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Daylighting and Shading of the Energy Efficiency Center

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Summary

This work describes the daylighting and shading concept of the recently constructed *"Energy Efficiency Center"*. There, an efficient utilization of natural lighting in the offices, corridors, function room and technical center was realized by use of a translucent membrane roof with subjacent translucent aerogel modules. Selectively coated solar blinds guide the visual spectrum of the sunlight into the rooms while blocking the infrared parts. Roller blinds for glare protection with special low-e-coatings improve thermal comfort in the office rooms. A high-level building automation system controls the different systems. The goal was to minimize the energy consumption for artificial lighting and at the same time to minimize the solar energy input into the rooms in summer while providing the highest possible thermal and visual comfort to the users.

Keywords: Textile architecture; energy efficiency; shading; sun protection; membrane; daylighting, artificial lighting; aerogel; g-value; U-value; transmittance; luminescence

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 and technical center attached to the north side. 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.

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 rooms as applicable.

Fig. 1 shows the main building viewed from south-east. The main axis of the building runs east-west.

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

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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 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 itself is partly transparent or translucent. The ceiling of the corridor in the 1st floor is glazed, so it is naturally illuminated through the translucent and transparent membrane roof, see Fig. 2.

Fig. 2: Corridor in the 1st floor in east-to-west direction illuminated by daylight.

Part of the ceiling of the corridor and stairways is glazed with an aerogel glazing [Okalux, 2013]. The ceilings of most of the office rooms contain a translucent double-skin-sheet filled with Lumira-aerogel [Cabot, 2013] with a width of about 1 m located in the back of the room, thus enabling an additional illumination of the room depth through the translucent roof (see Fig. 3).

Fig. 3: Translucent aerogel glazing in the stairways (left); Aerogel-filled double skin sheets in the office rooms (right).

The roof of the single-story function room and technical center at the north consists partially of translucent, double-layered, air filled PVC-membrane cushions with a glass fiber interlayer.

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 [Warema, 2008]. The result is a total solar energy transmittance which is lower than that of non-selective lamellae with the same visual transmittance. Fig. 4 shows the geometry and the cut-off-angle of these lamellae. 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.

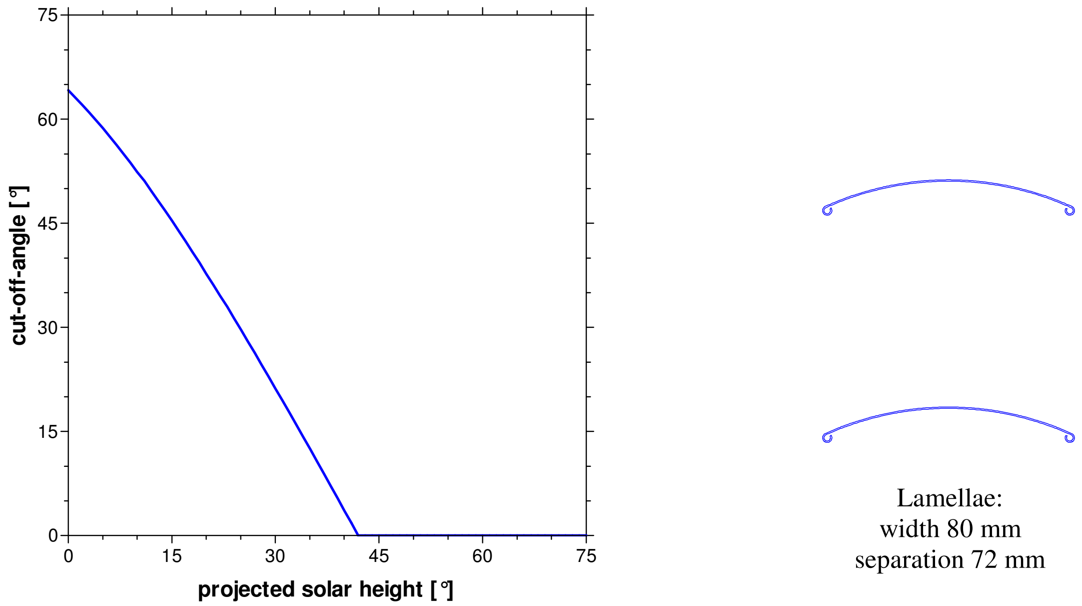

Fig. 4: Geometry of the lamellae of the outside sun protection system (right). Cut-off-angle depending on the projected angle of incidence on the façade (left).

