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Control strategies and user acceptance of innovative daylighting and shading concepts

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Abstract

At the last Eurosun in Aix-les-Bains 2014 the daylighting and shading concept of the Energy Efficiency Center was presented (*Reim et al. 2014*) – a translucent membrane roof with subjacent translucent aerogel modules improves the daylighting especially in the room depth, highly innovative solar blinds guide the visual spectrum of the sunlight only into the rooms while blocking the infrared parts. Roller blinds for glare protection with special low-e-coatings improve thermal comfort in the offices. A high-level building automation system controls the different systems. After these measurements surveys were performed to determine the effect of the different daylighting and shading systems on the users in the different offices. The results of the conducted surveys with the users of the EEC in the offices will be assessed and the consequences for the optimization of the control strategy will be discussed. Finally, the influence of the aerogel glazing on the energy consumption will be discussed.

Keywords: *daylighting, shading, artificial lighting, user acceptance, aerogel glazing, control strategies,*

1. The Energy Efficiency Center

The Energy Efficiency Center (EEC) is a combined office (1st floor) and laboratory (ground floor) building with a function room attached to the north side, shown in Fig. 1. It is located in Würzburg, Germany, and was finished in June 2013. The overall aim of the project was to create a reference building which implements innovative techniques, serves demonstrational purposes, and sets new standards (*Weismann et al. 2016* and *Römer et al. 2016*).

Fig.1: Energy Efficiency Center viewed from north-east, the north-orientated rooms on the first floor and the roof of the technical center. Clearly visible is the textile roof with translucent PTFE-glass membranes and partially transparent ETFE films in the ridge of the roof.

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2. Lighting and shading concept

The goal of the lighting and shading concept is to minimize the energy consumption of the artificial lighting system by maximizing the daylight input into the rooms while, at the same time, reducing the heating/cooling loads by maximizing/minimizing the solar energy input into the offices as applicable. Depending on the heating or cooling demand of the office the solar energy input can be varied by using either the outside (low solar energy input) or inside (high solar energy input) shading device.

The roof of the main building consists of translucent PTFE-glass-membranes and partially of transparent ETFE films. The membrane acts as a climate interlayer above the thermal insulation level, the ceiling of the 1st floor which is partly transparent or translucent. Some ceiling areas of the office rooms away from the façade consist of translucent double skin sheets filled with Lumira-aerogel thus enabling a high room illumination in the depth. The roof of the function room to the north consists of translucent, double-layered, air filled PVC-membrane cushions.

The sun protection system on the south façade consists of outside blinds from WAREMA Renkhoff SE with spectrally selective lamellae. The solar reflectance of the lamellae in the visible spectral range is significantly higher than the reflectance in the solar spectral range. The result is a total solar energy transmittance which is lower than that of non-selective lamellae with the same visual transmittance. Additionally, all rooms are equipped with an inside glare protection system, a roller blind with a low-emissivity coating on the inner surface to improve thermal comfort of the inhabitants. The luminaries are switched and dimmed automatically based on combined occupancy and illuminance sensors in each room. Depending on the heating or cooling demand of the room, the solar energy input through the facade can be varied by using either the outside (low solar energy input) or inside (high solar energy input) shading device. The operation of the lighting and sun protection system was tested for all weather conditions. When the correct operation of the control system was verified the interaction of the users with the control system was investigated by surveying the user interventions with the building control system during winter conditions (*Reim, M.,* et al., 2014). Other surveys to optimize control strategies will follow.

2.1. Control of lighting and sun protection system

Each room is equipped with a ceiling-mounted combined occupancy and illuminance sensor. The occupancy sensor selects a low-power mode for the room when nobody is present. This includes switching off the light and operating the external sun protection system depending on whether there is heating or cooling demand (completely open or completely close the sun protection system) for the room.

