Lighting at the heart of an integrated building control system

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

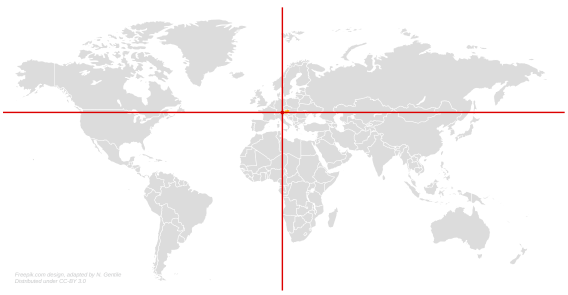
Integrated lighting solutions enable biologically active lighting in the glare-free Living Lab in the Bartenbach R&D building

In the Bartenbach R&D building a high level of daylight integration is realized while maintaining glare and heat protection. In combination with workstation-zoned LED lighting with color temperature and intensity control adapted to the time of day, the occupants experience a lighting environment that provides both visual comfort and biologically activating effects satisfying individual preferences. To exploit the energy effects of integral concepts, the heating and ventilation trades are also controlled in addition to the daylight and artificial lighting trades.

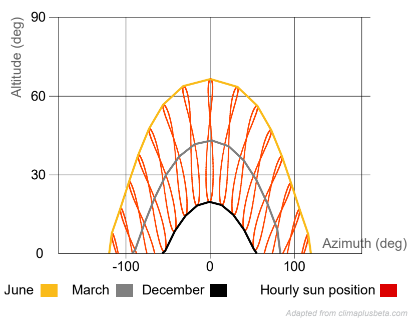
Figure 1. Careful daylighting design is integrated with CCT tuning at the Bartenbach headquarter in Aldrans, Austria.

The project

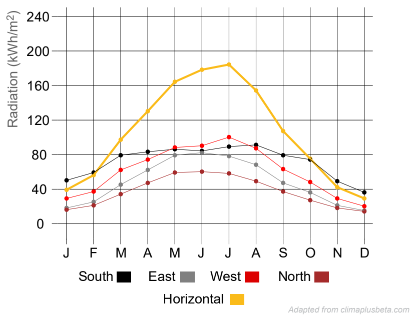
Upon entering the R&D office building of Bartenbach, the large, south facing windows together with north-oriented skylights are identified as prominent feature, ensuring a high daylight level in the office. 200 m² of office space are divided into an open-plan office, two individual offices and a meeting room (Fig. 2). To avoid disruptive effects of direct sunlight on the workplaces, external static daylight deflecting louvres are installed, the size and spacing of which were specially arranged and dimensioned for the geographical location of the building. The electrical lighting of the workplaces and transit zones is realized with a ceiling-integrated LED lighting system equipped with patented freeform surface reflectors developed by Bartenbach. With the artificial lighting, glare-free illumination of the workplaces is ensured by means of longitudinal glare control and asymmetrical beam characteristics. In addition, the luminaire arrangement provides uniform illumination of the workstations and prevents the user from shading the work surface. Via illuminance sensors and passive infrared sensors, the artificial light is automatically switched or



Location: Aldrans, Austria
47.24°, 11.46°



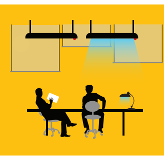
Sun path for
Aldrans, Austria



Global horizontal and vertical radiation for
Aldrans, Austria

IEA SHC Task 61 Subtask D

Monitored by **Sascha Hammes and David Geisler-Moroder**, Bartenbach
More info **David Geisler-Moroder**, Bartenbach, david.geisler-moroder@bartenbach.com