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.

Fig. 5 summarizes the different parts of the daylighting concept, Table 1 shows the thermal and optical properties of the glazing and the translucent parts of the façade. As the roof acts as an climate interlayer the solar and visual optical properties of the materials are important. The translucent part of the roof consists of a PTFE-glass-membrane Type Sheerfill II with Everclean-Coating [Saint-Gobain, 2014]. 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%. Fig. 6 shows transmittance and reflectance of both materials in the solar spectral range. The visual transmittance of the ETFE film and glass-PTFE membrane are 57% and 11%, respectively.

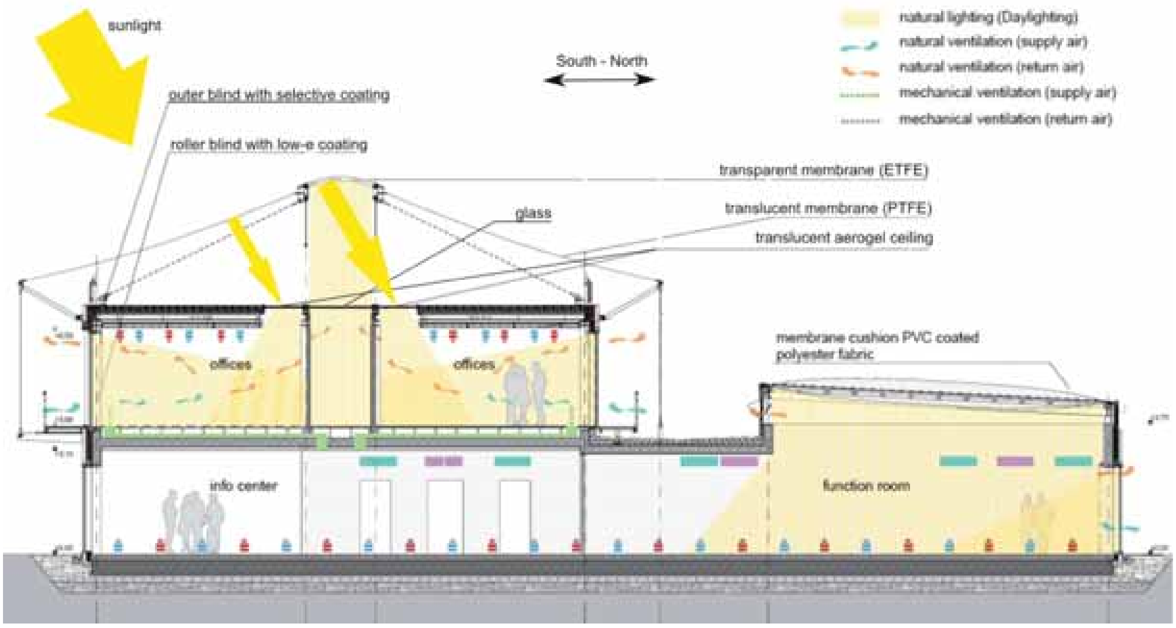

Fig. 5: Daylighting concept of the Energy Efficiency Center (EEC).

Table 1: U-value (center of glass U_g and window U_w), total solar energy transmittance (g-value) and visual transmittance of glazing and transparent roof and ceiling elements.

description	U_g [W/(m²K)]	U_w [W/(m²K)]	g	τ_v
glazing (south façade)	0.6	0.9	0.47	0.72
glazing (east and west façade)	0.7	0.9	0.35	0.55
glazing (north façade)	0.7	0.9	0.27	0.55
aerogel double skin sheets(office ceiling)	0.7	0.8	0.39	0.20
aerogel glazing (corridor ceiling)	0.6	0.9	0.25	0.25
glazing (corridor ceiling)	0.6	0.9	0.27	0.55
PVC-membrane cushion (function room)	0.9	1.0	0.05	0.03