When occupied, a default illuminance level of 500 lx (*EN 12464-1, 2011* for office rooms) at the work places is maintained using dimmable artificial lighting if necessary. The position of the shading system (open or closed) depends on the outside illuminance on the respective façade:

- It is closed at an outside illuminance higher than 45 klx. The lamellae angle is set depending on the position of the sun and the heating or cooling demand of the room. When heating demand is present the lamellae are closed just a few degrees more than the cut-off-angle, which ensures that no direct irradiation passes the sun protection system. The cut-off-angle is the angle to which the lamellae have to be closed in order to completely prevent direct radiation to pass through the sun protection system depending on the solar height. When cooling is needed the lamellae angle is set 10° higher than the cut-off-angle or a minimum of about 20°, further reducing the solar energy input to the room.
- It is opened when the outside illuminance is lower than 20 klx for some time.
- When the outside illuminance is higher than 30 klx the sun protection system is closed with a lamellae angle of 0° (horizontal). The same state is reached when the system is closed and the outside illuminance is lower than 30 klx.

All automatic settings for lighting and outside sun protection system can be overruled by the user; the control system is reset to automatic mode after 30 minutes without occupancy. The roller blinds used as inside glare protection are controlled manually.

Following a survey from spring 2015 the control strategy for the building was optimized as follows:

- The starting time for the room heating on Mondays after the weekend setback was changed from 6 am to 4 am to increase the room temperatures in the morning, especially in the corner offices.
- The maximal closing angle of the sun protection system of 50° was too big. Most of the users felt uncomfortable with the nearly fully closed shading system and artificial lighting switched on, so we set the maximum closing angle to 45°.
- At outside temperatures above 8°C, heating demand for the room and illuminance at the south façade above 45 klx the sun protection system was fully closed so far. In the rooms with room-high glazing we changed the control so that the sun protection system stops at a façade height of 40 % for the case of heating demand in the room. This improves the user acceptance, allows better visual contact to the outside and additionally increases the solar gains during the heating period.

After these changes, we performed new surveys to check if the changes really improved the situation in the offices. These results were presented in *Reim et al. 2015*. In nearly every room the number of the interventions by the users was reduced after the optimization of the control strategy of the sun protection system. Even in the rooms, where the users often intervene with the building control, the number of interventions was reduced after the optimization.

2.2 Daylight input through aerogel glazing

The ceilings in the back of the offices are equipped with aerogel glazing, shown in Fig.2. The aerogel glazing should improve the illumination in the room depth by daylight that is transmitted through the translucent textile roof. This should reduce the electric consumption needed for artificial lighting. To quantify this effect, measurements were made in two comparable rooms, one with and one without aerogel glazing (the aerogel glazing was covered for the measurements in this room) and the power signal for the artificial lighting was detected and analyzed.

Fig.2: Aerogel glazing in the back of the offices

3. Results

3.1 User surveys

After the control strategy of the sun protection system was changed as discussed in section 2.1, the efficiency of the changes was investigated. Assuming that the more comfortable the user feels the less he is intervening with building control, we compared the user interventions before and after the optimization, see Fig.3. The number of user interventions decreased, especially the cases when the sun protection system was manually opened fully (case “open”) or partially (case “middle”).

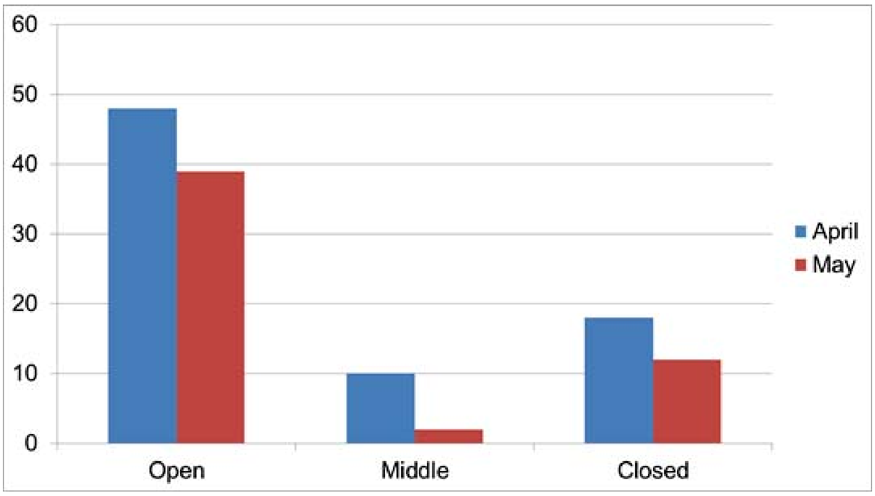

Fig.3: Number and sort of user interventions with the shading system before (april) and after (may) optimization of the control strategy.

