Summary of the Research Project

Daylighting in Dwellings and Office Buildings to Improve the Visual Comfort and Quality of Residence

The research project was founded by the resources of the research program "Zukunft Bau" of the "Bundesinstitut für Bau-, Stadt- und Raumforschung".
(Reference Number: SF-10.08.18.7-11.8 / II 3-F20-10-1-133)
The responsibility for the contents of the report lies with the authors.

Project Manager: Prof. Dr.-Ing. Stephan Völker
TU Berlin

Research Assistants: Dipl.-Ing. Stefan Gramm
Dr.-Ing. Sırrı Aydınlı
TU Berlin

Project Partner: Prof. Dr. rer. nat. Heinrich Kaase

1 Introduction

The sufficient supply of indoor spaces with daylight and adequate visual contact to the outside are both essential prerequisites for the safety, health and well-being as well as the productivity of the people. The findings obtained from measurements, field studies and user surveys in this project can contribute to improving the quality of life in residential areas and in addition to the improved design and the optimized operation regarding the safety and health of employees in workplaces with an energy-efficient lighting. The investigations were made possible with generous support by the companies OSRAM AG and SCHUECO International KG and by the VFL e. V. This provides a basis for determining the need for daylight in rooms and to increase the visual comfort using daylighting in buildings.

2 Laboratory Studies on Daylighting Components

The laboratory tests on eight different double glazings (Figure 1) and seven PC panels for skylights based on the measurement of spectral transmittance and allow a reliable assessment for comparison of materials among health-specific, photometric, colorimetric and energetic sizes too.

The determined values of the effective circadian action factor $a_{cv,\,eff}$ show that both the glazings and the tested PC panels have no significant deterioration of the $a_{cv,\,eff}$. However, the melatonin effective radiance seen through the daylight opening is reduced by the amount of the luminous transmittance τ_{D65}. Taking into consideration the high luminance or radiance of the sky and the saturation effects of melatonin effective radiant exposure, the reduction due to daylighting components is negligible.

All investigated daylighting components with the exception of one glazing and two PC panels change the light colour only slightly. In the mentioned exceptions, the correlated colour temperature is reduced by 500 - 1000 K. The glazings (except sun-protection glazings) and most PC panels have very good colour rendering properties ($R_a > 96$, $R_9 > 80$). With the sun-protection glazings and a PC panel with similar properties good colour rendering values with $R_a > 94$ and $R_9 > 67$ are obtained.