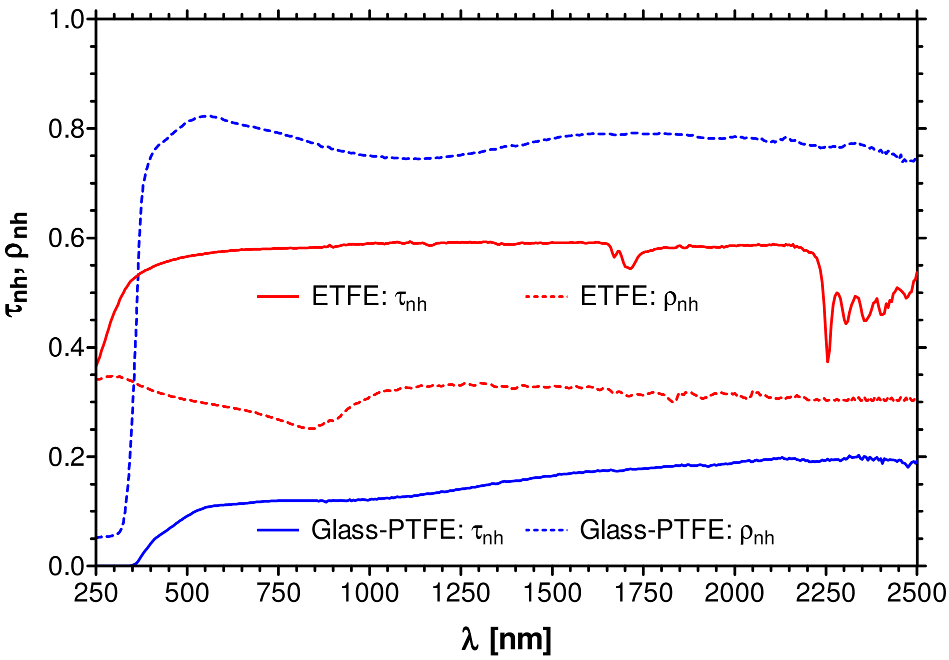

Fig. 6: Spectral normal-hemispherical transmittance and reflectance of both parts of the roof: Printed ETFE film and glass-PTFE membrane.

3. 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 opening or closing the external sun protection system depending on whether there is heating or cooling demand for the room. The sun protection system is opened when heating is necessary and nearly fully closed when cooling is necessary.

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

- It is closed when an outside illuminance higher than 45 klx is reached for more than 30 seconds. 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 to about 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 more than 20 minutes.
- When the outside illuminance is higher than 30 klx for more than 5 minutes 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 for more than 5 minutes.

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 in the room. The roller blinds used as inside glare protection are controlled manually.

4. Monitoring

Two office rooms at the south and north façade were equipped with some additional illuminance sensors at the working surfaces and below the translucent part of the ceiling.

