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Project Report

Case Studies
Circadian Lighting

AARHUS UNIVERSITET

CIRCADIAN LIGHTING

Case Studies

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PREFACE

This report is part of a set of reports describing the research activities for the project “Circadian Lighting (Dynamisk Døgnrytmelys)” funded by Danish Energy’s research and development programme ELFORSK under project number PSO 351-041. Danish Energy is a non-commercial lobbying organization for Danish energy companies. Through applied research, development and demonstration, ELFORSK supports the efficient use of electricity and energy in buildings and industry.

With this project, we have investigated and mapped data from selected lighting systems with dynamic properties that are already installed in the Danish healthcare system and the experiences with them. Circadian (from Latin circa=approximately and dies=day) lighting generally refers to lighting installations that mimic the course of a day with its natural variations. Circadian lighting is thus dynamic by nature. However, other dynamic lighting installations have also been described as circadian lighting. Integrative lighting is a term recently introduced by the International Commission on Illumination (CIE) to describe lighting specifically designed to produce a beneficial physiological and/or psychological effect upon humans. The terms circadian and integrative lighting are now often used interchangeably. Throughout this report, we have chosen to use the term circadian lighting, as the project was funded for studying circadian lighting, lighting that is intended to support the natural sleep and wake cycle of humans that is normally entrained by the presence and absence of naturally varying daylight.

At present, there are no clear guidelines for the technical aspects of circadian/integrative lighting installations or the energy framework with which these lighting systems must comply, as they are often categorized as specialized lighting. As of today, it is not a requirement that specialized lighting (such as dynamic circadian lighting systems) must live up to the current energy requirements in energy class 2015 and 2020, respectively, but as part of the overall reduction in CO_2 emissions, it must be considered necessary to define appropriate energy consumption limits for such lighting installations.

In this project, the lighting systems that form the basis of this study have been examined with a view to collecting data on how they perform with respect to lighting technology and energy aspects. Special focus was placed on the impact on lighting distribution in the respective spaces, glare and energy use of direct luminaires, luminaires indirectly illuminating wall surfaces, as well as on different light source types. The lighting installations have also been examined with respect to their user-friendliness, the frequency of interaction with them by staff and patients, and the perceived impact of and satisfaction with them.

In the longer term, these data could be applied in connection with the preparation of new and improved guidelines for circadian lighting systems, both in terms of energy savings potential as well as improving the technical quality of circadian and other dynamic lighting systems. The results presented in this report allow for some initial conclusions and recommendations for future circadian lighting installations.

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1

INTRODUCTION TO THE CASE STUDIES

1. Vikærgården Rehabilitation Center in Aarhus
2. Psychiatric Hospital in Slagelse
3. Skejby Psychiatric Hospital in Aarhus

1 INTRODUCTION TO THE CASE STUDIES

This project report relates to an ELFORSK-funded research project on dynamic circadian lighting in the Danish healthcare sector and contains more detailed information and data on selected dynamic circadian lighting installations currently operated in Denmark. While the original plan included more examples than the two case studies for the Vikærgården short-term facility for rehabilitation in Aarhus and the Psychiatric Hospital in Slagelse, the COVID-19 pandemic and related restrictions regarding access to the buildings in the name of patient and staff safety reduced the original list to just those two. At both locations, data were collected for analysis of lighting performance, including user perspectives, energy consumption and technical aspects of the lighting systems.

The majority of measurements and examinations at Vikærgården, were conducted as a part of a Master Thesis project; "Development of a light measurement method: Assessing lighting and human light exposure using a RaspberryPi camera and dosimeters in a short-term care facility" with the (Day)Lighting Design Research Group at Aarhus University in the fall semester of 2019 [1]. Additional material was collected later by the project team for further assessment and analysis.

