The Influence of Daylight Design in Office Buildings on the Users Comfort

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ABSTRACT: Fully glazed buildings are more and more spread throughout the building sector in the whole world. Especially office buildings are often designed with a high glazing ratio to fulfil representative architectural tasks. It is likely that with a high glazing ratio conflicts occur which are founded in a high solar load and glare problems. An unsatisfactory working environment can reduce productivity of employees severely. Furthermore it creates high cooling loads and therefore immense maintenance costs. Solutions provide light direction to illuminate the space naturally and shading to avoid glare as well as to reduce cooling load. Many studies have been carried out on thermal comfort, others on lighting issues, but mostly under artificial lighting conditions or under exclusion of sunny conditions. The performance of light directing elements under sunny conditions and the resulting lighting quality so far has not been investigated. To fill this gap an intensive monitoring program has been conducted at the University of Dortmund investigating different shading devices. Simultaneously user acceptance studies have been carried out to evaluate lighting quality issues. The paper discusses some of the results on the subjective rating of the indoor lighting environment. Space and light perception often does neither correspond with the regulations lighting levels nor the control strategies for shading devices.

Keywords: Daylight, user acceptance, comfort, perception, psychology, shading, glare, light directing systems, facades

1. INTRODUCTION

The comfort in office buildings depends on the surface temperature, the indoor air temperature, the ventilation rate, the incoming radiation and the air quality but also on the lighting environment, view and privacy. Regarding possible disturbances through one these factors, an unsatisfactory lighting environment in office buildings will be announced by between 57% [1] and 66% [2], most of them concerning the artificial lighting devices. The possibility to interact with the indoor environment enhances the user comfort and satisfaction with the working environment [2, 3] as well as an adequate contact to the outside and sufficient use of daylight.

Conventional shading devices create a conflicting situation between the need for shading to avoid overheating and glare and the need for daylight to avoid artificial lighting and additional internal loads [4].

In the last decade a number of light directing and complex shading systems have been developed to avoid these conflicts [5]. These usually use the upper part of the windows to provide daylighting and to reflect it in combination with a reflective ceiling deep into the room; the lower part of the window takes care of shading and glare protection but mostly provides only a restricted view. Figure 1 shows the principles of a well designed facade for office buildings.

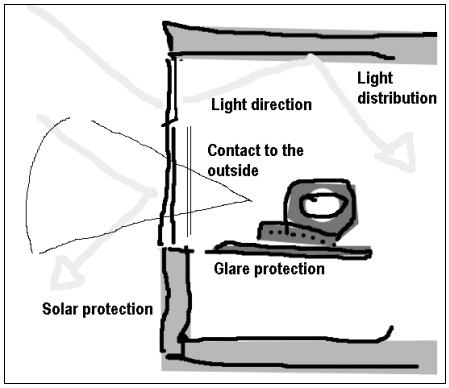

Figure 1: Task for a daylit office space

A number of studies have been carried out on the perception of artificial lighting devices [e.g. 6, 7, 8], less on the influence of daylit spaces onto the user [e.g. 9, 10, 11, 12]. But no studies have been carried out to assess any comfort issues with light directing and/ or complex facade systems under sunny conditions when issues such as the level of daylight, glare and the view out are most critical.

2. METHODOLOGY

Therefore a study has been conducted at the University of Dortmund comparing different shading and light directing devices under sunny conditions and with closed or active systems [13]. An overview of the installed systems is given in Figure 2.

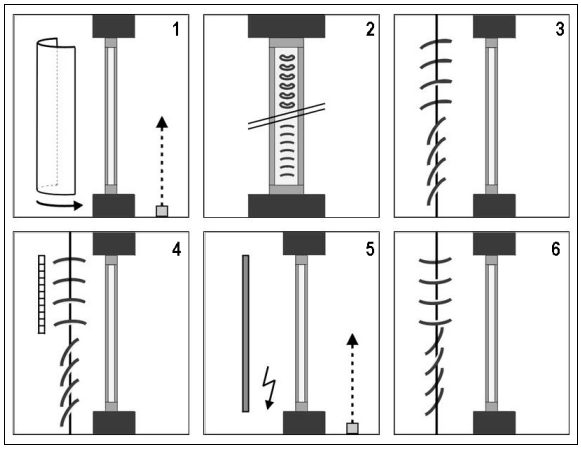

Figure 2: Overview of the installed systems

The systems include two shading devices such as photovoltaic elements with concentrating hologrammes redirecting direct solar radiation onto the pv (1) and electrochromic glazing (5). The other four systems consist of light directing elements such as a light directing glass (reflects direct light onto the ceiling deep into the space) and louvers in between two layers of isolating glass (2), light directing louvers (3), white light hologrammes for light direction in combination with light directing louvers (4) and daylight optimised louvers with concave lamellas which can be controlled separately in the upper and lower part (6).

