Dynamic electric lighting and daylight can lift up office life

An integrative lighting system dynamically changing in colour and intensity during the day was well valued by office workers.

The Spark, a new office building Lund, Sweden, combines abundant daylight with new LED ceiling panels delivering cooler light in the morning, and warmer dimmed light during the afternoon. The system was appreciated by four office workers. It seemed also to increase their alertness, mostly when access to daylight was limited.

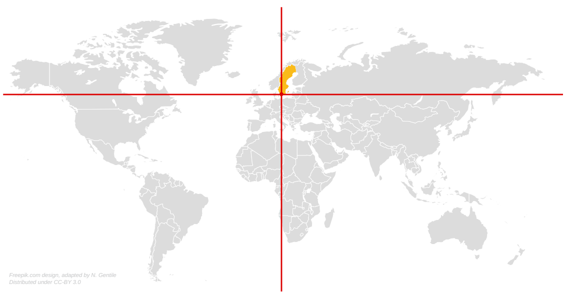
The project

The Spark is a seven-storey office building hosting nearly 2000 workers from different companies. Highly-glazed facades and sky openings provide the space with plenty of daylight. But when daylight cannot suffice, integrative LED panels should do the work. The lighting system works with a predefined "lighting recipe", which provides cooler (Correlated Colour Temperature, CCT = 6200 K) and intense lighting during the morning, warm (2300 K) and dimmed lighting in the late afternoon. Each office has its own lighting control panel where workers can override the system and choose their own lighting scenes, and adjust the dimming (Figure 1). Except for the offices on the north façade, all perimeter offices are provided with automatic shading systems that are controlled by solar radiation. Shading can also be manually overridden via a switch provided in each office.

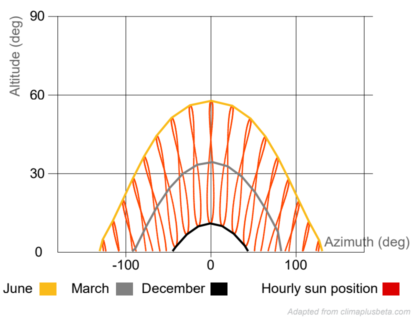
Figure 1. The Spark is designed with generous windows and skylights. The electric lighting uses a proprietary schedule called "biocentric lighting", with a daily variation in intensity and correlated colour temperature.

Monitoring

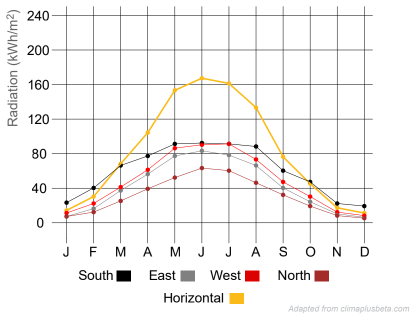
The site was visited several time starting from the end of February 2020. Four individual offices were monitored; they are located between the second and the sixth floor and with different orientations. For three consecutive weeks, the occupants were requested to use wrist-worn loggers for lighting (RGB, IR, lux) and movement. During this time and three times per day (morning, noon, and



Location: Lund, Sweden
55.71°, 13.22°



Sun path for
Lund, Sweden



Global horizontal and vertical radiation for
Lund, Sweden

IEA SHC Task 61 Subtask D

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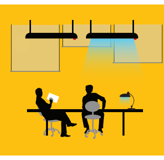

