Office space with light-emitting structures in upper part of the façade

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Large-scale micro-optical panels were integrated into the upper part of a façade. The lower part is operated with venetian blinds for sun and glare protection.

At the Fraunhofer IBP in Stuttgart, large scale light-emitting panels were integrated into glazing units and integrated into the upper part of the façade of a lab room. The evaluation of the performance of the lighting conditions and the energy related parameters were compared to a second identical room, with conventional lighting.

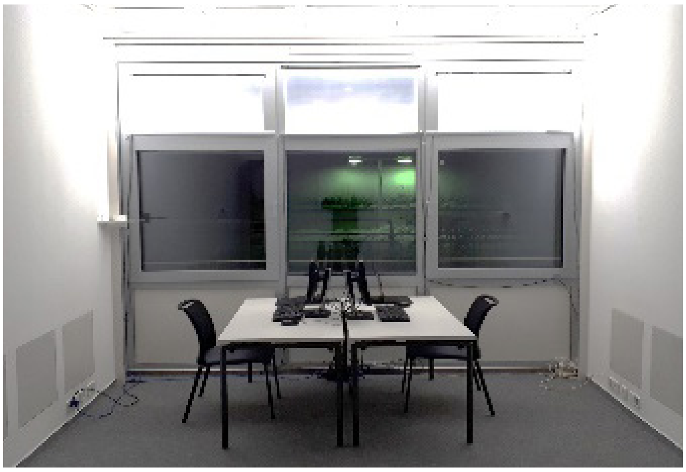
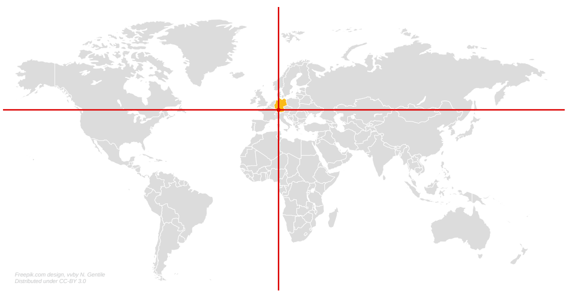


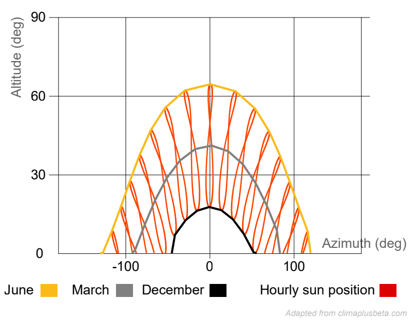
Figure 1. The lab room seen from the inside. The light-emitting structures are placed on the top part of the windows and provide illumination to the room interior.

The project

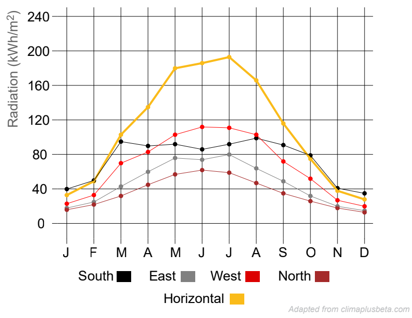
This case study is part of a bigger project project called TaLed, which was funded by the Federal Ministry for Economic Affairs and Energy (BMWI) (Project Management Jülich). The main purpose of TaLed was to improve the energy efficiency, life cycle balances and indoor comfort by employing micro-structured optical components for daylighting and electrical lighting. For this case study, a micro-optical structure, namely - Light-emitting structures, have been optimized for redirecting glare-free artificial light deeply into the building interior. The structure is placed on the surface of transparent substrates, which emit laterally injected LED light on one side only,. In this use case, large scale micro-optical panels were integrated into glazing units and placed into the upper part of the façade of a lab room at FHG-IBP (Figure 1). On the lower part of the window a standard venetian blind is being operated for sun and glare protection. To evaluate system performance the lighting conditions and the energy related parameters are compared to a second identical room, which has



Location: Stuttgart, Germany
48.74° N, 9.10° E



Sun path for
Stuttgart, Germany



Global horizontal and vertical radiation for
Stuttgart, Germany

IEA SHC Task 61 Subtask D
Monitored by **Carolin Hubschneider, Yuen Fang and Daniel Neves Pimenta**
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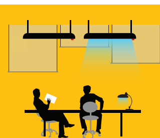

Figure 2. The facade seen from the inside, with the light-emitting structure on the upper part of the window.

Figure 4. An exterior view of the lab. The facades of both the reference and test room can be seen in the picture.

also blinds in the upper part of the façade. All blinds are automatically closed when direct sunlight reaches the façade.

Extensive documentation on the project and the monitoring is provided in the references at the end of this factsheet.