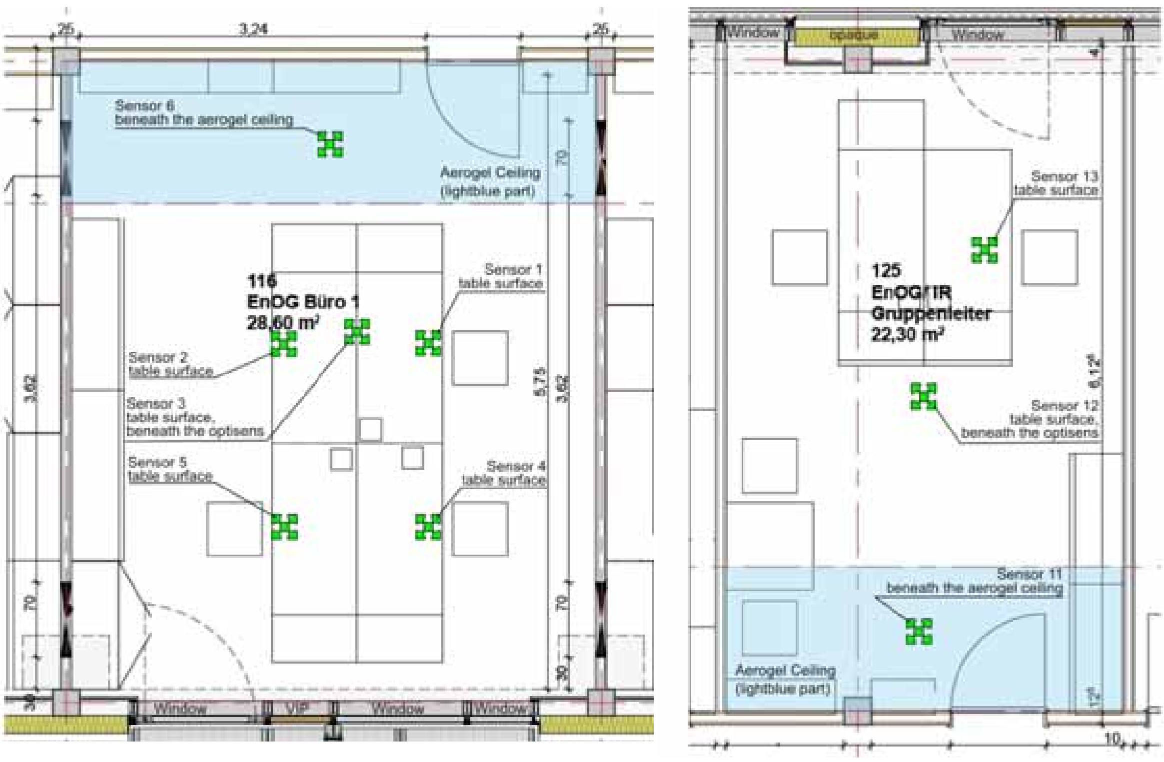

Fig. 7: Layout of a south-facing room (room 116, left) and north-facing room (room 125, right) equipped with additional illuminance sensors at the table surfaces and below the translucent (aerogel) part of the ceiling.

Fig. 7 shows the layout of the rooms as well as the position of the individual sensors.

The south-facing room has four work places. The illuminance is measured at each work place on top of the table as well as directly below the down-looking illuminance sensor used to control the luminaries in the room. Additionally the horizontal illuminance directly below the translucent part of the ceiling was measured (Sensors 6 and 11 in Fig. 7). At the chosen positions for these sensors – directly below the aerogel-filled double skin sheet – the effect of the luminaries on the sensor signal is negligible. The north-facing room with two work places was equipped with a similar setup.

Additionally the signal from the illuminance and occupancy-sensor, the control signal of the luminaries and the height and angle of the outside sun protection system were measured. The inside glare protection system was unused for all measurements shown, the artificial lighting and the sun protection systems were controlled by the building automation system. The control signal of the luminaries is the percentage of full output.

5. Results

5.1. Translucent ceiling panels

Fig. 8 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. For the south room this illuminance is approximately proportional to the global irradiance and peaks at about 2000 lx. 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 E_v 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.

The translucent ceiling panels cause no glare problems because they are outside of the field of view of people at the work places.