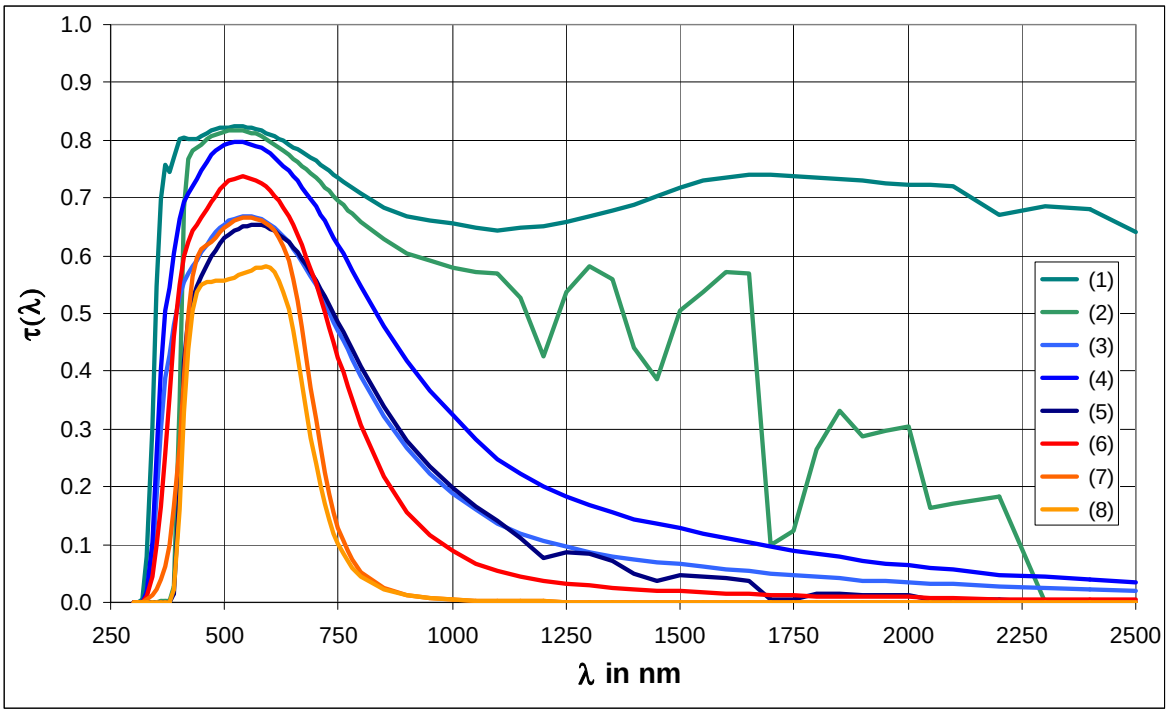

Figure 1: Measured luminous transmittance of double glazings

3 Test room with Artificial Window and User Survey

For the user survey with 34 subjects from age 20 to 39, a test room with a window and a novel artificial sky has been set up (Figure 2). The evaluation of the d2-R test shows that the illuminance on the working place for this age group has no influence on the measured concentration of the test performance. Significant differences are seen for the direction of light in combination with the different reflection properties of the paper types. For lateral light with semi-gloss and glossy paper the values are up to 4% higher than with direct lighting. When using non-reflective matte paper no noticeable differences can be observed. On glossy paper and direct illumination the reflected glare provides a reduced luminance contrast rendition which lead to a degradation of the visual conditions.

The subjective ratings of the lighting situations by the subjects reveal that the lateral lighting on the working place is rated darker than with direct lighting although the same illuminance levels were given. This may be due to the higher luminance of the visual object with direct lighting due to the reflective properties of the paper.

Regarding the types of paper the evaluation of the subjects is very clear. By using matte paper the ratings of the reflective glare are consistently low, the reflections on the glossy and semi-gloss paper can be perceived as disturbing or very bothersome for direct lighting. With using lateral light incidence provided by the artificial sky reflections on all types of

paper are very low or undetectable, which are then classified by the subjects as not disturbing. Furthermore, the illumination estimated by the artificial sky is assessed less tiring for the eyes. The brightness for reading and writing is rated similarly in the illumination levels of 500 lx and 300 lx. The brightness level of 100 lx is generally considered too dark, uncomfortable and tiring for the eyes. One subject remarked: "This is like overtime in the winter, when the light is not switched on in time."

These estimations of the user show significantly more difficult visual conditions, with which the results obtained with the d2-R concentration test can be justified.

Since in the planning process for lighting systems, the surface properties of the visual task and the working area will not be considered, one should expect the worst case. The studies with glossy paper materials show that the lateral light, as it is realized by vertical daylight openings, leads to significantly better visual conditions. For a universal quantification, however, additional studies are needed, for example, with other age groups.

Figure 2: Realized test room: Situation with artificial daylight

4 Daylighting in Buildings: Surveys and Field Investigations

4.1 Office Building

The surveys in office buildings have shown that most subjects place great value on an unhindered visual contact to the outside. The view out to a courtyard and to high opposite obstruction is rated as “very limited view out.” In contrast, natural barriers in front of the facade, such as trees, are not perceived as a limitation (Figure 3).

The brightness of the indoor space is valued by most subjects usually similarly like the brightness of the workplace. The working places with a daylight factor $D > 2$ % are evaluated “better than adequate bright”. Working places with less values of daylight factors are assessed as “not sufficient” ($1\ \% < D < 2\ \%$) or “too dark” ($D < 1$ %).

Rooms with large windows are generally rated as “just right bright”, regardless of whether the daylight factor is considerably higher than the value required by DIN 5034. Direct glare caused by the overcast sky luminance seen through windows is perceived as “non-interfering”, although high sky luminance can occur. This review is due to the positive effect of daylight in indoor spaces.

The reflected glare on the screen both at overcast sky condition and by the daylight system in the sunshine is perceived by 20 % of the respondents as “disturbing” to “intolerable”. This review shows that a glare protection is also necessary at overcast sky conditions. Another important interference of daylight louver-blinds in the sunshine is both the direct glare and reflected glare on the screen through the gaps between the slats.

