Integrative lighting for health and well-being in a rehabilitation facility

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Lighting with added vertical focus creates better daily rhythm for patients and staff, but light levels at night and controls need attention

A first study of the dynamic LED lighting installed in a section of the rehabilitation centre allows for comparison with the old fluorescent lighting and suggests that patients and staff experience better sleep under the new system that meets the target values for morning and evening circadian lighting suggested by state-of-the art research.

Figure 1. Typical patient bedroom at Vikaergaarden. Bedroom façade faces approximately East. Vegetation outside the window protects patients from people looking into their room, but also contributes to some loss of daylight.

The project

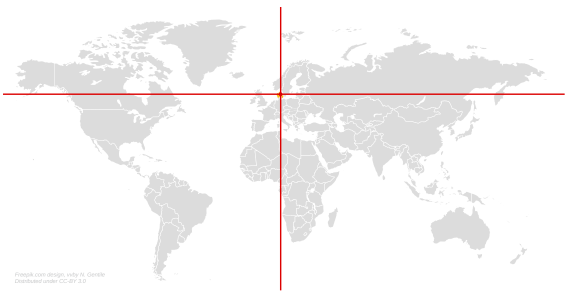
Vikaergaarden is a short-term rehabilitation and care facility where patients receive treatment and support for returning to normal life, for example after major surgery in a hospital. Located in the Vejlby district of the City of Aarhus, it was built in 1975 as a retirement home. Between 2014 and 2016, it was substantially renovated and converted into the rehabilitation facility it is today.

The City of Aarhus, who runs the facility, aims at providing conditions for their citizens that will help them recovering and returning to independence as early as possible. Stays vary in length, depending on the medical condition of a patient. A circadian lighting system was seen as one measure that could support this effort.

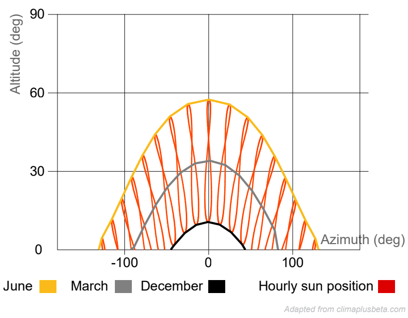
The dynamic LED lighting installed on one floor in one section of the rehabilitation facility (Figs. 1 and 2) provides a full-scale testbed for evaluating integrative lighting compared to the existing compact fluorescent lighting (CFL). Beyond programmed integrative lighting sequences implemented based on current knowledge and supporting circadian needs of patients and staff, the new lighting is used to energise or calm patients therapeutically by boosting or lowering light levels when needed (Fig. 3).

Monitoring

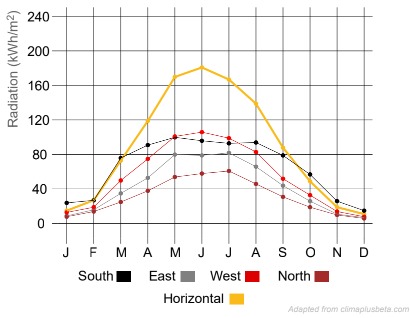
Researchers from Aarhus University's Lighting Design Research Laboratory conducted photometric measurements at Vikaergaarden in March 2019. These resulted in the addition of a wall-washing luminaire opposite the patient bed and the relocation of the other two LED luminaires a bit closer to the room centre (Fig. 4). Further photometric measurements and recordings of activity lev-



Location: Aarhus, Denmark
56.19°N, 10.21°E



Sun path for
Aarhus, Denmark
(56.19°N, 10.21°E)



Global horizontal and vertical radiation for
Aarhus, Denmark
(56.19°N, 10.21°E)

IEA SHC Task 61 Subtask D

Monitored by **W. Osterhaus, I. Erhardtsen, M. Gkaintatzi-Masouti, K. Nielsen and F. Dobos**
More info: **Prof. Werner Osterhaus,** Aarhus University, werner.osterhaus@cae.au.dk

Figure 2. Exterior night view of Vikaergaarden rehabilitation facility with existing fluorescent lighting (two top floors) and new dynamic LED lighting (bottom floor).