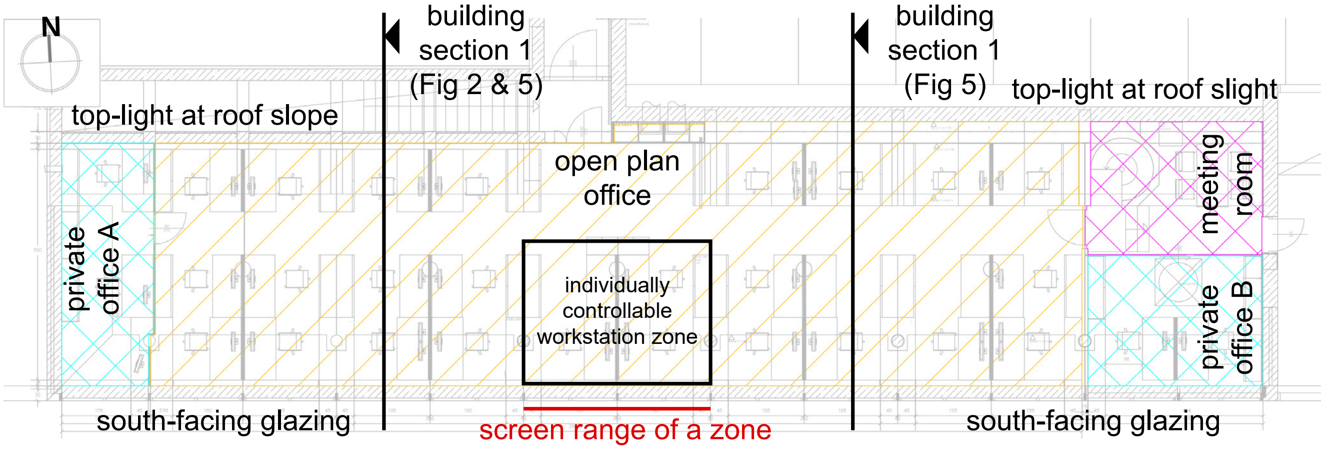


Figure 2. Floor plan of the Bartenbach R&D building.

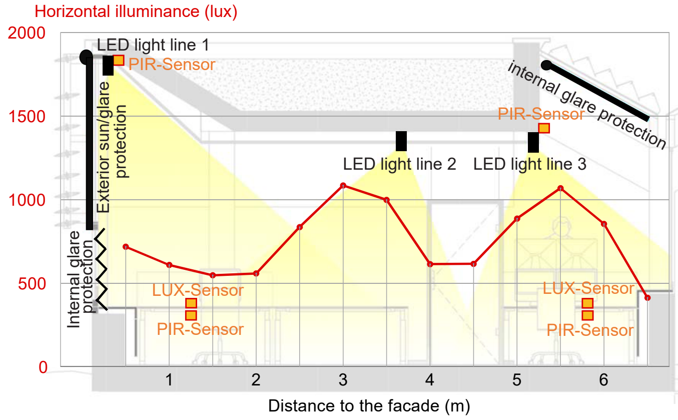


Figure 3. Position of light sensors, actuators, and maximum artificial illuminance. See Figure 2 for orientation of the office.

dimmed depending on the availability of daylight and presence. To follow individual lighting preferences, a zoning of daylight and artificial lighting systems is implemented in the open-plan office, in which the respective neighboring workplaces are interconnected to form workplace zones (Fig. 2).

To support the human circadian system, cold white light (5000 K) is used in the morning hours, which dynamically changes to warm white light (2200 K) and lower illuminance levels over the day following a predefined control curve. Figure 3 shows the maximum artificial illuminance levels depending on the room position, reachable in every color temperature between 2200 K and 5000 K. These high artificial illuminance levels allow individual preferences to be represented in the best possible way.

Monitoring

Measurement data from more than 80 sensors and the status information of the actuators are logged via the central Beckhoff building control system and converted into a data format that can be further processed. This includes, among other things, the illuminance and presence per workplace zone, information on the room climate and the dimming level of the lighting. Figure 3 shows a cross-section of the sensors and actuators relevant to lighting technology (viewing direction marked in Fig. 2). Depending on the measured variable, data acquisition is either based on a change of state or cyclically per minute. Long-term monitoring was started in March 2019. Due to the COVID-19, phases with reduced occupancy resulted. The field monitoring provides valuable insights, for additional evaluations computer simulations were performed. The building was first remodeled in Rhinoceros 3D and daylight simulations were made with Radiance through the Honeybee plugin. Among other things, daylight indicators such as daylight autonomy (DA) were evaluated. Here, an average daylight autonomy DA500 of 82 % resulted in relation to the normative minimum illuminance of 500 lx (reference time: 08:00-18:00, summertime not considered). Furthermore, potentials for increasing energy efficiency could be derived based on the collected data during post-occupancy evaluations. These findings on user-centered lighting and reduction of electric lighting demands have been published by Hammes et al. (2021a, 2021b).