Field studies in an office building with modern sun protection with enabled view out at the same time show that still 2/3 of the subjects perceived the view out “slightly limited” to “limited”. No direct glare and no reflective glare are noted by 90 % of the users, and the remaining 10 % of users rate the glare for the most part to be low. Only the electronic control of the artificial lighting and daylight can lead to dissatisfaction by the employees.

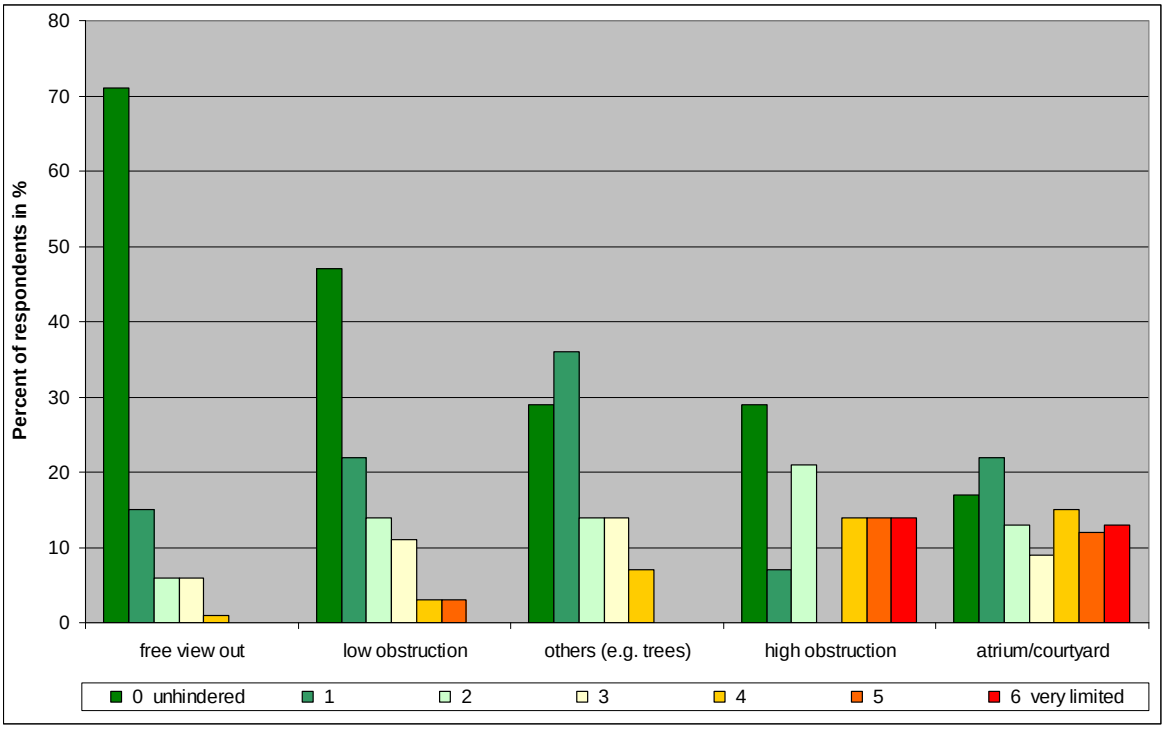

Figure 3: Evaluation of view out in a office building

4.2 Industrial buildings with Skylights

The investigated industrial buildings with skylights are characterized by an average daylight factor of 4 % to 7 % on the working plane. In one of the studied halls the daylighting is perceived as "not bright", although the average daylight factor in the hall is 4.4 %, it results in a rather equivocal assessment by the user ("too dark") (Figure 4). This confirms the minimum value for the average daylight factor of 4 % required by DIN 5034. The user survey in this hall showed that the daylighting of the workplace is perceived darker than the daylighting of the whole hall. This is due to the particularly strong shading within the work site through the items, so often the artificial lighting is switched on. In the examined halls no electronic control systems for lighting were installed, with the result that the artificial lighting was turned on all day.