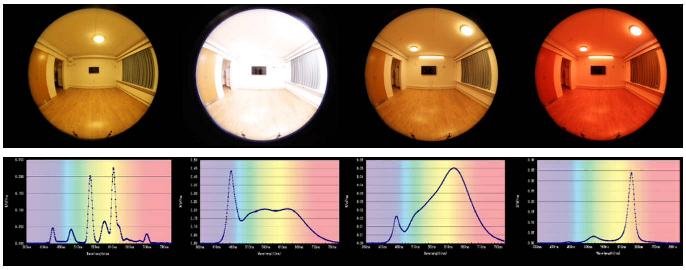


Figure 3. From left to right showing patient room lighting scene and its spectrum - original compact fluorescent lighting from 2014, “light therapy” setting, “night care” setting and “calming” setting.

els and sleep patterns via ceiling-mounted and wearable devices (Fig. 5) occurred in October/November 2019. Six members of the medical staff in a section with the original compact fluorescent lighting and seven in the section with the new integrative LED lighting were interviewed during June/July 2020. Monitoring closely followed the protocols established by the IEA-SHC Task 50 and extended by the current IEA-SHC Task 61.

Energy

The building’s lighting energy performance was evaluated via calculations according to the European Standard EN 15193-1. DIALux simulations and EN 15193-1 calculations in an Excel-based spreadsheet based on measured luminaire and driver power values provided the energy performance data. The Lighting Energy Numeric Indicator (LENI) was determined for three different lighting scenarios (Tab. 1):

- A standard reference scenario with four ceiling-recessed LED panels and a daylight-dependent control system (representing a typical Danish code-compliant design)
- The actually existing new integrative LED lighting systems with its programmed and switchable lighting scenes and
- A variant of the actually existing system with added daylight-dependent lighting control and passive infrared (PIR) motion sensors.

The actually existing lighting design with its different scenarios and longer lighting operating hours would likely have resulted in an 83% higher lighting energy use than the standard reference case, because daylight-dependent dimming was not implemented. Added daylight-dependent

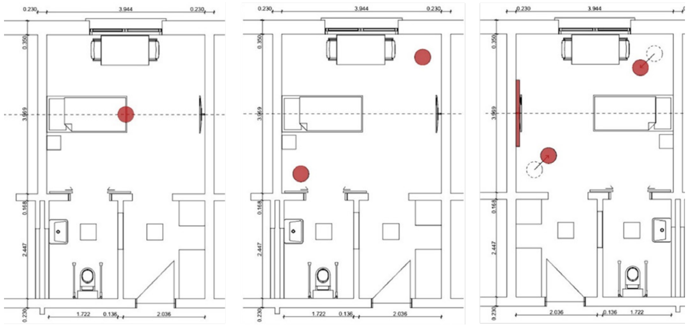


Figure 4. Compact fluorescent lighting in original patient rooms (left). Initially installed integrative LED-lighting system (middle) and integrative LED system after addition of wall washing luminaire and relocation of the other two luminaires (right).

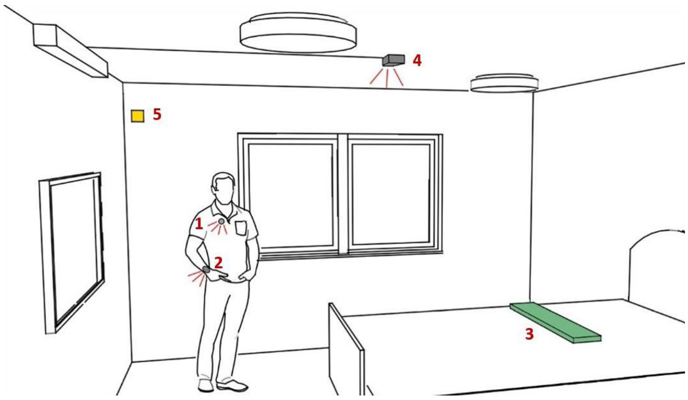


Figure 5. Devices used for monitoring over a period of two weeks in November 2019. 1) and 2) wearables, 3) mobility monitor, 4) camera sensor, 5) temperature sensor.

dimming and occupancy sensors (absence factor 0.2) would have resulted in 16.4% energy savings compared to the standard reference and 54.3% compared to the LED system as currently implemented. With standard operating hours, the existing design would have used 33% more lighting energy than the standard reference case without daylight-dependent dimming or occupancy sensors, and 39.4% less energy than the standard reference with the additional installation of daylight-linked dimming and occupancy sensors. Compared to the currently installed new LED lighting, the operating-hour-adjusted solution with daylight-linked dimming and occupancy sensors would have saved 54.4% energy.

Photometry

Illuminance measurements were taken across a 0.5m grid at 0.85 m above the floor and the on the wall opposite the bed in two rooms for (a) daylight only, and (b) electric lighting under one (CFL) or three different light settings (LED), respectively. During daylight assessment, the exterior horizontal illuminance was ca. 5000 lux around 17:00. The sky on 04 March 2019 was mostly overcast. Direct sunlight did not strike the illuminance metre. The average daylight factor was 1.4% in the patient room, reflecting exterior obstructions from vegetation, thus not meeting the aims of the European Standard EN 17037. Electric lighting from the original CFL lighting provided an average illumi-

Table 1. Energy Use and Lighting Energy Numeric Indicator (LENI) for the different lighting scenarios.