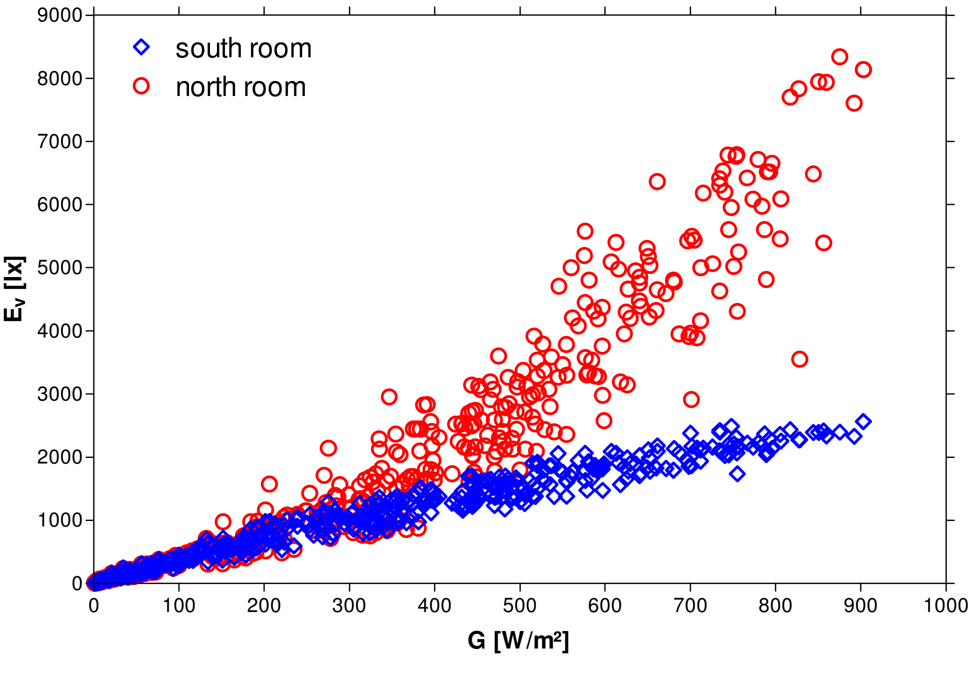

Fig. 8: Illuminance E_v below the translucent part of the ceiling depending on the global irradiance G for a period in summer 2014 (july 18th to august 18th), one-hour averages.

5.2. Control of external shading and artificial lighting

Fig. 9 shows the illuminance inside the monitoring rooms measured by the combined occupancy and illuminance-sensors, the control signal of the luminaries (in percent of the maximal light output) and the global solar irradiance. Additionally the slat angle of the outside sun protection system in the south room is shown at the times it is closed. The measurement was performed on a day with intermittent sunny and cloudy periods, the rooms were occupied in the time period shown (8:00 to 18:00) and there was cooling demand in both rooms.

