Horizontal light pipe brings natural light into office at high latitudes area

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Horizontal light pipe brings distinctive features of daylight to the back part of the office, increases light level, and saves energy

In this long-term pilot study at Norconsult AS, a horizontal light pipe (HLP) was used to bring daylight to the back part of the office. HLP brought up to 400 lux of natural light to the desk closest to the back part of the office, increased user appreciation of the space, and saved energy.

The project

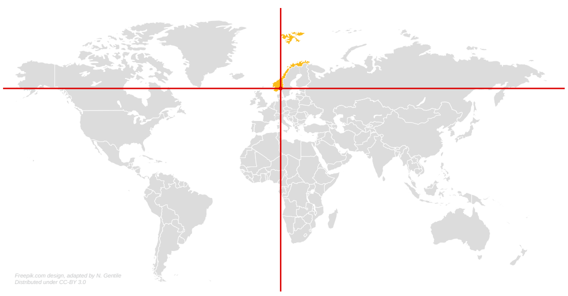
Clear skies and sunlight are appreciated in Scandinavian countries, but relatively simple solar protections are incapable of redirecting effectively sunlight and transforming it into functional daylight. People react instantly and close sun shadings when they experience excessive light, and do not open them until long after such conditions disappear. This study with horizontal light pipe (HLP) was mainly inspired by this issue. Norconsult AS dedicated an entire office of its headquarter near Oslo for this study (Fig. 1).

The test-office had standard finishes and colours and an area of 13 m². Windows are oriented southwest, and the HLP was installed at 45° from the southeast wall, Fig. 2. This design was chosen in order to place the pipe's exit above the desk closest to the door, without using any pipe-elbows (i.e., the pipe was straight), and to align the pipe inlet to the south. The installed HLP has a diameter of 22 cm, dictated by the building's constraints, and a length of 375

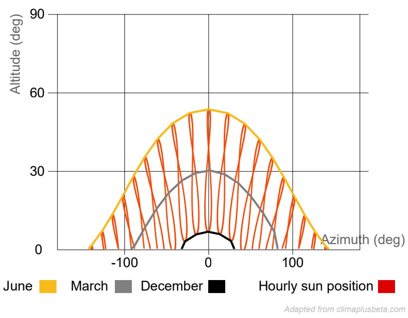
Figure 1. Norconsult AS Headquarter building.

cm (aspect ratio of 17). The light pipe has a clear diffuser and a custom-designed reflector to direct the light from the pipe down to the working area. The reflector helped to maintain the daylight's qualitative features like dynamics, variation, colour. Between 10:00 and 14:00, when the weather was sunny, the reflector provided delicate and balanced light patches, both on the desk and the wall (Fig. 3). Occupants' reaction to light patches are generally positive if the patches are of specific size and distance from the observer.

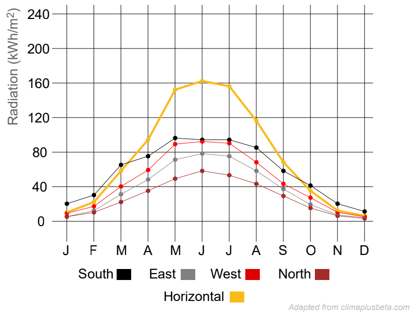
The office has also two windows oriented southwest. Man-



Location: Oslo, Norway
59.89°, 10.60°



Sun path for
Oslo, Norway



Global horizontal and vertical radiation for
Oslo, Norway

IEA SHC Task 61 Subtask D

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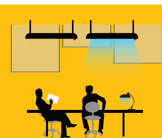

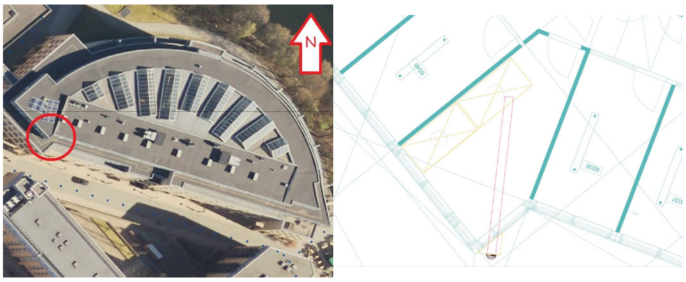

Figure 2. Building orientation (left) and office plan (right).