	Standard reference	Existing	Proposed change	Existing Adjusted	Proposed Change Adjusted
Day (DF = 1.4%), (Average Illuminance -->)	300 lux	47 - 431 lux	47 - 431 lux	47 - 431 lux	47 - 431 lux
Hours	3000 Hours	4927.5 Hours		3000 Hours	
Number of Luminaires	4 Total (4 Ceiling)	3 Total (2 Ceiling + 1 Wall)		3 Total (2 Ceiling + 1 Wall)	
Power per Luminaire	27 W	24 - 131 W*		24 - 131 W*	
Daylight-Dependent Control	yes	no	yes	no	yes
Occupancy Sensor	no	no	yes	no	yes
Total Annual Energy Use Day	181.4 kWh	381.4 kWh	170.8 kWh	232.2 kWh	104.0 kWh
Night (Average Illuminance -->)	100 lux	26 lux	26 lux	26 lux	26 lux
Hours	1000 Hours	1825 Hours		1000 Hours	
Number of Luminaires	4 Ceiling	1 Wall Washer		1 Wall Washer	
Power per Luminaire	8.1 W	5.4 W		5.4 W	
Total Annual Energy Use Night	32.4 kWh	9.9 kWh	7.9 kWh	5.4 kWh	4.3 kWh
Total Annual Energy Use	213.8 kWh	391.2 kWh	178.7 kWh	237.6 kWh	108.3 kWh
LENI (for Room of 15 m^2)	13.7 kWh/m^2	25.0 kWh/m^2	11.4 kWh/m^2	15.2 kWh/m^2	6.9 kWh/m^2
Energy Savings compared to Standard Reference		-83.0%	16.4%	-33.0%	39.4%
Energy Savings compared to Existing			54.3%		54.4%

* : power range for luminaire groups, as several lighting scenarios with different spectrum and illuminance levels are used throughout the day.
Calculation done on 16 Dec 2020 - WO_IVE

nance of just 80 lux at a height of 0.85 m. According to the European Standard EN 12464-1, 100 lux are needed in wards in health care facilities for general illumination (at floor level), and 300 lux for reading at the appropriate level and area. Regarding medical needs, 300 lux should be provided for simple examinations, 1000 lux for treatment. For the integrative LED lighting, illuminance and correlated colour temperature vary throughout the day according to the programmed schedule. Three specific settings that can be selected through a switch panel on the wall were assessed instead: “light therapy”, “night care” and “calming”. The average horizontal illuminance was 430 lux with the “light therapy” setting, well above the recommendation of 300 lux and aimed at activating patients’ alertness. With the “night care” and “calming” settings, the horizontal illuminance was less than 100 lux (on average 70 and 47 lux, respectively), which was the intention. Luminance maps for the assessment of room brightness distributions and glare ratings were created from various viewpoints in the bedroom for the lighting scenarios studied. Glare might be experienced for the brighter light settings in rooms with the dynamic LED lighting. The light source spectral power distribution (SPD, Fig. 3), correlated colour temperature (CCT) and colour rendering index (Ra) were also determined. Figure 3 illustrates that settings which aim to increase alertness (like “light therapy”) have a larger component towards the blue part, and in contrast, the settings which aim to create a calming environment occupy more of the red part of the spectrum (like “calming” and “night care”). The slowly changing SPDs of the daily schedule used with the dynamic LED contain more blue light in the morning and more red light in the evening. Similarly, the CCT follows a daily schedule that features cooler light in the morning and after lunch (to provide an afternoon boost) and moves towards warmer light in the evening (Fig. 6).

Circadian potential

Spectral information, appropriately weighted, allows for assessment of the circadian potential of different lighting scenarios. The circadian potential expresses how a specific lighting scenario could potentially support a building occupant’s daily sleep/wake rhythm and well-being. This was evaluated using two metrics: the Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) and the Circadian Stimulus (CS). Experience with these state-of-the-art metrics is still limited, but initial recommendations for appropriate values exist. Different spectrally weighted M-EDI levels contribute to inhibiting or enhancing the production of the sleep hormone melatonin. To obtain good circadian conditions for increasing alertness and supressing melatonin production in the hours before midday, the WELL Building Standard V2 recommends an M-EDI of at least 218 lux at eye level. CS is the effectiveness in suppressing the production of melatonin from threshold (CS = 0.1) to saturation (CS = 0.7). The Lighting Research Center in Troy, New York suggests, that CS should be kept below 0.1 in the evenings and at night to enhance melatonin production for a good night’s sleep. For increasing alertness, a value between 0.3 and 0.4 is recommended. For both metrics, the electric lighting scenarios during both night and day would provide good conditions for putting patients and staff to sleep. The integrative LED lighting as installed now can likely contribute to a balanced circadian rhythm of patients or staff, as the M-EDI and CS values for increasing alertness reach the desired “daytime” target zone (Fig. 7).