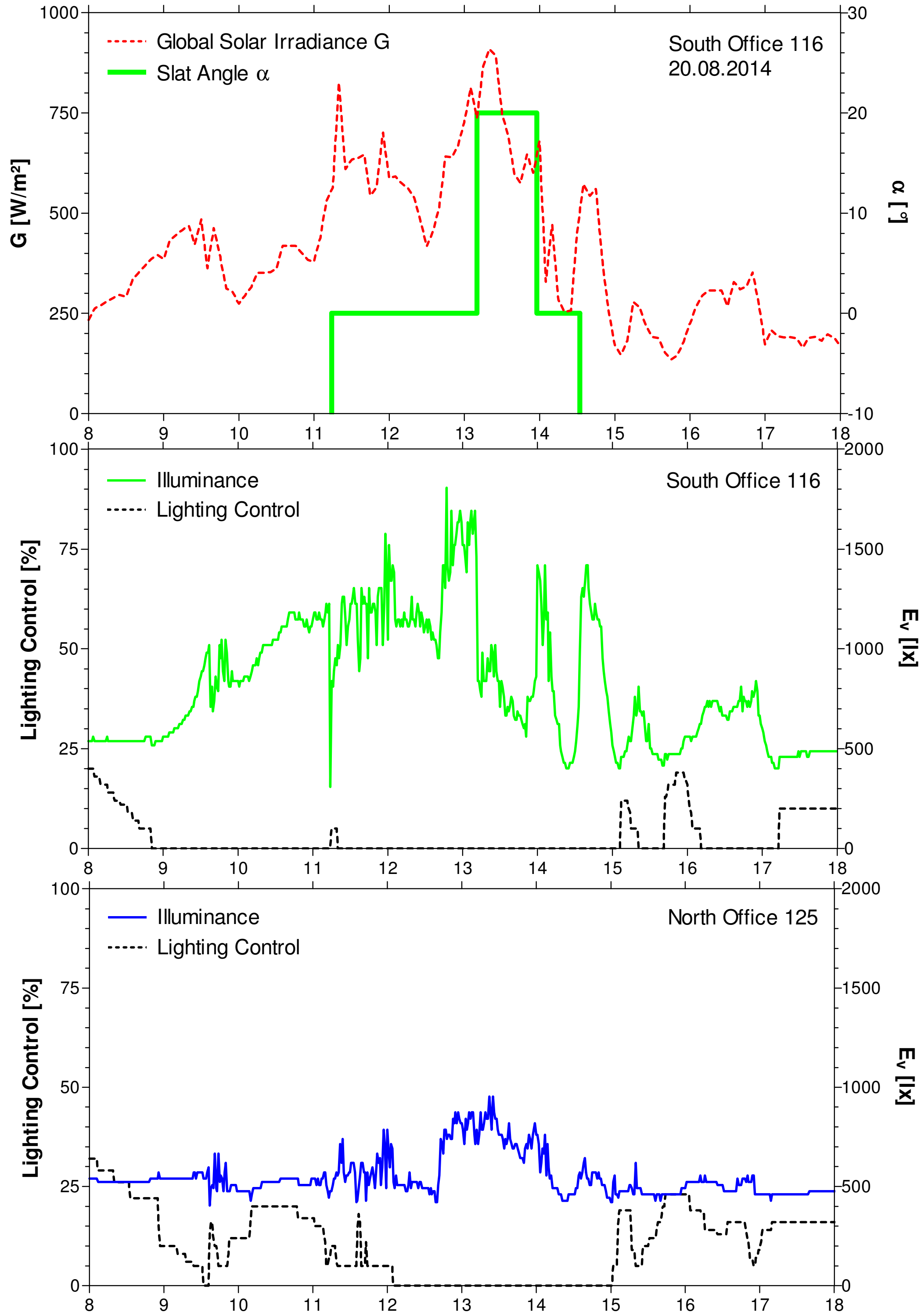

Fig. 9: Iluminance E_v and lighting control signal for the south and north office rooms at a summer day with intermittent sunny and cloudy periods. The top plot shows the global solar irradiance and the slat angle of the sun protection system of the south office. At periods where no slat angle is shown the sun protection system is open. The other two plots show illuminance and the control signal for the artificial lighting in the south and north room.

The sun protection system in the south office room 116 closes depending on the outside illuminance at the south façade, the slat angle is nearly zero at intermediate illuminance levels and is increased to 20° at high illuminance levels in order to limit the solar energy input to the room. In this room the automatic control of the sun protection system usually does not lead to situations where the sun protection system is closed and the artificial lighting is switched on. An exception are periods with fast decreasing outside illuminance, when the sun protection system is still closed due to the delay settings – the sun protection system remains closed for 20 minutes when the outside illuminance falls below 20 klx.

In the south office the artificial lighting is active in the morning and evening when there is no insolation on the south façade and for short periods of low solar irradiation.

Fig. 10 shows the illuminance levels at the work places in the south office for the same day. A illuminance level of about 500 lx is reached for both work places throughout the day. The change of the slat angle from 0° to 20° for the "low solar energy input"-mode results in a significant decrease of the illuminance in the room. At the day shown here the illuminance level is adequate without artificial lighting.

The illuminance level is lower than 500 lx for short periods of time when the room is mainly illuminated by daylight. This is allowed as an illuminance level of 60% of the value specified in [EN 12464-1, 2011] is sufficient when using daylight for illumination [DIN 5034-1, 2011].