An extensive monitoring database has been created measuring luminances with ccd- cameras, (two positions of the user and from the back wall), outdoor and indoor illuminances (vertical at eye height and from the back wall and horizontal in the working plane and at the ceiling), indoor and outdoor temperatures, the status of the shading devices and the artificial lighting components over a whole year. This program was complemented through occasional colour measurements [15]. The positions are indicated in Figure 3.

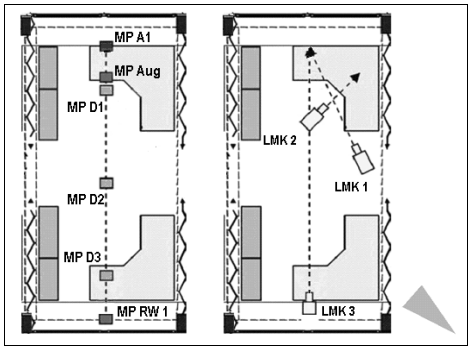

Figure 3: Illuminance and luminance sensors positions

Simultaneously, user acceptance studies have been carried out to asses the performance of the systems in a real world environment. These were based on existing questionnaires and adapted to the requirements for this study [16]. 336 questionnaires and statements of around 30 naive people (not involved in the subject of lighting design) have been evaluated on a short term basis (approximately half an hour).

To carry out the statistical analysis the resulting database of measurements and questionnaires was separated into ten different topics. An overview is given in **Table 1**, some of which will be discussed here.

Table 1: Overview of evaluation categories

Evaluation Categories	
Room temperature	Light direction
View out	Colour and space perception
Glare and reflections	Privacy and asthaethics
Function of systems	Overall comments
Brightness/ lighting levels	Working space and well-being

Four analysing steps included the simple counting of results as well as the analysis of room wise counting to evaluate the influence of different facades on the judgement of the interior lighting conditions. Furthermore relations between the topics such as view out and lighting levels have been investigated. The statistical correlation of the subjective results to objective measured data served the findings of the most important measured quantity for each topic. Limiting values for some of the measured data could be analysed in a fourth step to predict the subjective perception of users with a high probability.

3. RESULTS

The results of the study show a great influence of the selected facade system, its design and function on the office workers response and acceptance.

Some very first selected results of this study have been presented elsewhere in 2004 [14]. Within the study many more questions, based on an intensive literature review on the topic of lighting in office buildings, have been raised revealing some critical issues such as:

- The perception of brightness in offices
- The function of systems and the understanding of cause and effect
- The space perception in correlation to lighting levels and light distribution

A full report will be available to download via internet.

3.1 Brightness/ lighting levels

The brightness in office spaces within the regulations is controlled mainly by the illuminance in the working plane. For offices these are currently 500 lux or 300 lux close to windows respectively. These values are based on artificial lighting requirements.

There are rare comments on daylighting lighting levels.

Measurements taken in each of the six rooms with different daylighting systems result from situations with sunny conditions and closed systems. Figure 4 shows illuminances in the work plane close to the window.

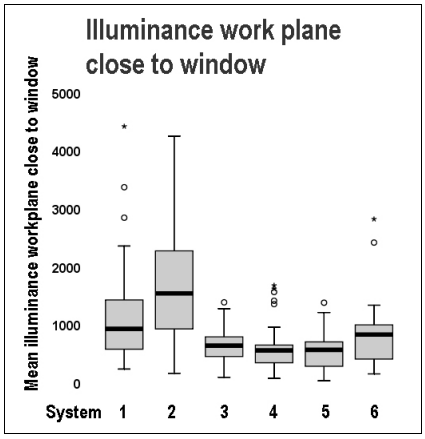

Figure 4: Work plane illuminances close to the window for all six rooms

The differences of illuminances in the work plane are very clear. System 2 reaches over 1500 lux as a median, often much more, whereas system 4 and 5 only reach around 500 lux in the work plane but more often even less. That leads automatically to the fact that artificial lighting may be needed with these systems even with sunny conditions.

The question for the user acceptance studies asked about the required lighting levels for a feeling of “brightness”. Figure 5 shows some of the questions and the resulting answers over the total database.

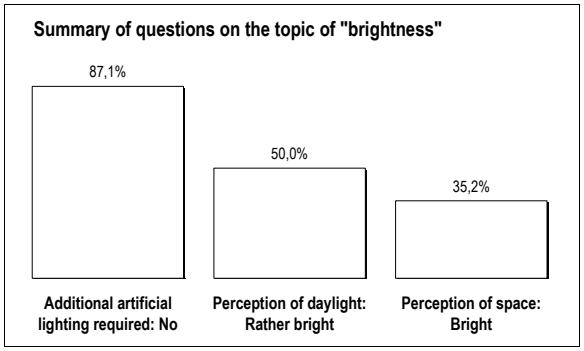

Figure 5: Counting of answers on “brightness”

Overall almost 90% of the tested people do not require additional artificial lighting under sunny conditions and closed systems but only 35% feel the perception of “brightness”; “rather bright” in contrast is the result of 50% of the questionnaires.