1.1 Methods and Measurements

The monitoring procedure for the two case studies at Slagelse Psychiatric Hospital and Vikærgården was based on the monitoring protocol for lighting and daylighting retrofits suggested by IES-SHC Task 50 [2]. The steps suggested by the protocol were adjusted to fit the purposes of the specific case studies at hand.

The two buildings were initially visited to get a general understanding of the space, collect basic information and select appropriate rooms for monitoring. Measurements in all the various types of spaces (patient rooms, staff rooms, corridors, common spaces etc.) were not possible and therefore patient bedrooms were selected as representative.

Figure 1-1 - Representative patient bedrooms at Vikærgården

Figure 1-2 - Representative patient bedroom at Psychiatric Hospital in Slagelse

Prior to the monitoring, decisions were made regarding which photometric and radiometric quantities to measure and how to measure them (equipment and specific measurement points). Legal agreements were made to ensure that privacy policies and the general data protection regulation (GDPR) were upheld, especially at Vikærgården, where patients occupied all other rooms than the one serving as the test room. Appropriate decisions before and during the monitoring process on-site, as well as with respect to the publication of data, were made in cooperation with the responsible staff members and their superiors.

At **Vikærgården**, the monitoring involved hand-held and automated measurements together with semi-structured questionnaire-based interviews. The hand-held measurements were completed in two steps. The first set of measurements took place during March 2019, right after a new circadian lighting system was installed. Photometric measurements were taken in two test rooms, one equipped with the old and one with the new lighting system. Based on this first round of measurements, suggestions for improving the new system were made. After these suggestions were implemented by the luminaire manufacturer and installers, a second set of measurements took place in November 2019. These photometric measurements included luminance mapping, illuminance (horizontal, vertical, cylindrical) and spectral power distribution.

Figure 1-3 - Preparing for the photometric measurements

In addition, automated measurements were set up in eight rooms (four with the old lighting system and four with the new) for a period of two weeks during November 2019 involving eight patients and ten nurses. The participants were given two kinds of wearable dosimeters to observe the lighting conditions to which they were exposed, one meant to be placed on the wrist (Figure 1-5) and one on the collar of the shirt (Figure 1-6). The dosimeters logged the participants' light exposure and activity. In addition, mobility monitors were located under the patients' mattresses to investigate their sleep quality. Moreover, camera-based sensors were placed on the ceilings of two rooms. The sensors, which consisted of Raspberry Pi computers with camera and fisheye lens, were used to continuously capture high dynamic range images (HDRI) for the purpose of generating luminance maps. Image sequences used for generating the luminance maps were automatically deleted once a false-color luminance map had been created to protect the privacy of individuals in the room.

Figure 1-4. The sensor, Raspberry Pi computer with camera and fisheye lens

Figure 1-5 - One of the dosimeters, Movisens LightMove4

Figure 1-6 - The other dosimeter, LYS Button

Additionally, ten nurses that were present in the monitored rooms during the two weeks of the automated measurements were given a questionnaire to assess their sleep quality. The questions focused on sleep and personal satisfaction with the lighting system. Eventually, during June 2020, a series of interviews took place with thirteen staff members.

At the **Psychiatric Hospital in Slagelse**, the monitoring involved hand-held measurements of the luminous environment present in a patient room and semi-structured interviews with medical staff working in the hospital. The hand-held measurements happened during February 2020 in one of the patient bedrooms. The measurements included luminance mapping, horizontal illuminance, and spectral power distribution. The interviews happened at the same day with six staff members.

Table 1-1 presents an overview of the equipment used during the case studies.