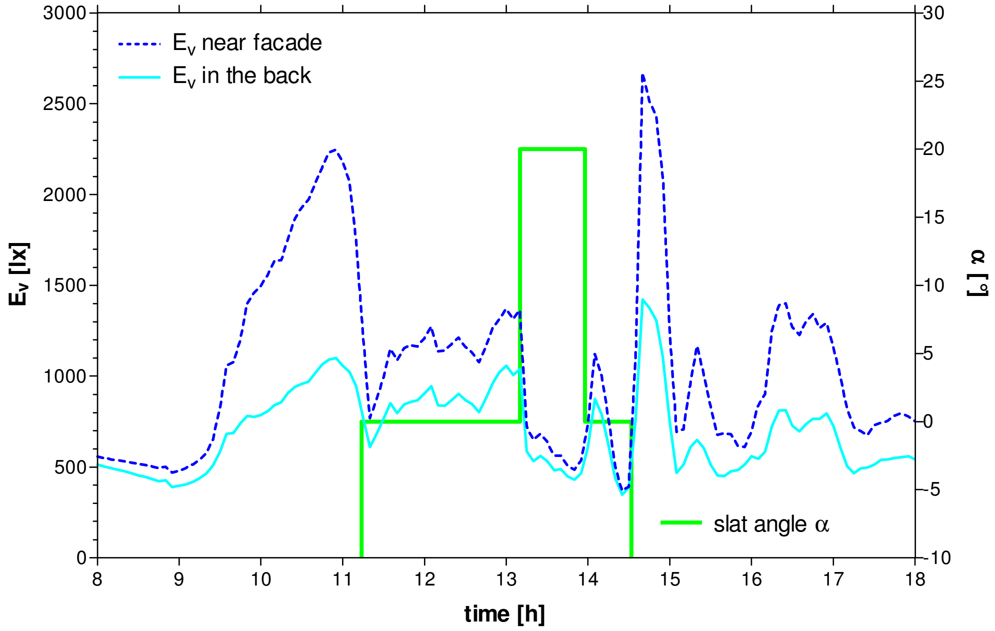

Fig. 10: Illuminance E_v at the working place near the window and in the rear of the room and the slat angle α of the sun protection system of the south office.

Fig. 11 shows the illuminance level measured at the work place in the north-oriented room 125 compared to the signal of the ceiling-mounted sensor used for the lighting control. Additionally the lighting control signal is shown. The illuminance at the work place meets the specified values when the artificial lighting is used. The illuminance values measured by the ceiling-mounted sensor are higher than the values measured at the work place at periods with high daylight input through the translucent ceiling panels, but the necessary illuminance levels at the work place were reached nevertheless.

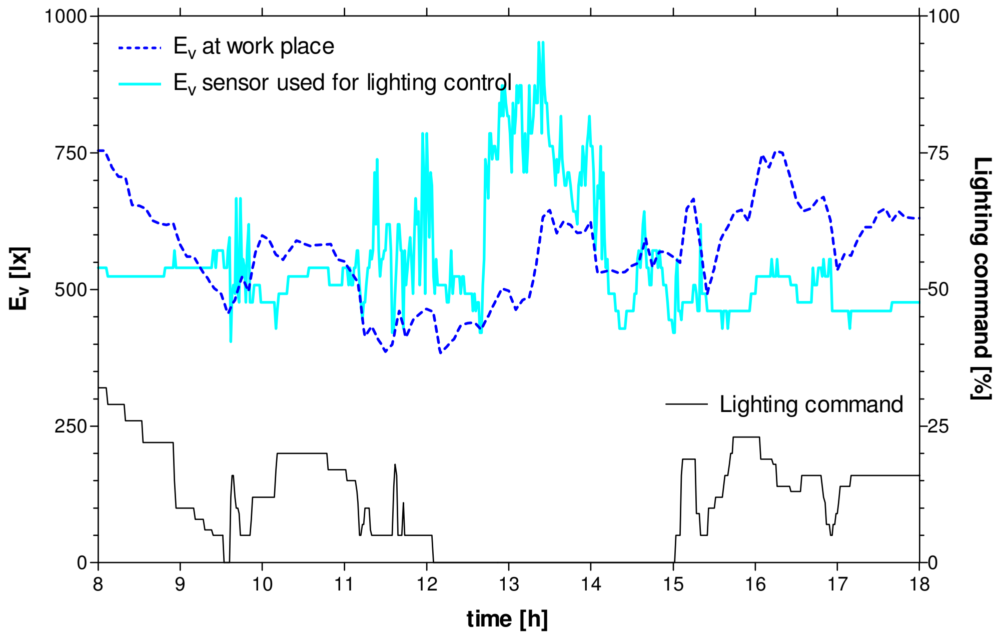

Fig. 11: Illuminance E_v at the working place near the window, illuminance signal from the sensor used for lighting control and lighting control signal of the north office.

6. Outlook

The operation of the lighting and sun protection systems were tested for summer conditions, i.e 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. Similar tests are needed for intermediate and winter conditions. When the correct operation of the control systems is verified the interaction of the users with the control system will be investigated by monitoring the user interventions with the building control system.

7. Acknowledgement

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