Separated by room different levels of perception according the selected question can be seen (Figure 6). The least requirements appear for the question on additional artificial lighting. Here, the best performance has been produces by Room 2 (light directing glass). More critical is the statement on “sufficient daylight in the work plane”, but the most critical level of perception is the feeling of “brightness”. Here only between 25 (Room 5) and around 80% (Room 2) state that the room appears “bright” whereas between around 80 and almost 95% of the questionnaires do not require additional artificial lighting.

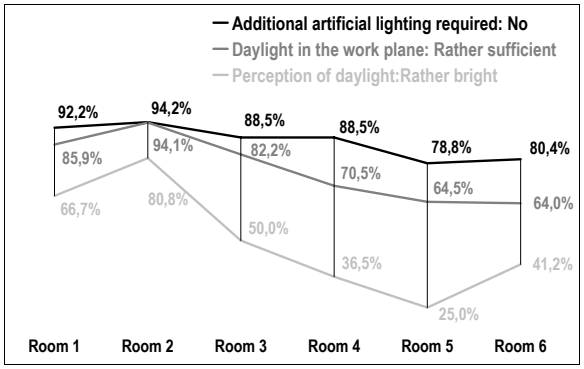

Figure 6: Comparison of the different levels of perception of brightness

“Brightness” therefore will be judged on a much more critical level than “sufficient daylight” or “additional artificial lighting required”.

The correlations to measured quantities are shown in Figure 7 exemplarily for the perception of daylight.

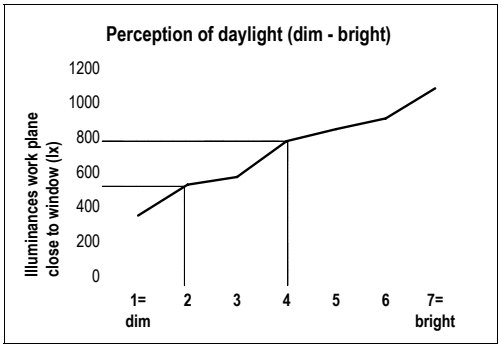

Figure 7: Perception of light, median of comments

The graph reflecting the median of results (50% exceed the values, 50% are lower) shows that 500 lux in the work plane close to the window will be judged as “rather dim” whereas the tendency to “rather bright” starts at about 800 lux.

Expressed in limiting values according to a statistical analyses of the quantity of satisfied people the additional artificial lighting will be requested when outside illuminances a lower than 5581 lux (global illuminance) or 12316 lux (vertical illuminance on facade). In contrast, the perception of brightness in a space will be stated when illuminances in the work plane exceed 3393 lux or vertical in eye height exceed 3797 lux. “Sufficient daylight” state most of the users when vertical illuminances in eye height exceed 3169 lux. A summary of the limiting values is given in Table 2.

Table 2: Limiting values for "brightness"

	illuminance in work plane close to window	Vertical illuminance at eye height	Global illuminance outside	Vertical illuminance on facade outside
Additional artificial lighting required: YES	X	X	> 5581 Lux	> 12316 Lux
Perception of daylight in space: Rather bright	> 3393 Lux	> 3797 Lux	X	X
Daylight at working desk sufficient: YES	> 4442 Lux	> 3169 Lux		> 40039 Lux

These values show clearly, that the requested values by the building regulations are not enough for the space perception "bright". Furthermore the vertical illuminance at eye height is a relevant measured quantity.

3.2 Function of systems

The function of systems plays an important role for the shading coefficient but also for the daylight distribution in an office space. The individual control is stated as "important" for the satisfaction of users [11, 17, 18, 19]. For the judgement of the function the understanding is an important criterion [21].

Over the whole database almost 90% state that the shading device performs "rather well". Nevertheless an additional protection was required by 21% of the user's answers. This mostly was the case in Room 1 (PV with concentrating hologrammes) where the "visible" shading function is less clear. There was no statistical significant correlation of the function with the indoor temperatures. The conclusion of a correlation between room temperature and the "protection against heat" therefore was not taken by the users. The most relevant value for additional protection was the illuminance at eye height. An additional protection was required when values exceeded 3797 lux vertical in eye height, but the system was stated as well functioning when vertical illuminances did not exceed 3169 lux at eye height and 4274 lux in the working plane.