Figure 1-7 - Canon EOS 60D DSLR camera with a fisheye lens for luminance mapping

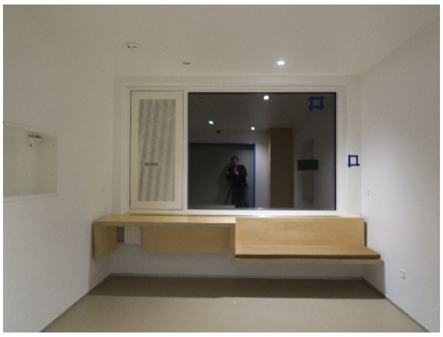


Figure 1-8 - The measurements of the electric lighting were conducted after dark in the late evening

Figure 1-9 - Konica Minolta CL-200 illuminance and chroma meter

Table 1-1 - Equipment used for case study measurements (CCT = correlated color temperature)

Equipment	Function	Facility
Extech HD 450 illuminance data logger	Exterior illuminance measurement	V
Konica Minolta CL-200	Illuminance and CCT measurement	V, S
Konica Minolta LS-100	Point luminance measurement	V, S
Konica Minolta CL-500A	Spectral power distribution measurement	V, S
Konica Minolta CM-600d	Surface reflectance measurement	V, S
Canon EOS 60D DSLR with a fisheye lens	High dynamic range luminance mapping	V, S
Lys Button 1.0	Wearable device for illuminance and CCT measurement	V
Movisens LightMove4	Wearable activity tracker	V
RaspberryPi with camera module 2 and fisheye lens	Continuous high dynamic range luminance mapping	V
TinyTag data logger	Temperature measurement	V
Mobility Monitor	Sleep quality and duration tracking	V

V: Vikærgården Rehabilitation Facility

S: Slagelse Psychiatric Hospital

1.2 Implementation of Semi-Structured Interviews

Semi-structured interviews were conducted with thirteen staff members at Vikærgården and six staff members at Slagelse Psychiatric Hospital to evaluate how they perceived the electric lighting system operation and resulting lighting conditions, as well as the impact of the lighting system on their work and their patients. A questionnaire guide with a series of predefined questions was used. The more informal atmosphere of the semi-structured interview procedure also allowed for staff members to add additional comments they felt were important. They were encouraged to discuss and share their thoughts without being restricted in their responses by the interview guide.

The interviewees' answers and personal comments were recorded and later transcribed for analysis in an Excel sheet. The interview guide was structured into the following sections:

- **Personal information**
- **Light Settings and Operation**
- **Visual Experience**
- **Effect of Circadian Lighting on Staff**
- **Effect of Circadian Lighting on Patients**
- **Emotional Effect**
- **Training and Implementation**

A summary of the guide sections is included in Table 1-2, and the detailed interview guide is shown in Appendix B.

Table 1-2 - Summary of the interview guide sections

Interview Guide Section	Description
Personal Information	General information about participants (age, gender, role, shifts)
Light Settings and Operation	Operation and usability of the circadian lighting system
Visual experience	How a person perceives the light in the different spaces
Effect of Circadian Lighting on Staff	Self-evaluation of influence on parameters related with staff's circadian rhythms (such as sleep quality and energy levels)
Effect of Circadian Lighting on Patients	Staff's evaluation of influence on parameters related with patients' circadian rhythms (such as sleep quality and energy levels)
Emotional effect	How it feels to stay in a space with circadian lighting
Teaching and implementation	Learning options and challenges

Employees working the day, evening and night shifts were included in the interviews. In the case of Vikærgården, the facility was additionally divided into wards where the circadian lighting system was already implemented and wards with an older compact fluorescent lighting system. That created the need to have an adjusted questionnaire guide for the participants who were working under the old lighting system (Appendix B). Moreover, due to the COVID-19 crisis, the interviews with the employees at Vikærgården were conducted over the phone instead of in personal meetings with them.