Figure 3. Working areas in the test office.

Figure 4. Office as seen from: the entrance to the office (left), the desk closest to door (middle), and the desk closest to the window (right).

ually operated sun shading were kept in a fixed position during the study, closed with slats angle of 40°, the latter found to be a suitable angle for this location. This shading strategy was developed to provide satisfying visual comfort at any time, a glare-free office. Fig. 4 shows the visual conditions from various view points. The hypothesis was that reducing glare occurences will reduce the occasions in which shadings are completely closed, which would in turn provide more lighting energy saving. Daylight calculations showed that the illuminance would be 120 lux and 50 lux at the desk closest to the window and door, respectively during an overcast sky (Fig. 5). During a summer clear sky day a 17:00 (sun altitude 30°), the illuminance will increase to 1000 lux and 500 lux at the desk closest to the window and door, respectively (Fig 5 right).

Two LED luminaires of 22W each were used to provide artificial lighting according to the NS-EN 12464-1: 500lux on both working desks, uniformity ≥ 0.6 and UGR < 19. The CCT was 4000 K, and the CRI was 80. Each luminaire had its own daylight-linked control system (DLCs). Luminaires should supplement additional light when daylight via the window and light pipe did not reach 500 lx (Fig. 6).

Monitoring

The pilot office was monitored continuously from March 2020 to March 2021. The monitoring was divided in two parts: a *test* period where the HLP was active and allowed daylight (21.06.2020 to 21.12.2020), and a *reference* period during which the HLP was disabled. These factsheets presents mainly results for the *test* period; preliminary results of users' perspective for both *reference* and *test* period are also presented.

Indoor illuminance values were recorded by logging values from five illuminance meters each minute: two meters were placed horizontally on the desks at 0.8 m height, two vertically illuminance on the wall at 1.2 m, while the last one was placed on a tripod to assess vertical illuminance at the eye position during the user's surveys. An outdoor illuminance meter was placed vertically, on the same vertical plane of the pipe's dome, and another one was placed horizontally at the roof level. The lighting energy use for each minute was provided by separate power meters 10-20A, one for each luminaire.

Energy

The lighting operating hours were 07:00-17:00 (10 hours) during both week days and weekends. The lighting was always on during working hours and dimmed according to the DLC, which accounts for a usage factor of 0,66%. The estimated LENI for this test office was 8,2 kWh/m^2, but the measured LENI was 6 kWh/m^2.

The energy consumption data need to be seen in parallel with the photometrical measurements. It was evident that the reflections from daylight on the sun shading slats affected the lighting sensors; the DLCs received wrong information on the level of artificial light they additionally supposed to provide. Typical sunny day showed that from 10:00 to 14:00, a high level of daylight was delivered through the pipe and enabled a luminaire to go on standby mode (Figure 8). After 14:00, the sun moved to the west and hit directly to the window/sunscreens, which affected the luminaire's sensors closest to the window more than the one closest to the door. During overcast days, there are higher daylight level closest to the window than close to the door. Energy use for artificial lighting is proportional to the daylight supplement (Figure 7).

It was expected that the energy use for the luminaire closest to the door would be higher than for the luminaire closest to the window. The first results suggest that the difference is approximately 35% for the total reference period and 29% for the entire test period. The window luminaire uses as much as two times the energy during the winter in respect to the summer. The luminaire closest to the door used 10% less power during summer than during winter in the reference period, but 20% less in the test period, indicating the beneficial effect of the HLP.