46% of the users felt disturbed when the shading device could not be controlled individually but was fixed and 90% state that the possibility of individual control is important. This supports results of other studies [11, 17, 18, 19]. The question raised includes the cause of using the individual control.

Within the study measurements were taken with fixed status to be able to compare the performance of systems. But at the end of each session of questionnaires the people had the possibility to readjust their shading device according to their individual needs. Overall only 46% did not vary their systems whereas between 29 and 74% opened or half opened their lamellas depending on the system they used. Room 2 with the light directing glass was the space with the most unvaried status (55%). The more light the users had in their spaces the less they wanted to change their systems' status. If they changed they rather tried to receive more contact to the outside, not because of thermal or lighting quality.

Summarizing the investigations regarding the function of systems the "visual" protection function [21] plays an important role as well as the individual control [11, 17, 22, 18, 19]. The most relevant value was the vertical illuminance at eye height. There was no correlation to room temperatures, therefore the individual control was based on the quality and quantity of daylight and the contact to the outside, thermally controlled shading devices therefore are likely to lead to misunderstanding and disturbance.

3.3 Space perception

The architectural layout is known to enhance the well-being when properly designed. But in an enclosed space, under which circumstances the feeling of openness does occur, especially in cases with closed shading systems, and how to relieve the conflicts between the necessary heat protection and the need for the contact to the outside?

Figure 8 shows the results of the questionnaires in relation to the perception of "open", "closed" or "locked in" over the whole database. Most of the users (67%) felt rather "enclosed" in their spaces, only 17% found themselves in an "open" environment.

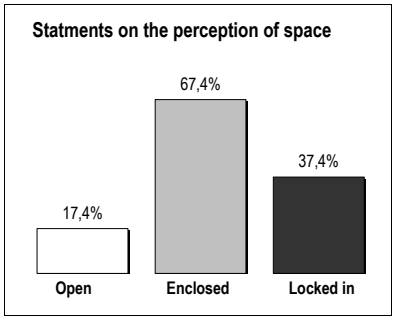

Figure 8: Perception of space

Room wise that means that the light directing devices not providing any contact to the outside when completely closed perform worse (86% answers "closed") than the shading systems which have been tested with an additional glare protection (20% answers "closed"). Amongst the louver systems the redirecting glass in combination with louvers in between the two layers of insulating glass (System 2) performed best with 14% of statements "open" (others only between 0% to 6%). This statement correlates significantly with the view out but is influenced strongly by the brightness in a room (Figure 9).

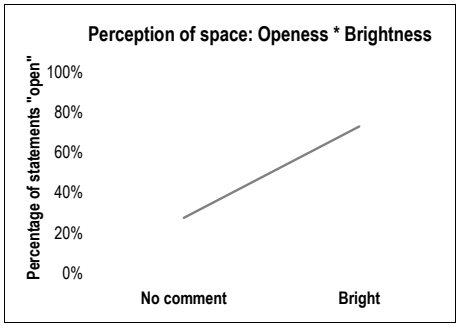

Figure 9: Brightness versus openness

The more "bright" the space was the less "enclosed" did the users feel.

Another correlation can be found between a noticeable light direction and the view out, where there is a tendency for a better statement on the missing view when effective light direction enlightens the space.

Therefore the feeling of "openness" can be enhanced with an effective light directing system, or in other words, negative statements on a missing view out or the feeling of "enclosure" can be influenced in a positive way when light direction is used.

4. CONCLUSION

The results of this study show the differences in the resulting lighting quality according to the shading device used. They also show the different levels of acceptance in terms of space perception, brightness and function.

For the perception of brightness they show that on the one hand 500 Lux in the working plane are not enough, but requested values are much higher, on the other hand they show that the measured quantity of illuminance in the work plane often does not reflect the perception of the daylit space.

The judgement of the function of systems is not based on thermal issues mostly used for the automatic control of shading devices but on the view out or the lighting quality. The "visual" protection therefore is the main criterion for the user.

The perception of openness is mainly influenced by the contact to the outside, but both, the openness and the statements on the view out can be enhanced through higher lighting levels and efficient light direction deep into the space.

As productivity is directly linked to comfort and well-being, the matter of subjective perception should not be neglected when designing and planning new working spaces. Especially the circadian effects of light which have been reported in the last years [23] are likely to be linked with the perception of brightness and the measured quantities of vertical illuminance or spatial luminance. Both, in terms of health and in terms of productivity these aspects have an impact on the costs and efficiency of employees.

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Remark: this study is part of a PhD Thesis submitted at the University of Dortmund, Germany, in March 2006. Reference: Schuster, Heide G.: Tageslichtsysteme im Spiegel der Nutzer. Dissertation am Lehrstuhl für Klimagerechte Architektur, Universität Dortmund, Deutschland 2006.

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