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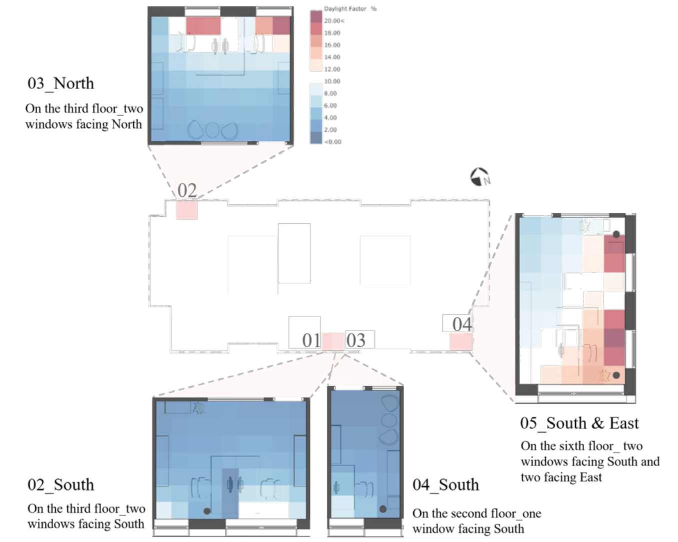


Figure 3. Overview of the building plan with the monitored offices and their measured daylight factors.

afternoon), an app on their smartphone asked to answer some questions dealing with self-reported alertness (KSS, Karolinska Sleepiness Scale). The field monitoring included a partial characterization of daylight and electric lighting in the rooms. The collection of these data was stopped by the Covid-19 pandemic, but they were sufficient to run a set of complementary simulations in Radiance and ALFA.

Energy

This project was designed with circadian health in mind, while energy use for lighting was not at the focus. Because there was no information available for electricity bills or meter-readings, lighting energy use was calculated for each office based on the European standard, EN15193. The *.ies file for the LED panel in a single state was available, and power requirements for the other states were derived proportionally after a site metering. The task lamps, which also exists, were not included in the calculation.

The delivered horizontal electric lighting illuminances at the desk height are well above the EN12464-1 recommendation, being as high as 1300 lux for some spots in the morning Scene 1, and 300-500 lux even for the dimmed Scene 4. The declared purpose of the designers was to increase the lumens reaching the eye in a circadian entrainment perspective; but this, together with relatively low efficient LED sources (≈ 88 lm/W) results in high lighting power density, about 18 w/m², and LENI above today's standard systems (Table 1).

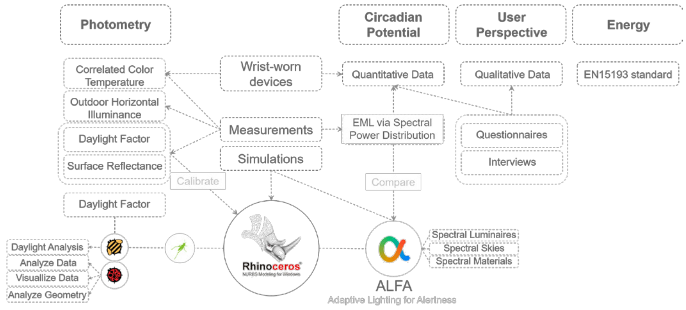


Figure 3. The workflow used to monitor The Spark case study. Due to Covid-19 restriction, field measurements served mainly as calibration to simulations.

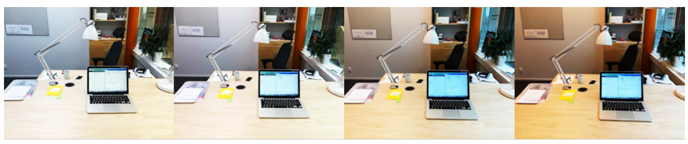
Table 1. Average calculated LENI for the four offices. Benchmark "Standard direct lighting system", Tab M1 EN15193-1:2017.

	LENI DHS kWh/m²	LENI Benchmark kWh/m²
Average for the four offices	22.43	14.80

Photometry

Site measurements of illuminance, spectral power distribution, reflectance, and surface colour provided a good starting point to characterize the offices. As general judgment, all monitored offices are well daylit, with daylight factor (DF) hardly dropping below 2% at any point of the rooms (Figure DF). The DF was both measured and simulated for a quick model verification.