Monitoring

In order to test the developed light-redirecting in practical application, the Fraunhofer IBP installed the new systems in two test rooms with identical construction. The two test rooms resemble an ordinary two-occupants office room, they are south-facing and have dimensions of 6.0 mx 3.5 mx 3.0 m (Figures 1, 2, and 4). In each case three window elements are separated by a bolt into an upper and a lower window element. In each case the test panels were installed into the upper part of the facade. The installation of two separate blind boxes per room allows a separate shading of the two window elements.

The reference room was equipped with six direct-indirect pendant luminaires for general lighting (Figure 3), the test room was equipped with the light emitting structures only, which were built into the façade system (Figure 1, 2).

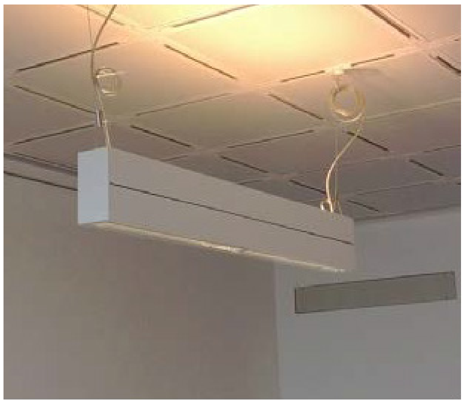

Figure 3. Luminaire with direct and indirect light output.

The lab room was equipped with sensors and actuators. As actuators, the luminaires and two separate blinds determine the lighting situation in the room. Five illuminance sensors were installed as sensors in a line in the middle of the room at the working level (distance between façade and sensors 1.0 m). Energy use is recorded separately for the luminaires with electricity meters. In total, the following data was recorded in both spaces:

- illuminance levels of the illuminance sensors positioned on the working plane,
- power and energy for the luminaires and light-emitting panels,
- temperature in the room,
- dimming levels of the luminaire group.

Energy

The energy use is proportional to the installed power of the lighting system. In relation to the entire room, the installed power (normalised to 100 lx) was 3.92 W/m²100lx for the light-emitting system and 1.83 W/m²100lx for the reference lighting system. As already shown in the calculated potential assessment, the installed power and thus the energy use of the façade-integrated light-emitting system in the test rooms is also significantly higher than the reference lighting system.

Photometry

To validate the light-emitting system, triple-pane laminated glass with light-emitting PMMA elements was installed in the upper window elements of the test room. The lower window elements and the window elements in the reference room were fitted with conventional triple-pane glazing. LED boards were installed on the lower edges of the PMMA panes, which are thermally connected to the frame by means of a copper braid. The two test rooms were each equipped with two computer workstations.

Figure 5 shows the course of illuminance measured over the depth of the room. Up to a depth of about 1 m, the lighting levels required for office workplaces are measured.

The required 500 lx is achieved at a depth of 1 m, and

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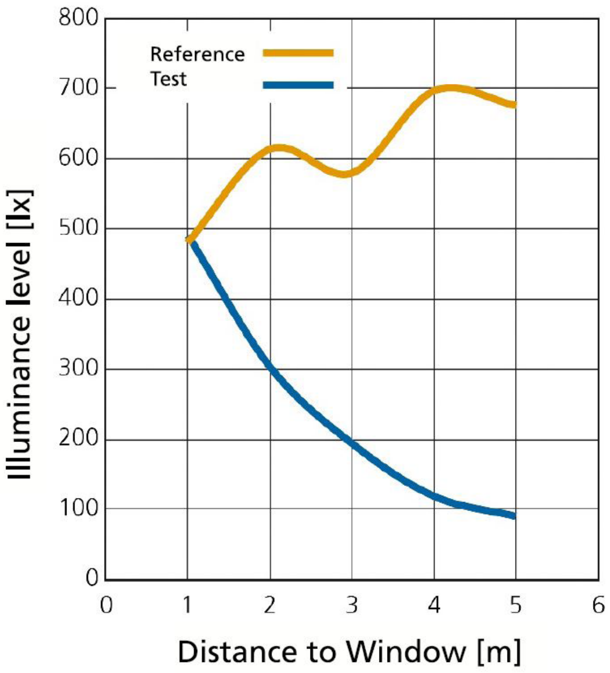

Figure 5. Horizontal illuminance on the working plane provided by electric lighting only. The illumination of the test room with light-emitting structures is provided by the structure only, which is located on the upper part of the window.

300 lx at a depth of 3 m. In areas far from the façade, the illuminance then drops to about 100 lx, which could be simulated via Dialux (Figure 6) in advance.

Circadian potential

The Circadian potential was not evaluated, but due to the lower lux levels (Figure 5) and the perceived lower light levels in it can be assumed that it was low.

