DAYLIGHTING AND SHADING OF THE ENERGY EFFICIENY CENTER – MONITORING RESULTS AND USER ACCEPTANCE

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ABSTRACT

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. The overall aim of the project is to create a reference building which implements innovative techniques and serves demonstrational purposes. The roof of the main building consists of membranes; parts of the ceiling of the 1st floor are transparent or translucent.

The operation of the lighting and sun protection systems as well as the associated control systems was tested for summer, intermediate and winter conditions. The interaction of the users with the control system was investigated by monitoring the manual user interventions during winter conditions. Furthermore a questionnaire was compiled to investigate the user acceptance of the control of the sun protection system and the artificial lighting, especially the lighting level and glare protection in the rooms.

Keywords: membrane; daylighting; artificial lighting; aerogel glazing; user acceptance

INTRODUCTION

The Energy Efficiency Center (EEC) is a combined office (1st floor) and laboratory (ground floor) located in Würzburg, Germany and finished in June 2013. The roof of the main building consists of translucent PTFE-glass-membranes and partially of transparent ETFE films. The translucent part of the roof consists of a PTFE-glass-membrane Type Sheerfill II with Everclean-Coating [1]. The transparent part consists of an ETFE-Film with a thickness of 250 µm printed with a hexagonal pattern with a pattern size of 9 mm and a print coverage ratio of 89%. The visual transmittances of the ETFE film and glass-PTFE membrane are 57% and 11%, respectively. The membrane acts as a climate interlayer above the thermal insulation level, the ceiling of the 1st floor. Parts of the ceiling of the 1st floor are transparent or translucent. The ceiling of the corridor consists of triple glazing. Part of the ceiling of the corridor and stairways is glazed with an aerogel glazing [2]. The ceilings of most of the office rooms contain a translucent double-skin-sheet filled with Lumira-aerogel [3] with a width of about 1 m located in the back of the room.

Figure 1 show the main building viewed from south-east. The main axis of the building runs east-west. Most of the office rooms are located on the south side on the 1st floor. In the north side there are staircases and lift, the library and two conference rooms as well as some office rooms. The basement mainly contains laboratories. To the north an additional single-story part contains a function room and a technical center.

The sun protection system on the south façade consists of outside blinds 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 [4]. The result is a total solar energy transmittance which is lower than that of non-selective lamellae with the same visual transmittance. The cut-off-angle is the angle to which the lamellae have to be closed in order to prevent direct radiation to pass through the sun protection system depending on the solar height. On the east and west façade triple glazing with integrated lamellae was used for

architectural reasons. On the north façade no sun protection system is used. In order to limit the solar energy input through the north façade a glazing with lower total solar energy transmittance was used there. 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 summer conditions, meaning high altitude of the sun and a control strategy for the sun protection system with the goal to minimize solar energy input through the façade [5]. Similar tests for intermediate and winter conditions were presented in Graz this spring [6]. 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. Other surveys for summer and intermediate conditions will follow.

Figure 1: Energy Efficiency Center viewed from south-east. Clearly visible is the textile roof with translucent PTFE-glass membranes and partially transparent ETFE films.

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 rooms as applicable.

METHOD

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 for the room.

When occupied, a default illuminance level of 500 lx ([7] for office rooms) at the work places is maintained using dimmable artificial lighting if necessary. The position of the shading system 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 a few degrees more than the cut-off-angle, which ensures that no direct irradiation passes the sun protection system. 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°. The same state is reached when the system is closed and the outside illuminance is lower than 30 klx.

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

Monitoring

Two office rooms at the south and north façade were equipped with some additional illuminance sensors at the desktop and below the translucent part of the ceiling. The illuminance sensors at the work places were used to calibrate the ceiling-mounted sensors used for lighting control.

Measurements were performed in two comparable south oriented rooms with additional illuminance sensors – behind and above the monitors at the work places, one in the middle (Height 110 cm) and one in the back (Height 130 cm) of the room. One room is with working Aerogel ceiling, the other room is with shaded Aerogel ceiling.

