: Indflydelsen af rudebelægninger på den visuelle opfattelse af rum. Et pilotstudie i skalamodeller

Bygningsreglementet stiller krav om en mindste varmeisoleringsevne for vinduer (U-værdi ikke over 1,8 W/m^2K). I praksis kan dette krav kun opfyldes ved anvendelse af 2-lags ruder med mindst én lav-emisionsbelægning, hvorved der kan opnås en U-værdi på 1,0-1,7, afhængigt af belægningstype, glasafstand og gasfyldning. Bygningsreglementet stiller også krav om, at der "ved valg af materialer, vinduesarealer, orientering og solafskærmning skal sikres, at der opnås hensigtsmæssige temperaturforhold også i sommerperioden, og at gener ved direkte solstråling skal undgås". Dette temperaturkrav kan kun opfyldes, hvis der anvendes en effektiv solafskærmning. For at reducere solindfaldet tilstrækkeligt er arkitekten derfor ofte fristet til at anvende ruder med en solafskærmende belægning, hvorved solindstrålingen kan reduceres til under halvdelen af det, som passerer en 2-lags rude uden belægning. Men denne reduktion opnås imidlertid ikke uden ulemper.

De største ulemper ved belægningerne er, at de reducerer lystransmittansen, samt at de ændrer på spektralfordelingen af dagslyset og forvrænger farverne på det, som ses gennem vinduet (udsigten). Disse ændringer i dagslyset kan påvirke oplevelsen af rummets kvaliteter i form af lysfordeling, luminansforhold, farvegengivelse og synlighed af detaljer. Desuden vil reduktion af dagslyset influere på brugen af kunstlys samt balancen mellem dagslys og kunstlys.

For at undersøge hvordan rudebelægningerne kan påvirke brugernes opfattelse af rummet og lyset i rummet m.m., har Statens Byggeforskningsinstitut gennemført en serie undersøgelser med forsøgspersoner og anvendelse af skalamodeller. Undersøgelserne er et mindre pilotprojekt under Energistyrelsens "Projekt Vindue", der har til formål at sikre varmebesparelser ved at mindske energitabet gennem vinduer i bygninger (se www.projekt-vindue.dk for yderligere oplysninger).

Metode

Skalamodellerne er præcise kopier (i størrelsesforholdet 1:7,5) af forsøgsrummene i By og Bygs Dagslyslaboratorium. Ved at bruge skalamodeller, er det muligt at afprøve mange rudetyper i forsøget, da det er nemmere, hurtigere og billigere at udskifte ruden i en lille kasse end i et rigtigt rum. Hver af skalamodellerne var møbleret med objekter med forskellig farve, form og tekstur (figur 2). Den ene af skalamodellerne blev benyttet som "referencerum" og var udstyret med en 2-lags rude med ét lag jernfattigt glas og ét lag glas med lavemissionsbelægning (glastype "Ref.", se table 1 side 8). Denne rudetype blev valgt som reference, fordi den var mest neutral i farven. Den anden skalamodel, kaldet "testrum", blev på skift udstyret med en af de andre rudetyper (ruderne "A", "B", "C", "D" eller "E", jf. tabellen).

I forsøgene deltog 18 forsøgspersoner, udvalgt blandt det administrative personale og forskerne på By og Byg. Alle forsøgspersoner var under 45 år og havde normalt farvesyn (efter deres egen opfattelse). Halvdelen af forsøgspersonerne var kvinder.

Ved hvert besøg i laboratoriet, blev forsøgspersonen bedt om først at se ind i referencerummet og udfylde et 2-siders spørgeskema. For alle spørgsmål skulle deltagerne foretage en vurdering på en såkaldt bipolar skala med 7 trin (fx kold/varm fra 1 til 7). Dernæst blev forsøgspersonerne bedt om at

se ind i testrummet og udfylde et spørgeskema magen til det første. Så snart det andet spørgeskema var blevet udfyldt, blev ruden i test rummet udskiftet, og forsøgspersonen blev bedt om at vurdere forholdene i testrummet på ny og udfylde et tredje spørgeskema magen til de to første. Dette sidste trin blev gentaget en gang til, således at der i hver forsøgsrunde blev vurderet 3 testruder ud over ruden i referencerummet. Hele proceduren blev gentaget, hver gang forsøgspersonen var i laboratoriet. Det var nødvendigt med 3 forsøgsrunder for at fuldende vurderingen.