Energy

The LED luminaires in the R&D office building have a connected power of 42.5 W each. Based on the logged status information for the artificial lighting system, the LENI was determined (Table 1). In relation to the normative minimum illuminance for office activities of 500 lx (EN12464-1), the office area of about 200 m² results in an energy demand per area of about 3.65 kWh/m²y. The low energy demand results from the high daylight autonomy. For the extensive sensor technology in the R&D building, including an Embedded PC as hardware for the integral building control, an energy demand of 1.09 kWh/m²y results. Without the

Table 1. LENI values: monitored and calculated benchmark.

	Monitored	Benchmark
LENI [kWh/m²y]	3.65	16.5

Table 2. Logged cumulative system interventions from Mar-Nov 2019, from 06:00-20:00.

Cumulative system interventions per year	South façade	North side
Daylight system	638	241
Artificial lighting system	315	676

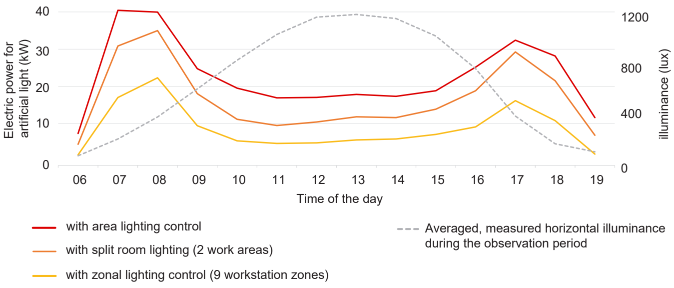


Figure 4. Comparison of the electric power for artificial light for different lighting zonings, supplemented by the averaged measured daylight-based illuminance values (data set from: 02.09. - 03.11.2020).

benefits of illuminance sensors, the benchmark energy demand per area would be about 16.5 kWh/m²y (calculated for electric light providing 500 lx when presence was detected). The influence of the daylight responsive control is therefore very important. Similar considerations apply to the influence of occupancy sensors on the energy demand of artificial lighting. The positive effects of the sensors on the energy demand therefore clearly outweigh the monitoring units' own energy demand. The users act rarely on the daylight and artificial lighting system, showing a high level of user satisfaction; however, number of interventions differs noticeably depending on the room zone (Table 2).

To test and evaluate different concepts, the effects of different room zoning were considered (control of the open-plan office as a whole; divided into 4 west-facing workstation zones and 5 east-facing workstation zones; 9 workstation zones; see Fig. 2). The results show that with greater user-centeredness, there is not only greater system acceptance, since it is possible to follow individual lighting preferences more closely, but also significant reduction of the energy demand (reduction by a factor of 2.6 from area lighting to control at the level of the workstation zones, cf. Fig. 4). In addition, data logging shows that little or no artificial lighting is required during daylight hours. The need for artificial light in the office therefore mainly occurs in the daytime marginal areas. As these times also show high user dynamics, the use of occupancy detection is of high importance in the Bartenbach R&D building to ensure energy-efficient operation.

Photometry

The office building is designed in such a way that daylight

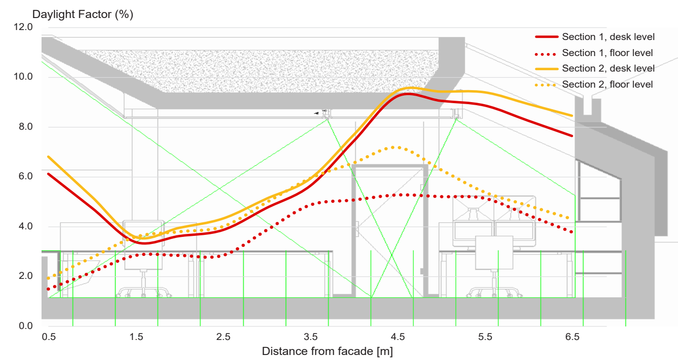


Figure 5. Distribution of Daylight Factor in the building section. Location of Section 1 and 2 is provided in Figure 2.