User perspective

The user perspective was evaluated in terms of light exposure and activity levels of staff and patients, and answers of medical staff to the semi-structured interviews regarding

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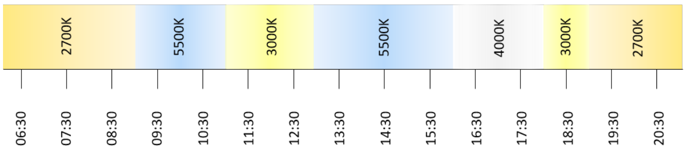

Figure 6. Daily schedule for CCT implemented at Vikaergaarden.

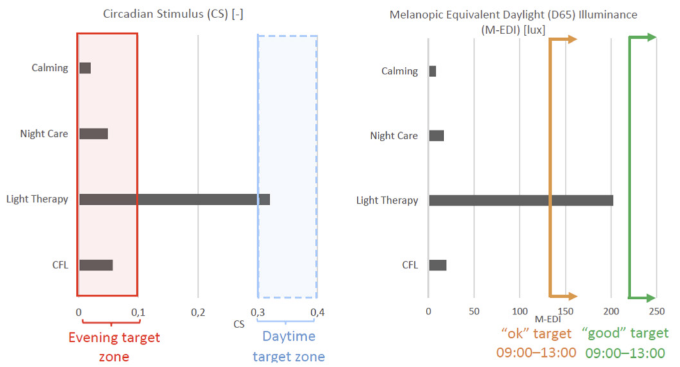

Figure 7. CS (left) and M-EDI (right) both calculated for an estimated vertical illuminance simulated by DIALux at a height of 1.2 m above the floor for the four lighting scenarios. The target zones for CS refer to the recommendations of LRI and target zones for "ok" and "good" refer to the recommendations of the WELL Building Standard V2.

their experiences with the two lighting systems in June/July 2020. Unfortunately, the small scale of this study did not allow for drawing any statistically robust conclusions. Some trends could still be observed. In the ward with dynamic LED lighting, medical staff rated their own sleep quality, as well as the perceived calmness, lower voice volume, physical well-being and security higher than in the wards with the older CFLs. The patients' activity levels at night were also lower, suggesting better sleep. For the wards with CFLs, the light did not seem to affect their own or their patients' mood, attention or energy, whereas in the ward with LEDs, some of the nurses claimed to notice an effect on their. Nurses generally liked the circadian LED lighting, except when moving between different wards with and without the integrative lighting (high contrasts and some glare), or in the morning, when the dynamic LED lighting was changing from the night light to the morning light a bit too abruptly. Here, staff thought there was a need for transition settings before the light turned to the morning light. During the daytime, all interviewed employees rated the dynamic lighting as suited for their work. This was different at night, when half of the employees found the light rather too dark or to red for working. They sometimes manually changed the light to perform visual tasks requiring higher light levels. Some indicated that patients had difficulties with the switches in their rooms (poor and too small labelling). Some staff said that they had not received sufficient instructions for using the integrative LED lighting. In all rooms, curtains were usually opened after waking up and closed around sunset. This suggests that staff and patients wanted to allow for as much daylight access as possible.

Lessons learned

Providing light on the wall faced by a patient sitting in the bed – in addition to the ceiling lights – contributed to a more balanced lighting environment. Ceiling light fixtures could use better shielding to prevent glare, especially for the high light levels of the "therapy lighting". Some adjustments of the transitions between lighting scenarios and additional task lighting for medical staff at night are needed, as is the introduction of daylight-dependent dimming of the electric lighting and occupancy sensors for saving electric lighting energy. In addition, better instruction on the purpose and use of the circadian lighting system and its control for both staff and patients and clearly labelled control switches in patient rooms would be beneficial. Trustworthy wearable devices are essential for getting reliable data. Not all of the available devices were found to be suitable. Careful comparison of devices and their data is important prior to use in case studies as measurements can vary widely, even between devices of the same type. Manufacturers of the devices often do not know or do not want to reveal details of technical specifications or accuracy levels.

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Further information

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