1.3 Requirements for Electric Lighting and Daylighting

To provide a pleasing visual experience and constant high performance of the employees, there are some standards, which should be satisfied. Back in 2005, DS 700 was the Danish standard for the artificial lighting of workplaces [3]. In this standard, lighting for healthcare premises was not included, but it referred instead to DS 703, which provided guidelines for artificial lighting in hospitals [4]. DS 703 was withdrawn in October 2018 and has been substituted by the European standard DS/EN 12464-1, which represents lighting for workplaces as a complete document and contains lighting for healthcare as well [5]. According to the Danish Building Regulations, the artificial lighting installation needs to fulfil the requirements in DS/EN 12464-1 for workplaces in Denmark. Some of the requirements for healthcare spaces relevant for this project are presented in Table 1-3. The values for the rooms for general use, wards and examination rooms are the most important for the case studies described in this report.

Table 1-3 – Light requirements for chosen types of health care premises - wards, maternity wards [5]

Ref. no.	Type of area, task or activity	E_m	UGR_L	U_o	R_a	Specific requirements
5.39.1	General lighting	100	19	0,40	80	Illuminance at floor level
5.39.2	Reading lighting	300	19	0,70	80	
5.39.3	Simple examinations	300	19	0,60	80	
5.39.4	Examinations and treatment	1000	19	0,70	90	
5.39.5	Night light, observation lighting	5	-	-	80	
5.39.6	Bathrooms and toilets for patients	200	22	0,40	80	

In DS 12464-1, the recommended illuminance is given by the maintained illuminance (E_m) which considers possible light loss from the luminaires over time. In the table, the maximum value for The Unified Glare Rating limit (UGR_L), the minimum illuminance uniformity (U_o) and the minimum value for color rendering index (R_a) is shown as well.

For evaluating potential glare issues in the patient rooms, the Daylight Glare Probability (DGP) is used to measure glare under daylight conditions, and the Unified Glare Ratio (UGR) is used to assess glare under the electric lighting conditions. Table 1-4 presents the DGP categories and ranges according to DS/EN 17037 – Daylighting of Buildings [6]. A DGP below 0.45 is recommended for minimum glare protection, below 0.40 for medium glare protection and below 0.35 for high glare protection. According to DS/EN 12464-1 [5], the UGR in the wards of health care facilities should be limited to 19 for general lighting, reading lighting, and examination lighting as shown in Table 1-3. DS/EN 17037 also calls for a minimum illuminance of 300 lux for 50% of the space and 50% of the daylight hours across the year.

Table 1-4 - DGP ranges [6]

Criterion	Daylight Glare Probability (DGP)
Glare is mostly not perceived	DGP ≤ 0.35
Glare is perceived but mostly not disturbing	0.35 < DGP ≤ 0.40
Glare is perceived and often disturbing	0.4 < DGP ≤ 0.45
Glare is perceived and mostly intolerable	DGP > 0.45

1.4 Requirements for Melanopic Illuminance

According to the Danish Building Regulations, there is no recommendation for melanopic lux. Neither the standards EN/DS 12464-1 or DS 703, nor DS 700 list any demands for using melanopic illuminance or other relevant lighting parameter for circadian lighting. However, the biological effects of lighting for different interiors, task areas or activity levels are taken into consideration in the recommendations for “living spaces” in the German DIN SPEC 67600 [7]. DIN SPEC 67600 is looking into non-visual effects obtained through the eye. DIN SPEC 67600 is linked with DIN SPEC 5031-100, where information about the melanopic action factor for different light sources is available [8]. Additionally, the WELL Building Standard released some design recommendations equivalent melanopic illuminance (EML) as shown in Table 1-5.

Table 1-5 - Recommendations for equivalent melanopic illuminance (EML) at selected places [9]

Work areas	250 equivalent melanopic lux or more for at least 4 hours per day every day of the year
Living Environment	During the daytime: at least 200 equivalent melanopic lux During night-time: less than 50 equivalent melanopic lux
Break Rooms	At least 250 equivalent melanopic lux as measured on the vertical plane facing forward at surfaces 1.2 m above finish floor
Learning Areas	125 equivalent melanopic lux at 75% or more of desks for at least 4 hours per day every for every day of the year

The newest version of the WELL Building Standard (Version 2) [10] suggests the melanopic equivalent daylight D65 illuminance (M-EDI) to be at least 218 lux for demonstrating that the lighting design meets circadian lighting recommendations in regularly occupied spaces. The recommendations are summarized in Table 1-6, and these values were later in this project for comparison with measured and simulated data.