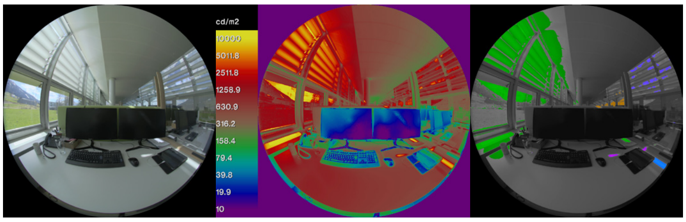


Figure 6. Representative workplace on April 8, 14:00 CEST, additional glare protection screens not activated: E_v = 2576lx, DGP = 0.316 („imperceptible glare"), maximum luminance: ca. 25.000 cd/m² in reflection at windowsill.

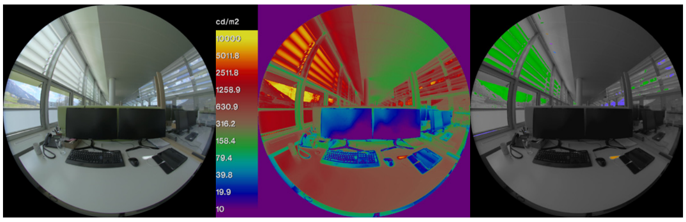


Figure 7. Representative workplace on April 8, 14:00 CEST, additional glare protection screens activated to block direct sunlight: E_v = 1898lx, DGP = 0.274 („imperceptible glare"), maximum luminance: ca. 15.000 cd/m² in bright cloud above mountain.

can be used with high efficiency, resulting in an average horizontal daylight illuminance at the workplace of over 1000 lx at lunchtime, averaged over the measurement period and across all workplaces. At the south-facing window workplaces, temporary daylight-based illuminance levels of more than 2000 lx result. To avoid disturbing effects such as glare, in addition to the external static lights, there are also external screens (south side) and internal screens (north side), which are controlled automatically with the option for manual override. The external screen on the south side is supplemented by an internal screen for the lower window area at table height that is controlled manually. Due to the high proportion of glazing in the office building, the transit zones are sufficiently illuminated with daylight between the morning and evening hours. The well daylit design results in an average daylight factor (DF) of 6 % at workstation level and of 4 % at floor level, providing sufficient illumination even under overcast skies (Fig. 5).

An evaluation of the luminance distribution at a representative workplace demonstrates the effectiveness of the installed shading systems. Even without activating the additional glare protection screens, the DGP of 0.316 predicts "imperceptible glare" (Fig.6). However, the high luminances in the reflection at the windowsill and from the uppermost part of the exterior louvers with the largest distance still can lead to visual discomfort and problems in the stable perception. In such situations the automatic control closes the exterior screen in the upper part just enough to block direct sunlight, the user can manually close the interior screens in the lower part to block out the reflections.

Fig.7 shows the resulting situation that provides a real human centered lighting situation: glare free (DGP = 0.274) and at the same time biologically active with a vertical illuminance at the eye of 1898 lx. This is confirmed by the high system acceptance and the low number of user interventions in the daylight shading system (cf. Tab. 2).

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Table 3. Measured Melanopic Lux (benchmark WELL v2: 180 EML for daylight and electric lighting).