Resultater

Resultaterne af pilotprojektet viser, at reference ruden ("Ref", table 1) giver et koldere men klarere (mindre tonet), skarpere og mere behageligt dagslys end alle de andre rudetyper, der blev testet. Resultaterne viser også, at denne rudetype farver dagslyset tilpas til, at det blev vurderet som det mest acceptable af alle de testede rudetyper.

Rudetyperne A og D får en anelse mere negativ vurdering end referenceruden, selvom forskellen mellem disse to rudetyper og referenceruden ofte er meget lille eller ubetydelig. Generelt er forskellene i den subjektive vurdering af disse to rudetyper små, selvom rudetype A har en smule højere transmittans end type D.

Vurderingerne af rudetyperne E og B ligger ofte i den negative ende af skalaen (under 4). Rudetype B bliver vurderet en smule mere positivt end rudetype E, hvilket vil sige, at dagslyset og farverne inde og ude opfattes en smule klarere, skarpere, mere behageligt og naturligt samt mindre farvet og blændende. Forskellen i den subjektive vurdering mellem disse to rudetyper forekommer større end forventet, når man tager den lille difference i rudernes lystransmittans i betragtning (4 %).

Endelig får rudetype C den mest negative vurdering af alle de testede rudetyper, og forsøgspersonerne synes, at denne rude farver dagslyset i en sådan grad, at det betragtes som ubehageligt og uacceptabelt af de fleste.

Konklusioner

Undersøgelser i skalamodellerne giver anledning til følgende konklusioner:

- Opfattelsen af dagslysets *farve*, farven på genstande samt i udsigten påvirkes markant af rudetypen (typerne varierede i både lystransmittans og farve)
- Opfattelsen af *lysheden* (brightness) i rummet påvirkes også af rudetypen, men ikke som en lineær funktion af transmittansen. Der synes at være en mere kompleks sammenhæng mellem rudens lystransmitans og farven på det transmitterede lys
- Opfattelsen af *detaljer* på genstande i rummet og letheden ved at læse en tekst påvirkes i moderat grad af rudetypen
- Opfattelsen af *blænding* påvirkes kun i ringe grad af rudetypen
- Opfattelsen af *skygger* på og omkring genstande i rummet påvirkes ikke af rudetypen

Pilotundersøgelsen giver anledning to at konkluderer følgende vedrørende den anvendte fremgangsmåde:

- Skalaen "kold-varm", der benyttes til at beskrive farven på dagslyset, kan ikke korreleres med skalaer som "behageligt-ubehageligt", "farvet-klar", "sløret-skarp", etc. Således opfatter forsøgspersonerne, at referenceruden (Ref) giver et koldere lys, men samtidig var det også opfattelsen, at denne rudetype gav et mere "behageligt", "skarpt", "naturligt" og "acceptabelt" dagslys.

References

American Society for Testing and Materials. (1996). *Standard practice for visual appraisal of colors and color differences of diffusely-illuminated opaque materials* (Standard D1729-96). West Conshohocken, PA.

Berman, S. M. (1992). Energy efficiency consequences of scotopic sensitivity. *Journal of the Illuminating Engineering Society. 21*(1), 3-14.

Berman, S. M., Bullimore, M. A., Bailey, I. L., & Jacobs, R. J. (1996). The influence of spectral composition on discomfort glare for large-size sources. *Journal of the Illuminating Engineering Society, 25*(1), 34-41.

Berman, S. M., Fein, G., Jewett, D. L., & Ashford, F. (1993). Luminance-controlled pupil size affects landolt-C task performance. *Journal of the Illuminating Engineering Society. 22*(2), 150-165.

Blackwell, H. R. (1985). Effects of light source spectral distribution upon visual functions. *Annals of the New York Academy of Sciences,* (453), 340-353.

Chain, C., Dumortier, D., & Fontoynont, M. (1999). Integration of the spectral and directional component in sky luminance modelling. In *Proceedings of the 24th session of the CIE, Warsaw, June 24-30 1999* (pp. 248-252). Wien: CIE.

CIE. (1987). *International lighting vocabulary* (Publication CIE No. 17.4). Genéve: Bureau Central de la Commission Electrotechnique Internationale.

Danish Ministry of Housing. (1995). *Building regulations 1995.* Copenhagen.

Dansk Standard. (1997). *Kunstig belysning i arbejdslokaler* [in English; Artificial lighting in workrooms] (5. udg.) (DS 700:1997). København.