After these changes, we checked the number of user interventions (see table 1) and additionally performed new surveys to check if the changes really improved the situation in the offices.

Table 1: Number of user interventions with the building control for different rooms before (april) and after (may) optimization of the control strategy.

Room Intervention	1	2	3	4	5	6	7	8	9	10	Total	Mean per workday
april	12	11	-	2	3	2	4	4	14	6	58	2.9
may	6	9	-	3	3	-	1	2	8	5	37	2.1

In a ‚pop-up‘ survey we asked users about their satisfaction with their working environment (happy/unhappy). After this window a second pop-up window opened asking for reasons for satisfaction/dissatisfaction (temperature/ light/ other reasons). In order to keep the user from choosing the shorter version of answering the survey, the number of windows and the number of clicks had to be similar. This was discussed with a psychologist in advance. In the course of the survey a problem became obvious: one can easily determine whether the office is too warm, cold, dark or bright, but it is difficult to decide if the office is just as warm or cold as one would like it to be. Many users got put off by the number of clicks needed (3 - 6). Hence the survey was reduced to one window with 2 clicks,Fig 4.

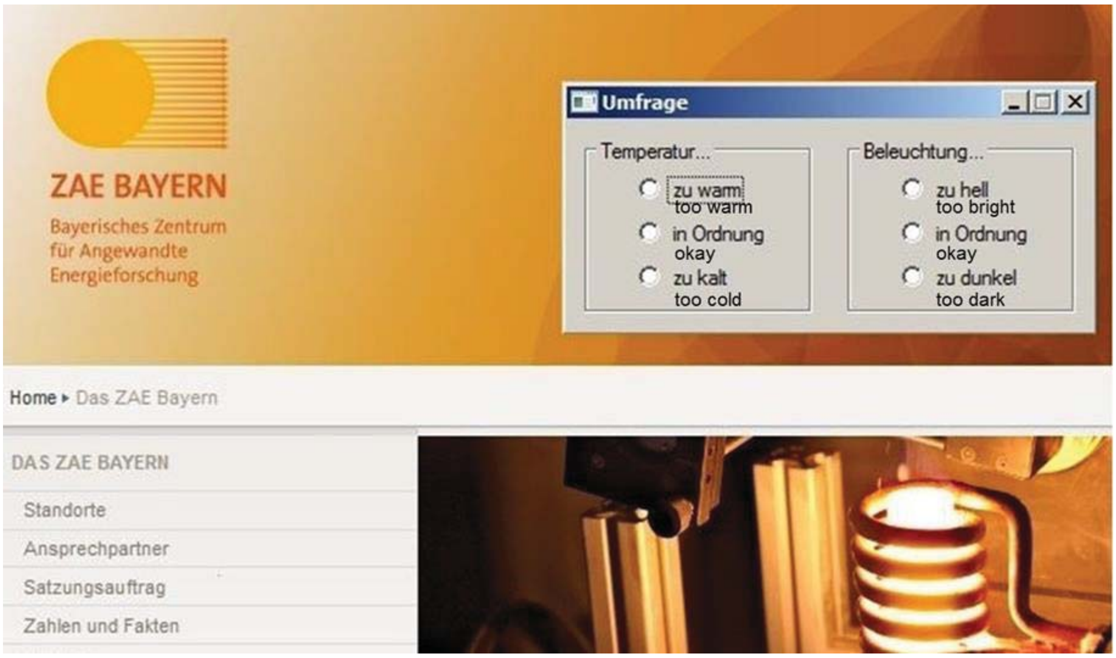

Fig.4: Optimized Pop-up window.

Evaluation of the survey between 16/08/2016 and 16/09/2016 is depicted in table 2 and table 3. In this timeframe the weather was very warm and sunny. In table 2 the user satisfaction in south- and north-facing as well as corner offices is depicted.