The north-facing office shows higher daylight factors



Boost	Efficient	Relax	Lounge
≈ 6200 K	≈ 4000 K	≈ 2700 K	≈ 2300 K
Highest E_h			Lowest E_h

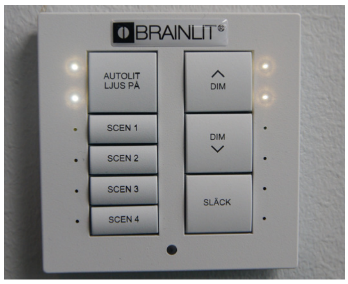


Figure 4. Left: one of the monitored offices. Top-right: overview of the scenes (E_h stands for horizontal illuminance Bottom-right: the manual switch to override the "lighting receipe" and the wrist-worn light logger used by the four employees.

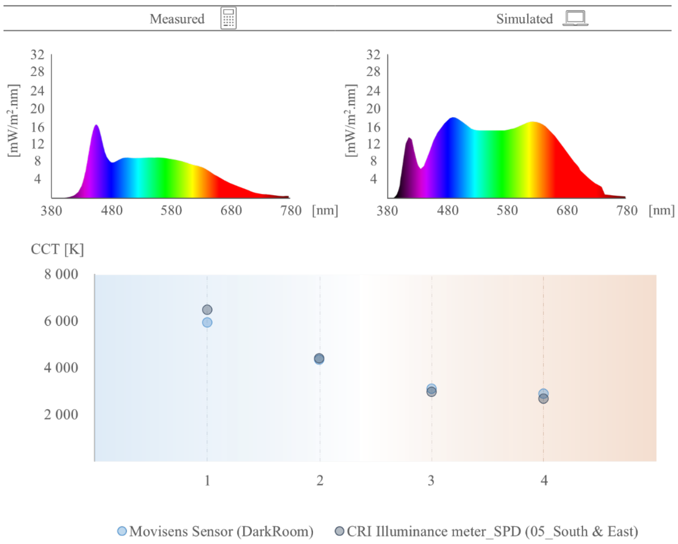


Figure 5. Comparison between SPDs for the measured Scene 1 and LED light source with equivalent M/P ratio (see "Circadian potential section for the definition") provided by ALFA (top), and comparison between CCTs measured with professional spectrometer and the wrist-worn light logger Movisens LightMove 4 (bottom). Scenes on x-axis (1="boost", 4= "lounge").

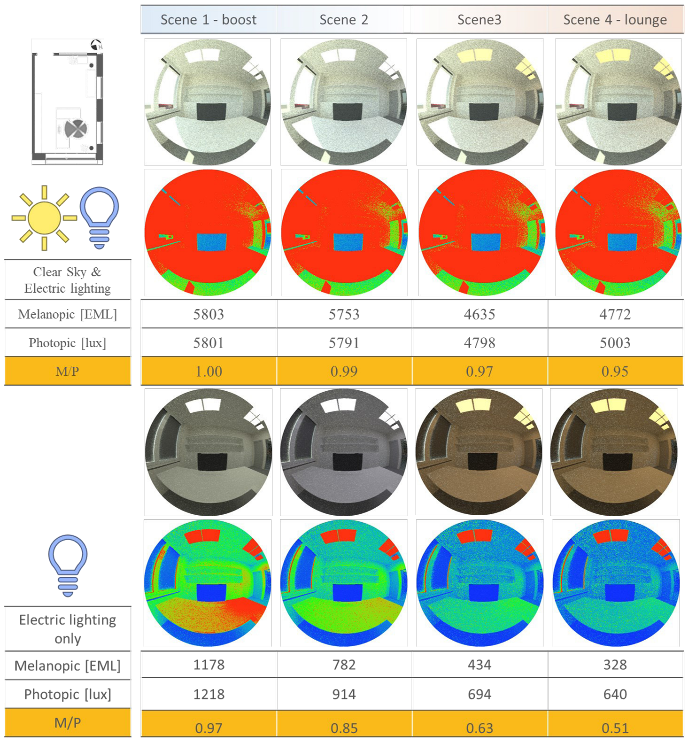
than those facing south, the reason being a different and wider wall construction on the south designed to reduce overheating.