Table 1-6 - WELL Building Standard v2 recommendations for illuminance levels for circadian lighting [10]

Option 1		Option 2	Points
At least 150 EML [136 melanopic equivalent daylight D65 illuminance]	OR	The project achieves at least 120 EML [109 melanopic equivalent daylight D65 illuminance] with electric light and at least 2 points in Feature L05: Enhanced Daylight Access	1
At least 240 EML [218 melanopic equivalent daylight D65 illuminance]	OR	The project achieves at least 180 EML [163 melanopic equivalent daylight D65 illuminance] with electric light and at least 2 points in Feature L05: Enhanced Daylight Access	3

2

VIKÆRGÅRDEN REHABILITATION CENTRE

EVALUATION OF DAYLIGHT AND ELECTRIC LIGHTING INSTALLATION IN PATIENT ROOMS

2 VIKÆRGÅRDEN REHABILITATION CENTRE

Vikærgården is a short-term rehabilitation facility located in Vejlby, a part of Aarhus in Denmark. The purpose of the facility is to assist patients recovering from surgery or physical injury get back on their feet and return to their own home.

Figure 2-1 - Vikærgården

Figure 2-2 - Site plan for Vikærgården (Google Maps)

At the time of our investigation, the facility was equipped with two different electric lighting systems. Most of the patient rooms were lit by existing compact fluorescent lamps (CFL) and some patient rooms at the ground floor by a new circadian LED lighting (more information follows in Section 2.3), which was programmed to change intensity, correlated color temperature and spectral distribution throughout the day. The new LED lighting aimed to support the patients' circadian system by providing suitable illuminance and color spectrum for different times of the day. In the morning, the lighting system attempted to increase people's energy and alertness, whereas in the evening the goal was relaxation and sleep support. Additionally, specific light scenarios were defined to help nurses with providing better care. The motivation for the investment in the new circadian LED lighting was to reduce the patients' recovery time and make the facility more comfortable for patients and staff.

Figure 2-3 - Outdoor area and view from patient rooms out of the windows

Figure 2-4 - Illustration of the different electric lighting system in the residential property

The (Day)Lighting Design Research Group at Aarhus University conducted measurements in one of the patients' room during two measurement periods – The first period was in spring 2019 and the second period in the fall 2019. Additionally, a series of interviews with staff members was undertaken to assess their experience with the lighting system.

2.1 Description of a Typical Patient Suite

The typical small patient suite consisted of a bedroom, bathroom and a small entry hall with desk, fridge and closets. The measurements were conducted mostly in the patient bedroom, where the patient and staff will spend many hours during the day. Most patient suites had the same spaces and dimensions, but could be mirror images of the layout shown.

Figure 2-5 – An example of a patient bedroom

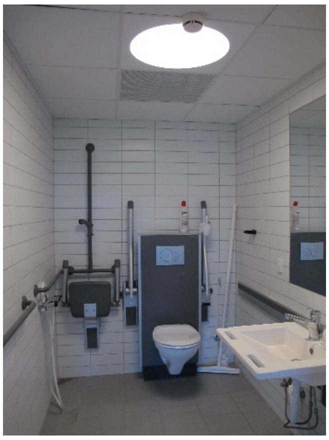


Figure 2-6 - An example of a patient bathroom

Figure 2-7 - An example of an entry hall to a patient's suite

The bedroom was an approximately 4m x 4m square room, with one larger double-pane window facing south-west. The room height is 2.5 m. The window was 1.88 m wide and 1.27 m high. The view out of the window could vary, but mostly it was to a green area with a few larger trees and bushes. The surrounding buildings partially limited the daylight access to the rooms and obstructed the view as well due to their closer distance.