Table 2: Comparison of user satisfaction in south- and north-oriented as well as corner rooms

	South orientated	North orientated	Corner
too warm	1.6 %	3.8 %	8.1 %
okay	90.3 %	90.9 %	90.4 %
too cold	8.1 %	5.3 %	1.5 %
too bright	0.9 %	3.4 %	5.6 %
okay	95.3 %	90.0 %	92.1 %
too dark	3.8 %	6.6 %	2.3 %

With an overall satisfaction over 90 % we conclude, that for all offices – independent of their direction – the sun-protection and artificial light regulation is working very well at least for summer conditions.

In table 3 the user satisfaction as a function of daytime is depicted.

Table 3: Comparison of user satisfaction depending on daytime

	too cold	too warm	too dark	too bright
before 10 am	10.0 %	1.5 %	4.9 %	3.8 %
10 am – 2 pm	7.3 %	2.6 %	3.3 %	2.5 %
after 2 pm	2.0 %	5.5 %	5.2 %	2.0 %

There is neither a correlation between daytime and sensitivity of light, nor for perception 'too dark' (average 4.5 %) or too bright (average 2.8 %).

However, there seems to be a tendency in perception of temperature. During morning hours it is often too cold, in the afternoon often too warm.

One important change to the control was the last point mentioned in section 2.1, where the sun protection system was not closed completely any longer at outside temperatures above 8°C and heating demand as well as illuminance levels at the south façade of more than 45 klx but instead stopped at a façade height of 40 % thus shading only 60 % of the façade area instead of 100 %. This should lead to a reduced heating demand due to increased solar gains. In order to estimate this effect, we investigated the control log of the sun protection system and looked how long the sun protection system was in this optimized mode from September 1st 2015 to September 1st 2016. During the whole year, twelve office rooms stayed in this optimized mode for a total of 1891 hours in which the solar energy input was increased by 40 %, which equals a mean value of 158 hours per year and room.

In case of high irradiance on the south façade, which causes the mode of maximal shading angle this adds up to 2271 hours per year, which equals a mean value of 189 hours per year and room, in which most users switched on electric light, since it was too dark for them. Therefore, some energy savings should be achieved in this mode, however it is difficult to estimate how much.

3.2 Energy savings potential of aerogel glazing

Finally, we compared the illuminance and the lamp control signal for two similar rooms – one with and one without aerogel ceiling panel, see Fig. 5.

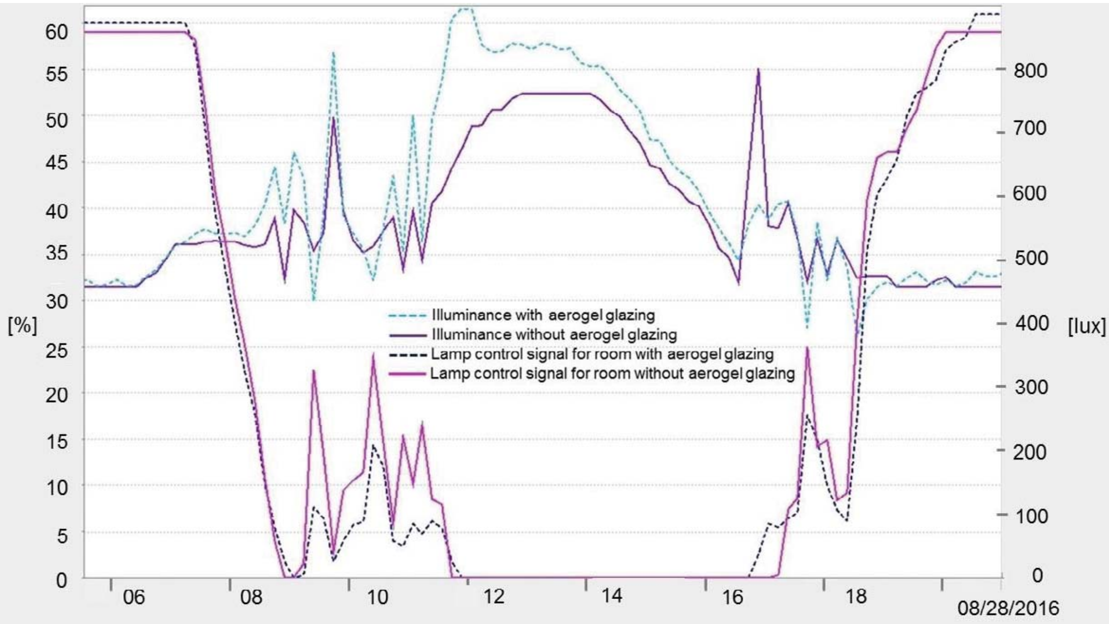

Fig.5: Comparison of illuminance in a room with (dotted line) and without (single line) aerogel glazing as well as the signal for lamp control; illuminance right axis [lx], lamp control signal left axis [%].