Photometry

Due to the reflected daylight/sunlight from the sun shading slats cut-off 40°, the DLC system did not perform as expected. Luminaires received incorrect information about the luminous output light they needed to provide, and the illuminance on the tables varied a lot. Following best prac-

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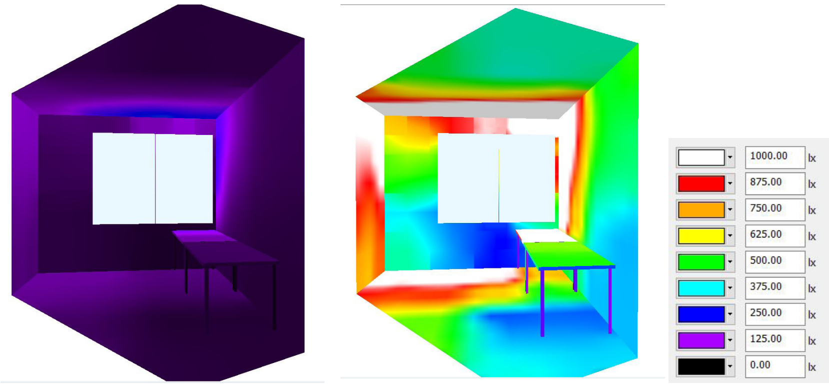

Figure 5. Calculated daylight illuminance for overcast (left) and clear sky (right).

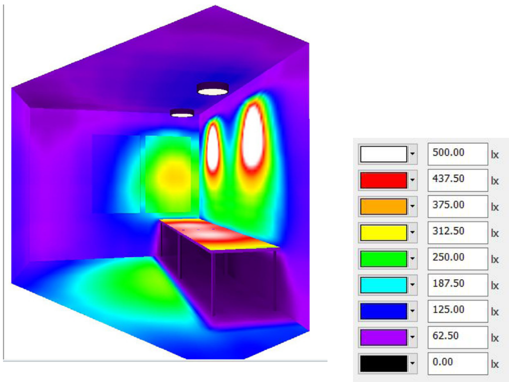

Figure 6. Calculated artificial light illuminance.

tice and considering rules-of-thumb for tolerance of light variation, a fade-out time of 10 minutes was applied to the DLCs. However, it was noticed that magnitude of changes in daylight intensity was substantial and the DLCs appeared unsuitable. The illuminance level on the desk closest to the door was as low as 230 lux in some situations, and the 500 lux could be guaranteed only with overcast sky, as the issue with reflections did not occur. When the photosensors was affected by reflections, the lighting was almost completely dimmed. In those cases, the illuminance registered on the desk (Figure 8) was given by daylight only and it did not reach the 500 lux set-point. During the overcast sky, both desks' levels are stable, starts with the 450-500 lux, and minor variations happen if the sky luminance changes (Figure 8). But, from noon, as the sun turns from south to west (windows are south-west oriented), the illuminance level on the desk closest to the window increases. The same happens with the illuminance on the desk closest to the door, but to a lower extent. For clear sky, the variation of illuminance values' starts already at 09:00M, as the sun approaches the south alignment. Both horizontal and vertical illuminance on the desk closest to the door follow the daylight supplemented via HLP, especially between 10:00 and 14:00.

Circadian potential

The melanopic lux level in the test office has not been measured. However, the adopted daylighting strategy guarantees permanent all-day and year-long presence of the natural light in the entire room, with clear impact on the circadian potential of the space.

User perspective

The user surveys were performed during September 2020 (equinox) to cover a yearly average daylighting condition. Fifty employees from Norconsult participated in the study, 26 male and 24 females, from 23 to 65 years old. Participants were without an architectural or lighting engi-