Figure 2-8 – The patient bedroom at Vikærgården used for the full photometric assessment

The bedroom was equipped with a bed, a table with chairs, a nightstand, TV and an armchair. During the measurement period, the furniture had been removed from the room, and only the TV was left on the wall opposite the headboard of the bed.

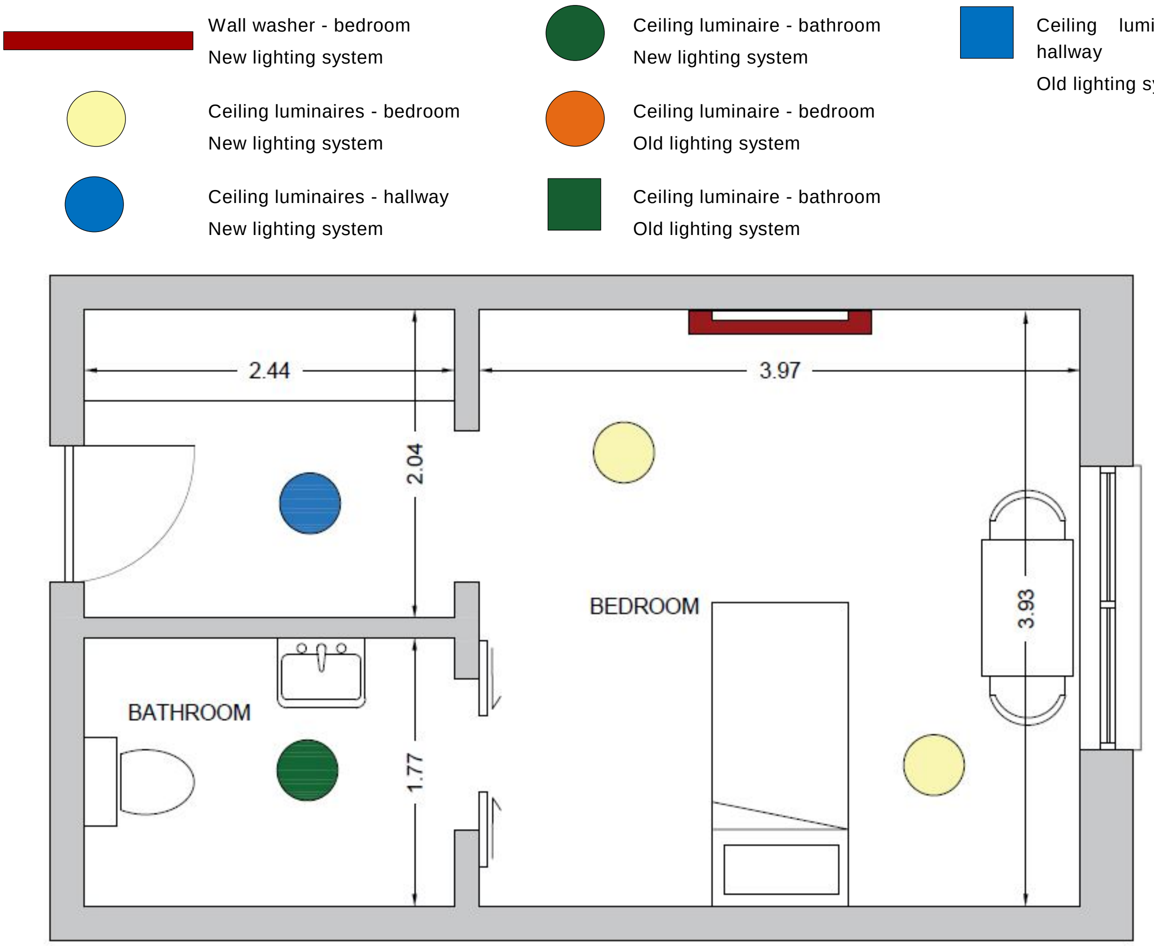


Figure 2-9 - A patient suite with the new LED lighting system

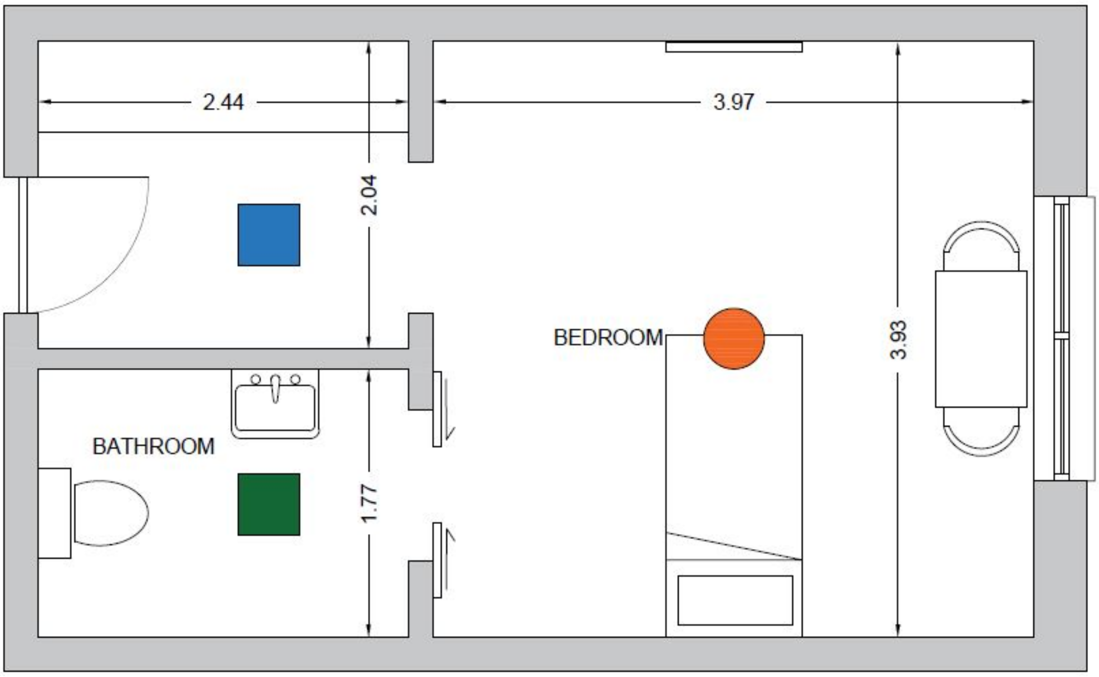


Figure 2-10 - A patient suite with the old existing lighting system (CFL in the bedroom)

The surface reflectances were determined with the Konica Minolta CM-600d spectrophotometer and are presented in Table 2-1. The reflectances were measured by placing the spectrophotometer's head directly on the surface. The reflectance was measured for the most common surfaces in the room.

Table 2-1 - Surface reflectance values for the bedroom at Vikærgården

SURFACE	CLOSEST RAL COLOR CODE	REFLECTANCE (LRV) [%]
Floor (wood laminate)	RAL 1011 Brown Beige	25
Curtains (blue cloth)	RAL 7036 Platinum Grey	30
Walls (white matte paint)	RAL 9010 Pure white	84
Door to bathroom (wood veneer)	RAL 1011 Brown Beige	36

The room was equipped with nearly opaque indoor curtains at the window as shading devices. The curtains secure complete darkness in the room at night. The curtains were drawn closed while measurements of the electric lighting scenarios were undertaken.