RESULTS

Monitoring results

Figure 3 shows the illuminance below the translucent part of the ceiling in the south and north offices depending on the global solar irradiance for a period in summer 2014 and winter 2014/2015.

In summer this illuminance is approximately proportional to the global irradiance and peaks at about 2000 lx for the south room. The corresponding illuminance for the north room is significantly higher and peaks at above 8000 lx. This is caused by direct irradiation through the ETFE films above the corridor, which hits the translucent panels at the north side. As the visual transmittance of the ETFE films is significantly higher than the transmittance of the glass-PTFE-membrane this yields higher light input through the translucent panels for the north rooms compared to the south rooms. When comparing the illuminance Ev below the translucent part of the ceiling for overcast sky (direct solar irradiance near zero) the values for the north- and south-oriented rooms are identical.

Due to the lower elevation of the sun in winter, no direct radiation hits the translucent panels on the north side. Therefore, the illuminance below the translucent parts of the ceiling is nearly identical for the north- and south-oriented office rooms.

Measurements of the illuminance E_v and global irradiance G for south-facing rooms with open and shaded Aerogel ceiling showed that the Aerogel ceiling contributes on sunny days in winter with about 200 lx up to 400 lx to the room illumination, especially in the back of the rooms. Even at overcast skies in winter ($G < 200$ W/m^2) and closed sun protection system the illuminance through the Aerogel ceiling is about 100 lx in the back of the room. These results

show that the translucent aerogel ceiling has a significant effect on the room illumination, especially when regarding the illumination in the room depth. Even on overcast days, the aerogel ceiling contributes significantly to the room illumination thus reducing the electrical energy consumption for the luminaires.