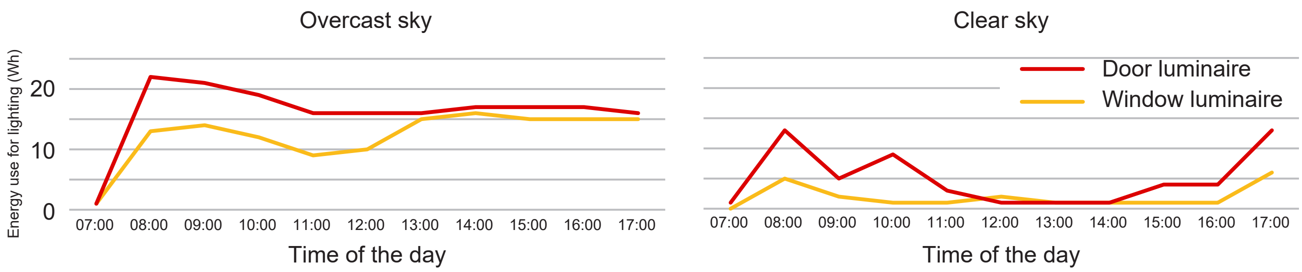

Figure 7. Energy use for lighting for the window and door luminaire during the test (HLP active), overcast and clear sky conditions.

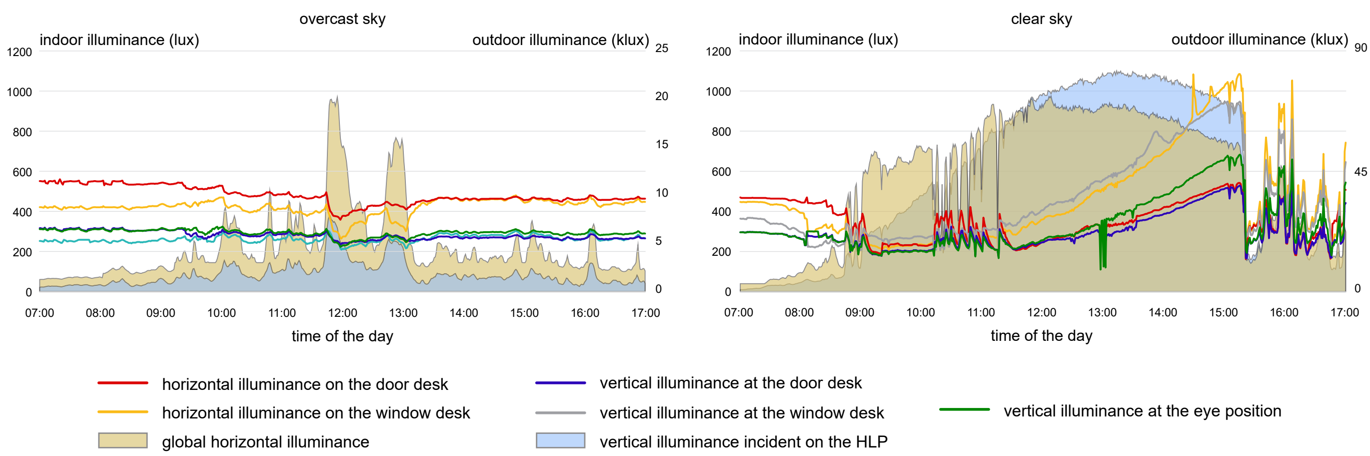

Figure 8. Indoor and outdoor illuminance values for occupancy hours during the test (HLP active), overcast and clear sky conditions.

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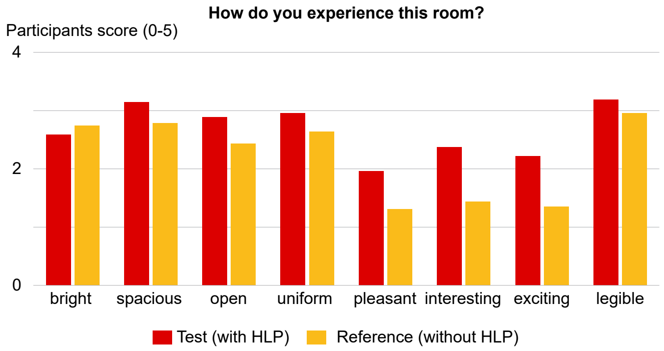

Figure 9. Visual experience and perceptual impression of the room.