	Daylight, sunny sky, April 16, 11:50 CEST	Daylight, overcast, April 19, 12:25 CEST	Electric light, 5000K @ 500 lx Eh	Electric light, 2200K @ 500 lx Eh
CCT	5451 K	5317 K	4095 K	2174 K
Ev	1647 lx	901 lx	190 lx	190 lx
EML	1558	842	138	66
M/P	0.946	0.935	0.726	0.347

Circadian potential

Due to the industry-specific dynamics regarding working hours, both longer working phases and working hours that lie before and after typical business hours can result. As a result, the standard use of space is from 06:00 to 20:00. This has a great influence on the well-being and productivity of building users, so daylight is also important as a regulator of circadian rhythms. Despite a high level of daylight integration, care was also taken to support the circadian rhythm of the employees through the dynamic intensity and color temperature control of the artificial light (5000 K to 2000 K), which is adapted to the time of day. The individual circadian phase was not considered for the color temperature control since zonal differences in color temperature in the open-plan architecture have a detrimental effect on visual comfort. To ensure a homogeneous appearance in the room, adjustment of the color temperature is only possible at room level. The spectral distribution was measured at the user viewpoint as shown in Fig. 6 and 7 for the different lighting situations. Table 3 shows the resulting photometric and melanopic illuminance and the derived M/P ratio. The broad range confirms the effectiveness of the human centered approach and its biological effectiveness.

"An office space that really implements Human Centric Lighting: high daylight doses in a glare-free environment"

User perspective

The high proportion of daylight combined with the user-centered design is also reflected in the perception of the lighting atmosphere. A voluntary user survey conducted in February 2016, in which 19 building users (17 male, 2 female, age: 20-60 years) participated, revealed a high level of satisfaction (Fig. 8). The uniform room illumination and high illuminance levels were recognized as such by the user respondents (bright = 95 %, uniform = 100 %). All respondents rated the lighting situation in the R&D building as very pleasant, orderly, calming, appropriate, and modern. In addition to the high proportion of daylight, the visual reference to the outside has a high relevance to

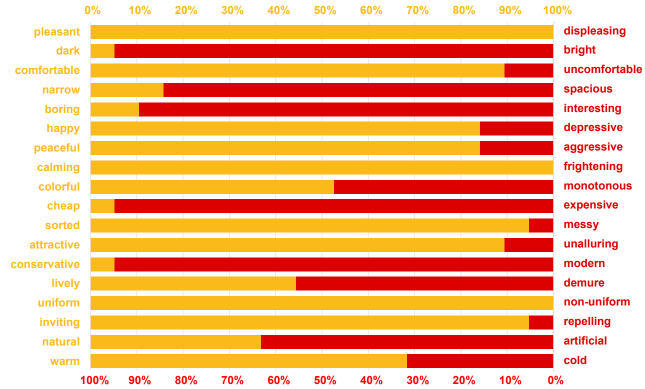

Figure 8. User survey on the lighting atmosphere in the R&D building.

user satisfaction. Another recent user survey on the R&D building and the building control system from November 2020, in which 16 building users participated, revealed that despite the high proportion of glazing, no glare occurs for the majority (approx. 80 %). This confirms the effectiveness of the glare protection concepts used. Furthermore, the control curve underlying the building control system proves to be very accurate, as the majority is satisfied with the illuminance on the work surface (approx. 80 %) and there is hardly any intervention in the automatic mode (approx. 90 %).

"In the integrated control heating and ventilation dance to the lighting's tune"

Lessons learned

By fulfilling individual lighting preferences with high illuminance levels and varying color temperatures, a positive impact on work performance and wellbeing is reached. The integrated Human-Centric-Lighting concept supports the circadian rhythms of the building occupants. The high daylight input and the use of lighting sensors for daylight-dependent artificial lighting adjustment allow to significantly reduce artificial lighting energy demands. With the ability to log and monitor a wide range of condition information in the building, post-occupancy evaluations can be used to account for user effects in the control logic that only occur after commissioning. This can reveal potential for reducing energy demand.

Further information

Geisler-Moroder, D. (Editor) (2019). *Workflows and software for the design of integrated lighting solutions. A Technical Report of Subtask C*. IEA SHC Task 61 / EBC Annex 77.

Hammes, S., et al. (2021a). *Reduzierung des Kunstlichteinsatzes durch Anpassung der Nachlaufzeit an individuelle Anwesenheitsmuster. Bauphysik*, 43: 50-64.

Hammes, S., Weninger, J. (2021b). *Die Bedeutung nutzerzentrierter Beleuchtung*. LICHT2021. Online 21.-24.03.2021.

Acknowledgements

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