The horizontal illuminance (E_h) measured at the task height confirms what anticipated when discussing the high energy use by the system. For scene 1, the powerful morning boost, hardly drops below 950 lux at any point of the room, and it reaches as much as 1300 lux in some points. As far as the vertical illuminance at eye is concerned, this scene delivers about 500 lux at eye position, when the computer screen was left on. Even for the dimmed Scene 2 and 3, the vertical illuminance at eye position is still lying between 300 and 400 lux. For the most dimmed Scene 4, this value drops to around 200 lux, which is still considerable.

The spot measurements for electric lighting were also used to characterize the spectral power distribution (SPD) and CCT of the light source for the different scenes. These data were compared with SPD profiles provided by the software used to measure circadian potential, Alfa, and the CCT measured by the wrist-worn devices. There were substanstial differences with SPDs from Alfa, due to the fact that the software uses a preloaded library. This might be problematic for advanced simulations, but it did not affect much this monitoring. There was instead good agreement between CCTs measured with a professional spectrometer and with the wrist-worn devices, especially for lower CCTs.

Circadian potential

Apart from providing illumination, lighting affects a number of non-visual responses like alertness and a more general concept of well-being. A growing chunk of literature is providing evidence of the circadian effects of lighting, but



	Scene 1 - boost	Scene 2	Scene3	Scene 4 - lounge
Clear Sky & Electric lighting				
Melanopic [EML]	5803	5753	4635	4772
Photopic [lux]	5801	5791	4798	5003
M/P	1.00	0.99	0.97	0.95
Electric lighting only				
Melanopic [EML]	1178	782	434	328
Photopic [lux]	1218	914	694	640
M/P	0.97	0.85	0.63	0.51

Figure 6. Results of ALFA simulations for the office with south and east facing windows. The results are shown for daylight and electric lighting (top) and electric lighting only (bottom), and for one view direction, sitting position.

there is still a limited knowledge of the practical impact of lighting in everyday life settings. The lighting industry is moving at fast pace, proposing a number of "circadian" or "human-centric" – more correctly defined as "integrative lighting" - solutions for offices, which should improve the overall well-being of employees, including their alertness during the day and their sleep quality during the night. But are these systems effective in practice?

The integrative lighting system monitored here is one of these solutions, and its "circadian" potential became the focal points in this case study.

The lighting was first characterized with field measurement of Spectral Power Distribution (SPD) for electric lighting, and for mixed daylight-electric lighting conditions. The SPDs were imported to the Lucas toolbox – a well-known instrument to account for circadian stimuli of lighting -, in order to obtain the Equivalent Melanopic Lux (EML, measured in lux), currently one of the most widespread circadian metrics among practitioners. The ratio between EML and the "ordinary" illuminance is called M/P ratio. Given the same illuminance, higher EML indicates a higher capacity of light to suppress melatonin production, a hormone responsible for tiredness. Therefore, high M/P ratios indicates a blue-enriched lighting which should prompt alertness. A proper integrative system should provide high M/P ratios in the morning (M/P > 0.90) and low in the afternoon (M/P ≈ 0.35 to 0.90, a neutral effect, namely neither alerting nor calming).

Indeed the system here tested does follow this pattern

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under electric lighting conditions. Scene 1, the morning boost setting, shows M/P ≈ 1.00, while Scene 4, the evening "lounge" setting, provides M/P as low as 0.50.

There are few simulation software today which are able to account for circadian light, one being ALFA. This software was used to simulate some additional lighting scenarios. A first electric lighting simulation was compared with the field measurements just mentioned. The results matched nicely, thus the model was used for a further simulation with a mix of daylight (clear sky) and electric lighting. In this case, the illumination provided by the daylight is at least five times stronger than that of electric lighting during the morning (Figure 6). Therefore daylighting becomes the main driver of circadian stimuli. During the late evening, when the sun is setting, but the working day is not over yet, a low M/P electric lighting can still provide illumination without preventing melatonin secretion (Figure 6).