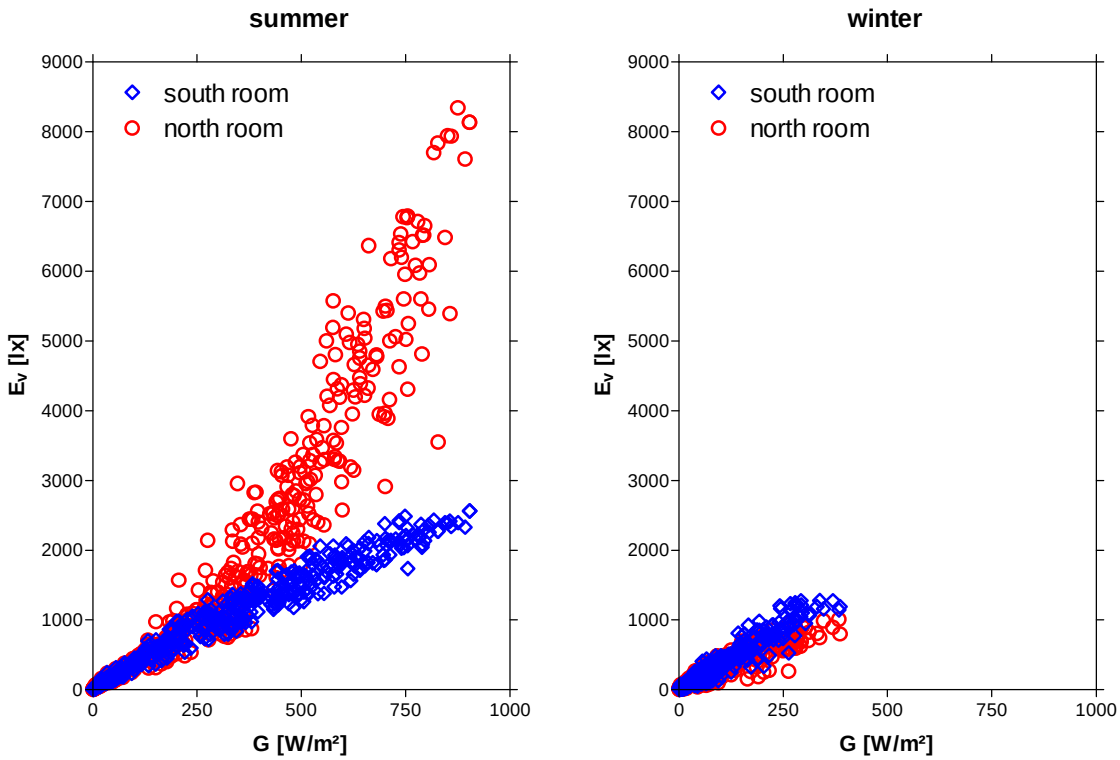

Figure 3: Illuminance E_v below the translucent part of the ceiling as a function of the global irradiance G on the horizontal for summer 2014 (left) and winter 2014/2015 (right).

Survey results

37 users participated in the first survey (24 male, 13 female). 6 users occupy a north-oriented room; they omitted the questions regarding the control of the outside sun protection system. 29 users work in rooms equipped with an outside sun protection system, 17 of them are male and 12 are female. The work places of 18 users are near the façade, 11 users are seated in the back of the room.

Tables 1 to 3 show the results of the first survey for winter conditions. The analysis showed almost no difference in gender related temperature perception regarding hot temperatures. However, there was a significant difference regarding cold temperature perception where 76% of the females sometimes or often feel cold compared to only 26% of the males. A difference was also found in luminance perception regarding daylight, where males seem to prefer darker environments – only 39% of the males sometimes or often feel too dark compared to 69% of the females. Regarding the luminance perception by artificial lighting, males as well as females find it often too bright – 26% and 46%, respectively. One additional result of this first survey was that there was no dependence between the interactions of the users with the control system regarding the time of day.

In general, the results show that the building control seems to work quite well. Usually, the users find the conditions acceptable – the category “often” is used by less than 10% of the people. Exemptions are the temperatures which are often too low for the females and the artificial lighting which is often too bright for males and females. The number of interactions

with the control shows, that there is still room for improvement: about 50% of the people manually intervene more than three times a day. There is no difference between males and females in interacting with the building control, whereas the position of the desktop in the room seems to influence the number of interactions significantly. Users near the façade intervene more often than users in the back of the room - despite the building control being located in the back of the room.

Table 1: Difference in temperature perception of male and female.

	Too hot		**Too cold**	
Temperature	**male (24)**	**female (13)**	**male (24)**	**female (13)**
Never...	54%	62%	71%	23%
Sometimes...	38%	31%	29%	38%
Often…	8%	8%	0%	38%

Table 2: Difference in daylight and in artificial lighting perception of male and female.

	Too bright		**Too dark**	
Daylight	**male (24)**	**female (13)**	**male (24)**	**female (13)**
Never…	58%	69%	58%	31%
Sometimes…	29%	31%	33%	54%
Often…	13%	0%	8%	15%
Artificial lighting	**male (24)**	**female (13)**	**male (24)**	**female (13)**
Never…	67%	46%	79%	69%
Sometimes…	8%	8%	17%	23%
Often…	25%	46%	4%	8%

Table 3: Nr. of interactions per day with the building control depending on gender and position in the room.

Interactions per day	**male (17)**	**female (12)**	**window (18)**	**back of the room (11)**
0 - 3	59%	50%	44%	64%
4 – 6	24%	33%	33%	27%
7 – 9	18%	17%	22%	9%
9 – 12	0%	0%	0%	0%

DISCUSSION AND CONCLUSION

After the analysis of the survey and discussion with the users we changed some points in the control strategy.

- 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 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 60% of the height of the façade 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.

Up to now the control of artificial lighting is either automatic (500 lx at workstation offices) or by manual dimming. Another possibility is manual control of the set point of the lighting control system. This would allow the users to change the illuminance level in the room without disabling the control of the artificial lighting. It is not clear up to now if this is possible using the hardware installed in the rooms.

After one year of measurements and operational experience, we started a survey of the users to improve the control system. After the first survey this winter we optimized the control strategy and adapted the questionnaire. Now we will start an interactive, monthly repeating survey over one year to receive an impression of the user acceptance and potential for optimization including all seasonal conditions.

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