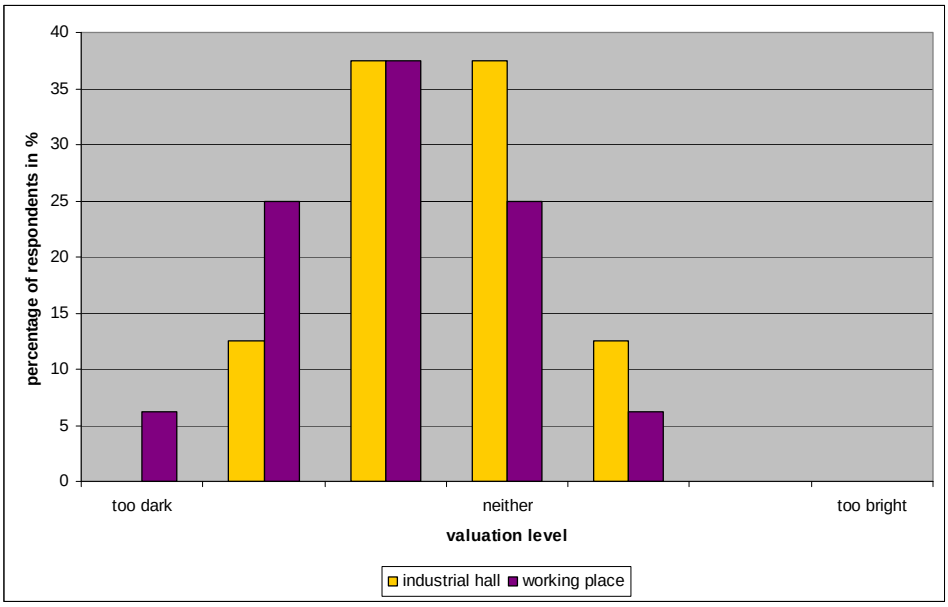

Figure 4: User assessment for brightness by daylight in an industrial building; Histogram

4.3 Shopping Arcade

In the shopping arcades most visitors set a significant value to an overall pleasant atmosphere while shopping. Also, the daylighting was mostly rated as very positive (Figure 5).

However, above certain limits, a large proportion of daylight seems to show disturbing effect. In the objects with a maximum daylight factor on the first floor of $D_{max} > 15$ %, 10 % - 20 % of the subjects perceived the daylighting as "bright" or "too bright".

In the objects with a maximum daylight factor of $D_{max} > 20$ %, even 20 % - 30 % of the visitors felt the daylighting as "glaring" and "strong glaring". Therefore, a daylight factor of $D_{max} = 15$ % in the first floor has to be considered as threshold. In the arcades with a maximum daylight factor in ground floor of $D_{max} < 8$ %, the daylighting was deceived by about 10 % of the visitors as "dark" or "too dark". Higher values of daylight factor of $D_{max} < 15$ % were not disturbing in this area for the visitors. Therefore, the empirical value of $D_{max} = 8$ % should be considered in future rather than a minimum value for planning.

The daylighting should therefore be planned in terms of visual comfort so that the maximum value of the daylight factor in the mall area is not less than a value of $D_{max} = 8$ % and doesn't exceed in the first floor a value of $D_{max} = 15$ %. With these values of daylight factor the radiation and heat load of corresponding objects is largely reduced at the same time.