Krtilova, A., & Matousek, J. (1980). The importance of daylight for human organisms and its function in integrated lighting system. In J. Krochmann (Ed.). *Proceedings of the Symposium on Daylight: Physical, Psychological and Architectural Aspects, July 9 and 10, 1980, Berlin* (pp. 226-237). Berlin: Technischen Universität Berlin, Institut für Lichttechnik.

Küller, R. (1996). Seasonal effects on well-being in hospitals with and without windows. In *Proceedings of the 25th International Congress on Occupational Health: Book of abstracts II:OS 417* (p. 190). Stockholm.

Küller, R., & Küller, M. (2001). *The influence of daylight and artificial light on diurnal and seasonal variations in humans - a bibliography* (Technical report No. 139). Wien: CIE.

Küller, R., & Wetterberg, L. (1993). The impact of two types of flourescent light tubes and two light intensities on melatonin, cortisol, EEG, ECG, and subjective comfort, in healthy humans. *Lighting Research and Technology, 25*(2), 71-81.

Liljefors, A., & Ejhed, J. (1990). *Bättre belysning* [in English; Improved lighting] (Report T17). Stockholm: Statens råd för byggnadsforskning.

Pilkington Danmark A/S. (1999). *Glasfakta 2000*. Lokaliseret 20030902 på: www.pilkington.com/europe/denmark/danish/building+products/default.htm

Satel-light. (2001). *The European database of daylight and solar radiation*. Lokaliseret 20030902 på: www.satel-light.com/index2.htm

Simonson, E., & Brozek, J. (1948). The effect of spectral quality of light on visual performance and fatigue. *Journal of the Optical Society of America, 38*, 830-840.

Thomson, W. D. (1996). A guide to colour vision testing, Part one. *Optician, 211*(5552), 20-26.

Yorks, P., & Ginthner, D. (1987). Wall lighting placement: Effect on behavior in the work environment. *Lighting Design & Application, 17*(7), 30-37.

Appendix A

Original version of the questionnaire filled by the research subjects (in Danish)

#	Spørgsmål		Bipolar skala (1-7)
A	Opfatter du rummet som helhed som værende lyst eller mørkt?	1	Lyst - mørkt
B	Hvordan vil du beskrive dagslyset i dette rum?	1 2 3 4	Koldt - varmt Klart - tonet Sløret - skarpt Behageligt - ubehageligt
C	Hvor let er det for dig at læse teksten på papiret?	1	Vanskeligt - let
D	Hvordan vil du beskrive skygger på objekterne (tomat, broccoli, etc.) og omkring dem (fx på gulvet)?	1 2	Slørede - skarpe Hårde - bløde
E	Hvordan opfatter du detaljerne af disse objekter?	1	Klare - slørede
F	Hvordan opfatter du farverne af disse objekter?	1 2	Naturlige - forandrede Farvede - ufarvede
G	Hvordan vil du beskrive farverne i billedet på væggen?	1 2 3 4	Varme - kolde Naturlige - kunstige Slørede - klare Levende - triste
H	Har du opfattelse af, at dagslyset i rummet er farvet?	1	Farvet - ufarvet
I	Hvis du opfatter dagslyset i rummet som farvet, hvilken farve opfatter du? (du må gerne angive farven ved flere farver eller som to-farvet)		
J	Finder du dagslysets farve acceptabel?	1	Uacceptabel - acceptabel
K	Hvordan oplever du vejret udenfor lige nu?	1 2 3	Overskyet - skyfrit klart (ingen dis) - diset Smukt - trist
L	Hvordan er dit generelle indryk af *dagslyset* udenfor lige nu?	1 2	Svagt - stærkt Blændende - ikke blændende
M	Hvordan opfatter du farverne udenfor?	1 2 3 4 5	Varme - kolde Slørede - klare Naturlige - unaturlige Levende - triste Vellignende - forandrede

There is at present an architectural trend promoting the use of large glass facades in commercial and office buildings. These facades generate a large cooling and heating demand creating the need for combined solar-protective and low-emissivity coated windows. This report describes the results of a pilot study that investigated the impact of six coated glazings on daylight conditions in scale models. The study focused primarily on visual perception.
Generally, the pilot study indicated that some types of coated glazings (especially solar protective coatings) significantly affect the perception of brightness and colours in a space. Overall, the study shows that coated glazings may moderately affect the perception of details, slightly affect the perception of glare from window and do not affect the perception of shadows on and around objects in the room. The results also suggest that the perception of brightness and other visual aspects such as sharpness, details, character, etc., seem to be a complex function of the intensity *and* colour of the transmitted light and is not solely and linearly dependent on the glazing light transmittance.

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