User perspective

The studies for the user acceptance were conducted as a within-design, so the test persons experienced both rooms (reference room and test room). They completed various performance tests and questionnaires. The performance tests were not evaluated, but only served to simulate a working atmosphere. The questionnaires examined the following topics:

- task completion (perceived performance in completing the tasks),
- fatigue and visual stress,
- Perception,
- room atmosphere,
- subjective management atmosphere,
- light distribution,
- artificial lighting for the light-directing system.

The data collected was analysed using the SPSS statistical software. For the individual questions of the questionnaires, a t-test was carried out in each case to compare the test room and the reference room.

In the user study the acceptance of the light-emitting element was tested on six days from 11th December 2018 to 19th December 2018. Twenty test persons with a student background (7 female, 13 male) aged between 23 and 29 were invited.

The results show, that 2 out of a total of 52 measures show a statistically detectable difference between the two rooms ($p \leq 0.05$). Compared to the reference room, the light-emitting elements in the test room were rated with a slightly higher glare of the façade and at the same time with a lower brightness inside the room. Other glare phenomena on the table, wall and screen did not show any significant result. The perceived difference in brightness inside the room is reflected in the lower illuminance levels measured inside the room.

"What if we could have light, instead of luminaires?"

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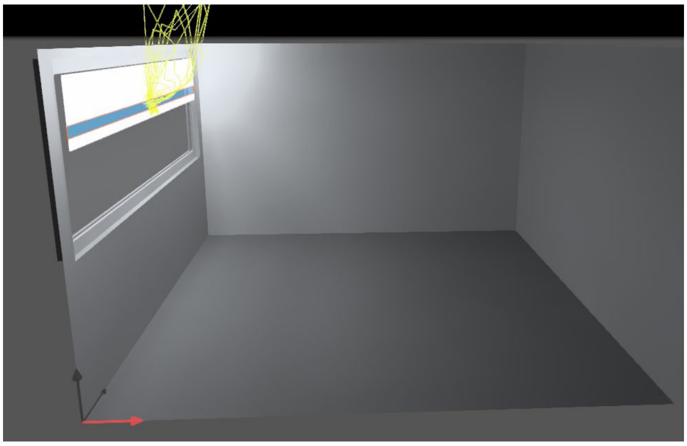

Figure 6. DiaLux rendering of the light-emitting structure used in this case study.

Lessons learned

The development and future use of micro structured optical components for artificial light utilisation is intended to improve energy efficiency, life cycle balance and the quality of interior usage in buildings. The starting point for the work of this joint research project was formed by new types of optical structures that are applied to transparent carrier layers. One was a structure that emits light. This emits LED light (brought in via the edges of the pane) in a targeted manner from the substrate surface. The elements remain transparent. The structure is to be used directly in façade glazing and in new types of luminaires. The basic structure was available as laboratory sample at the beginning of the project.

In the project, the structure was optimised, scaled to practical building sizes with newly developed manufacturing processes and the system integration was implemented in glazing units. Lighting and energy parameters were determined and prepared for use in planning tools. Life cycle balance and influence on the energetic building behaviour were estimated. Furthermore, the structures were tested in real installation situations in test rooms in terms of energy and user acceptance. Future architectural application concepts were developed. The main project results are summarised below.

Manufacturing processes for scaling for construction applications

The production process used, “UV nanoimprints” with structures of less than 100 µm has been further developed, that components can be produced in sizes for building applications (windows) on the one hand and in high quality at low cost on the other. The processes allow the structuring of rigid PMMA sheets. In the project, dimensions of 1,200 mm x 600 mm were realised for testing in the test rooms. Larger dimensions can be produced. The costs for the light-coupling structure are around 30 - 35 €/m².

Subsequently, a modular system was developed for integrating the elements into different façade and luminaire solutions. Based on this, the structural integration into a façade system consisting of glass composite, frame constructions took place.

The light-emitting structure was implemented as a transparent, luminous window, with thermal management of the LEDs via the frame construction. The LED light guides with coupling construction were designed to meet the special requirements such as the provision of high luminous flux, high positioning accuracy to the edge of the substrate, reversibility and heat dissipation.

The light-coupling structure itself showed a light-coupling efficiency like comparable LED systems today, with a luminaire operating efficiency of 64 %. However, the actual installation situation in the façade composite had an efficiency-reducing effect.

Recycling possibilities of the glass laminates were evaluated as uncritical. The measurement data was processed for use in planning and evaluation tools such as DIALux Evo, IEA SHC Task 50, CFS Express and Trnsys.

Validation in pilot projects

In areas close to the façade, sufficient lighting could be provided by the light-emitting elements integrated into the façade. The previously calculated energetically less favourable behaviour was confirmed. In contrast, the design advantages of the solution (free ceiling, transparent light sources) and roughly comparable as user acceptance compared to conventional lighting could be demonstrated.

Further information

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