On the August 28th depicted in Fig. 5 the amount of daylight between 11:30 am and 4:30 pm is sufficient to illuminate the offices with 500 lx without any artificial lighting (lamp control is off). Here the illuminance during midday hours of a room with aerogel glazing exceeds that of a room without aerogel glazing by 100 lx. During morning (8:30 – 11:30 am) and evening hours (4:30- 6 pm) artificial lighting is added by the control strategy to guarantee a working place illuminance of 500 lx. In order to conduct measurements with defined boundary conditions, the control of the sun protection system was identical for both rooms and the presence was turned on all day without any user influence.

An overview of the measured electrical energy consumption in the two rooms with and without aerogel glazing is depicted in Fig. 6 for some days in May and August 2016. If we ignore the first measurement day on May 14th because of the very low consumption values with a corresponding high measurement error, typical energy savings of 10 % – 50 % can be achieved with the aerogel glazing as headlight. The mean value for all five measurement days yields energy savings of 30 %.

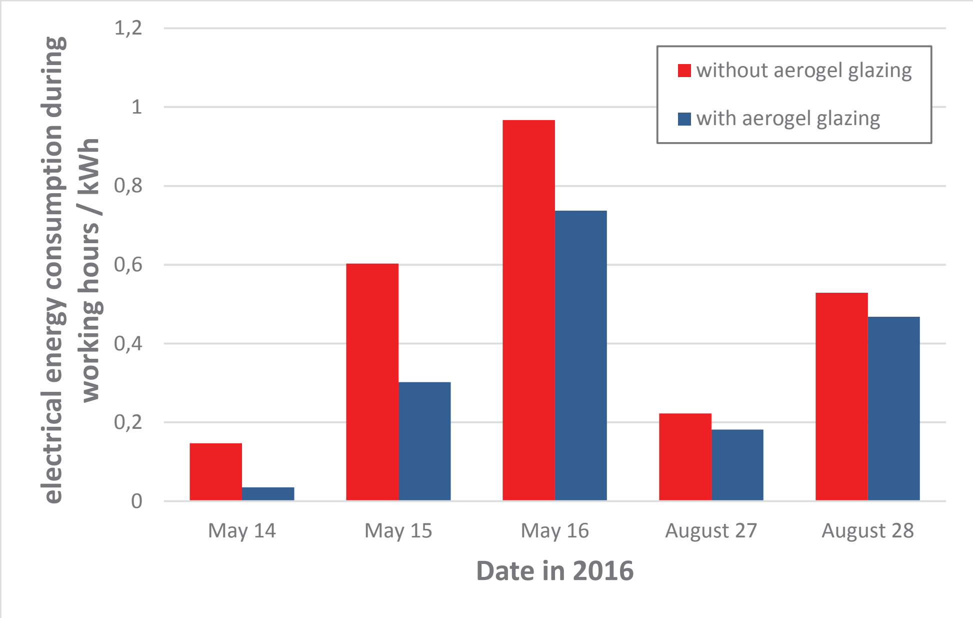

Fig. 6: Electrical energy consumption for artificial lighting in two rooms with and without aerogel glazing as headlight.

4. Summary and Outlook

During recent work, the building control of the Energy Efficiency Center with its innovative daylighting and sun protection concept was investigated and optimized. The various optimization measures were controlled and confirmed by user surveys. In addition, we started to evaluate the electrical energy savings potential of aerogel glazing as headlight in the offices to reduce artificial lighting. First measurement results are presented here that show an electrical energy savings potential of about 30 %.

Further surveys will be made to continuously check the quality of the building control. Measurements of the electrical energy consumption due to artificial lighting in the two offices with and without aerogel glazing will also continue.

5. Acknowledgement

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