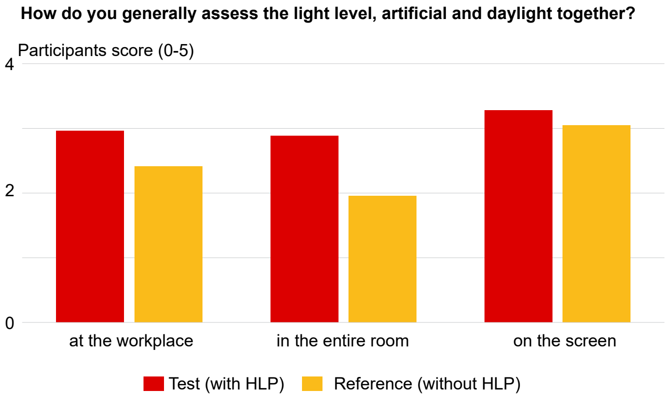

Figure 10. Evaluation of the level of light, artificial and daylight together.

neering background to avoid bias. The participants were only visiting the space and they did not use the office permanently. The weather conditions variated during the surveys, spacing from clear sky to completely overcast sky days. Consequently, the daylight provided through the HLP was different for the different participants. In order to test the hypothesis on occupant impression of the room the participants were divided into two groups, one with noticeably higher daylight and the other without noticeably higher daylighting provided by the HLP. There were 27 participants in the HLP group ("test") and 23 participants in the group withouth daylight from the HLP ("reference"). After the survey, the participants were assigned to different groups. This was done by analysing the logged information on indoor illuminance, outdoor illuminance, and energy for lighting. For the test group, there was on average 70% of the light on the test desk that was delivered by HLP, and just 9,5% that came from the artificial lighting, while for the reference group, those values were 14% of the light from the HLP and 70% from the artificial lighting..

Participants got the opportunity to stay and work (on their laptop) for half an hour before the survey. When they needed to fill out the questionnaire, they sat at the desk closest to the door to experience a working place under the light pipe's daylighting. Analyses of participants scores given for the test room's visual experience and perceptual impression revealed a more positive evaluation of the room as spacious, open, uniform, and legible in the test group. There was a significant better evaluation of the test room as pleasant, interesting, and exciting in the test group, Figure 9. The room's brightness was evaluated better in the reference group. That was expected since higher indoor illuminance levels were recorded just in case of an overcast sky (reference group). The test group evaluated the level of daylight and artificial light more positively than the reference group (Figure 10). The most significant difference in assessment is the light level in the entire room. When the light level on the desk was just about 350 lux, a noticeable share of daylight was provided by the HLP. In such occasions, the participants provided interesting comments like: ''*it feels pleasant, and my eyes can relax*.'', ''*very unusual lighting, it feels simple/flat, but it's satisfying to work on screen.* '', ''*The first impression was that the room was not bright, compared to the lighting in the corridor and neighbouring rooms, but the room is bright enough to be able to perform work.*''. This contrasted quite clearly with comments provided in for surveys conducted under overcast sky conditions, with artificial lighting providing most of the 450-500 lux of illumination on the desk: ''*The corner towards the door is dark*''; ''*Rooms and work furniture/tables are white and uninspiring. Can probably seem a little cold in our climate*''; ''*The room is somewhat monotonous and dull*''; ''*No colour dynamics. It keeps me awake, but I can get tired faster with exertion.*''

"It feels pleasant, and my eyes can relax"

"Very unusual lighting, it feels simple/flat, but it's satisfying to work on screen"

Lessons learned

When daylight was provided by the HLP, the participants perceived the room appearance as uniform, open, exciting and pleasant. There was also a statistically significant positive evaluation from the test participants for the integration of daylight and artificial lighting in the entire room for the HLP case. Daylight reflected on the slats and pointed against ceiling affected DLC sensors, which resulted in wrongful information given further to the luminaires to adjust the artificial light level. In the case of an overcast sky, the fade time for DLC was less critical than in the case of clear sunny skies, where the magnitude of sun/sky illuminance variation was much higher.

Further information

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