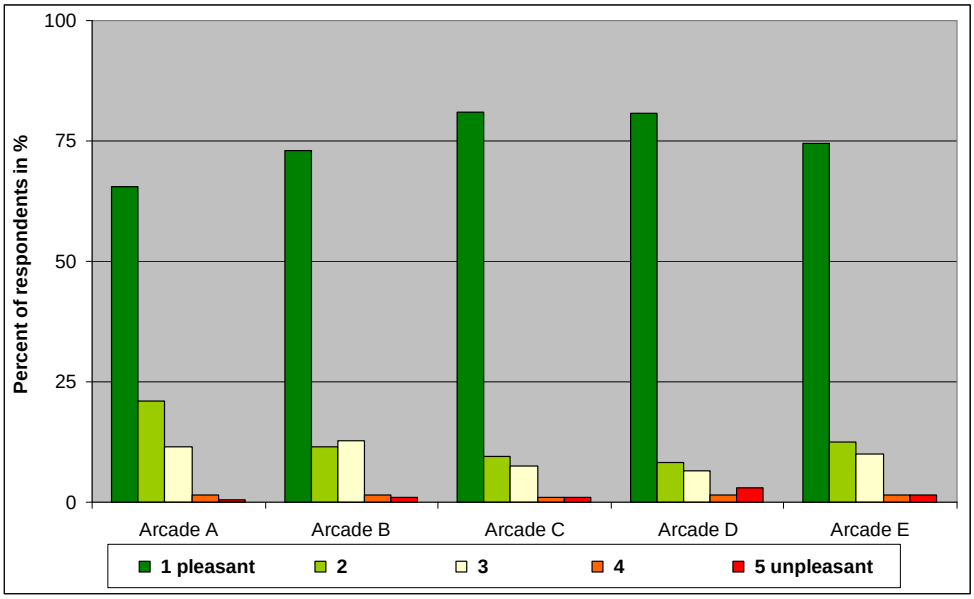

Figure 5: General assessment of the daylighting (pleasant / unpleasant)

4.4 Dwellings

The user surveys in private homes (Figure 6) showed that the minimum value for daylight factor specified in DIN 5034 of 0.9 % is not suitable for a positive user assessment. The minimum value of 0.9 % is to be interpreted as a limit and as such may still apply, but rooms with such low values are also perceived as too dark.

It turns out that a mean of daylight factor of about D = 2 % is good for the vote "just right". Higher values do not lead to an assessment as "too bright". Here a saturation effect can be observed. Even homes with much higher values of D are not rated as "too bright". Further when the ratio of the shell window area related for space floor area has a value of 0.3, then the daylight is "just right".

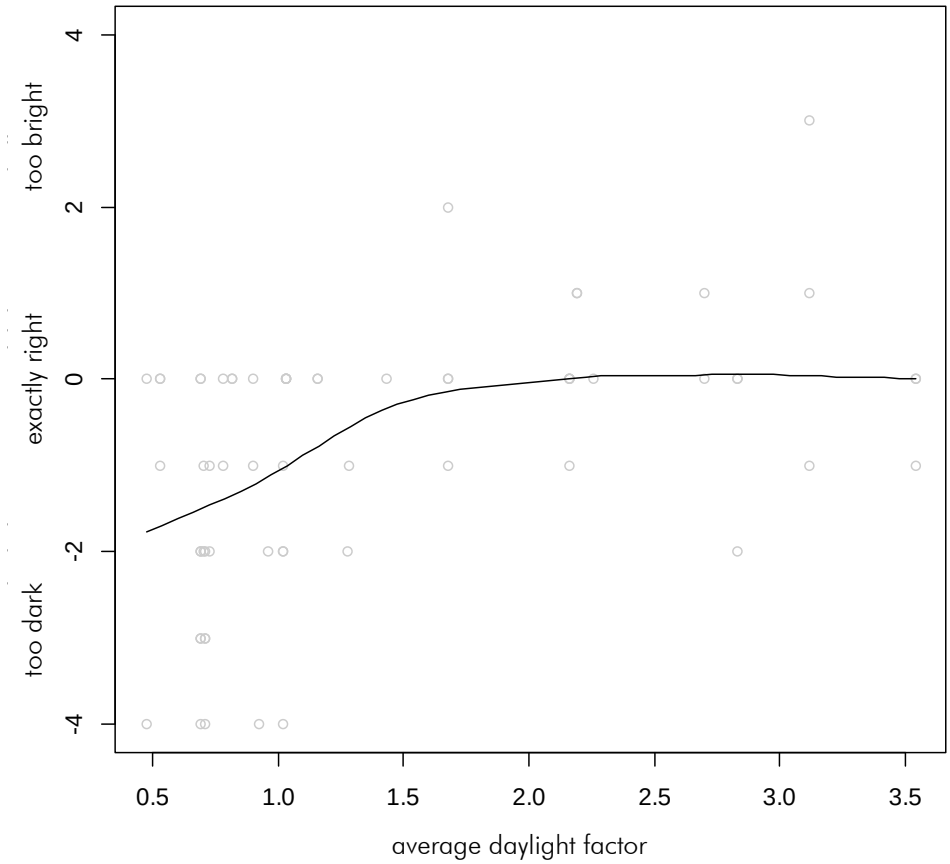

Figure 6: Brightness rating, depending on the average daylight factor

5 Conclusion

Daylighting of interior spaces are of great importance regarding the aspects of energy, light and psychology. The research project provides basics of daylighting both for standards as well as for use in lighting and building design. It has been shown, however, that technical solutions for daylighting systems and electronic control systems need to be developed and optimized with particular attention to health and energy evaluation.