User perspective

Five employees - one sitting in an office which was not modelled -, took part in this monitoring had a central role in understanding the benefits of the integrated project. They wore the wrist-worn device for three weeks providing an understanding of normal "lighting patterns", replied to the KSS and were happy to share thoughts in some interviews. According to the results, all but one of the participants were more alert in the morning, when the offices were lit with the bright blue light. But later when the system started dimming down providing a warmer reddish light colour in the afternoon, they reported more sleepiness. The logged data showed also that the employees did not sit for the whole working day in the office, but they went to other rooms or enjoyed a break outside. Therefore figure 7, which correlates the alertness to CCT and illuminance, refers to the general lighting stimuli and not only to these from the integrative lighting system. However, one participant, who sits in an office next to the atrium space with no view-out, showed a very clear and consistent relation with alertness and lighting levels, although this single and limited observation cannot be seen as a scientific evidence.

> ***"Other offices I had been in were darker. Here, it is like sitting outdoors and I do not need extra lighting like task light"***

The integrative lighting system raised quite extreme feelings. One participant was particularly annoyed, finding the morning light too cold and too bright ('*It was terrible. I can't stand this light* (...) *very upsetting* (...) *I got a migraine from the beginning*"). Note that the curve with different trand in Figure 7 represent this participant. The other three were enthusiastic about it, as reported in the box quotes. One

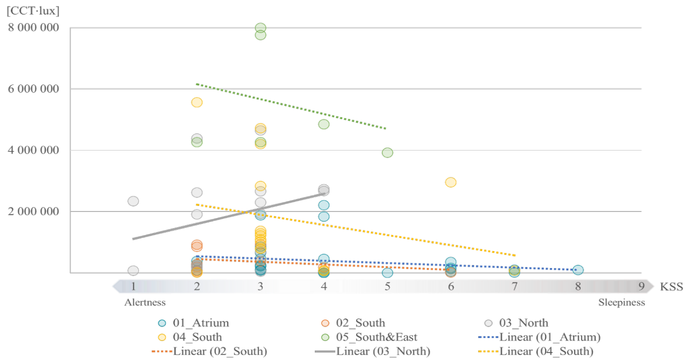

Figure 7. Alertness correlated to higher level of CCT and illuminance measured by the wrist-worn loggers.

interesting finding was that only the critical subject was used to override the system and fix Scene 4 during the whole day. The other participants sticked always to the proposed "lighting recipe", which is rare according to literature on automatic lighting controls. On the contrary, all the participants believed that the shadings, which are also automatically activated, can be annoying and usually prefer to override the system.

> ***"What I notice is that I am more alert, and I forget to go home at the end of the day"***

Lessons learned

The Spark is a building designed for daylight, and the integrative electric lighting system provides a powerful addition during the darker months of the year. Looking at the hard numbers, the lighting system could really propel circadian stimuli throughout the day. If those numbers correspond to actual stimuli is more difficult to determine. The limited time and subject could provide nothing stronger than mere indications. Maybe as result of both the system design and a sort of wow effect, the employees perceived a lift in their working life. The monitoring helped also to verify that existing circadian lighting software are already mature enough to provide some support to designers.

Looking at the energy use, however, the needs of circadian lighting design were put above traditional lighting design rules, resulting in an overlit and energy consuming design. Future projects should look at a good balance between the different demands of modern lighting design for sustainable buildings.

Further information

Yilmaz, E.C., Abdulhaq, R., 2020. *Assessment of the circadian stimulus potential of an integrative lighting system in an office area*. MSc thesis, Faculty of Engineering, Lund University, Sweden.

Acknowledgements

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