2.2 Daylight Factor

The rooms have a window-to-wall ratio of approximately 25% and the daylight conditions in Aarhus are more often partially or fully overcast than sunny. The daylight factor (DF) is a useful indicator of daylight performance and expressed as the ratio of the indoor illuminance at a point to the outdoor horizontal illuminance under an unobstructed overcast sky. To determine the daylight factor of the room at several different points, the outdoor illuminance had to be continuously measured during the whole monitoring period under overcast sky conditions. It was measured at the highest accessible point of the roof of the building (Figure 2-11) by an Extech HD450 illuminance data logger. At the same time, indoor horizontal illuminance values from daylight were measured inside across a grid at 0.85 m height above the floor.

Figure 2-11 – Placement of the exterior illuminance data loggers on the roof

The average daylight factor that was measured on 04 March 2019 at around 17:00 under such an overcast sky was 1.4%, but it was 2.2% when simulated with DIALux. However, the simulation did not consider the exterior obstructions. Daylight in the room is sufficient for a person to read by the window, but further into the room, additional electric lighting will most likely be necessary, especially for the older users of the facility.

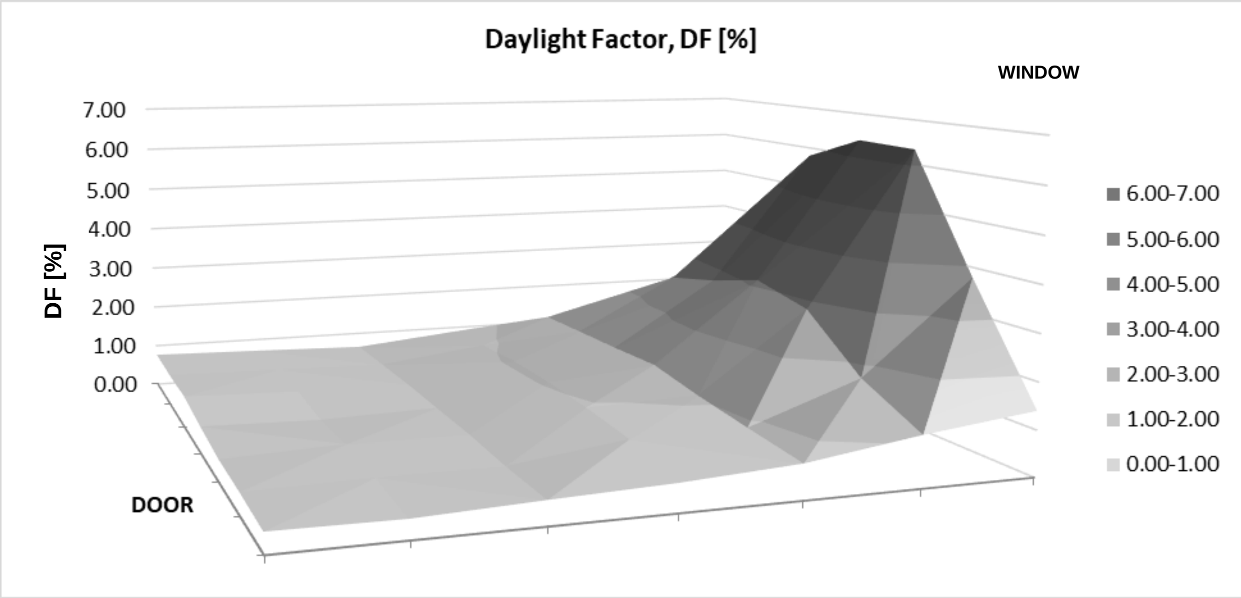


Figure 2-12 - The measured daylight factor (DF) at a height of 0.85 m in the entire room (average DF = 1.4%)

2.3 Electric Lighting System

In the CFL and LED patient suites, the light sources were different. The old system used compact fluorescent luminaires and the new installation used LED luminaires, both mounted below the ceiling. Specifications are shown in Table 2-2 and

Table 2-3. Some of the old luminaires where more difficult to specify, while the new LED system was specified in collaboration with a manufacturer.

The two electric lighting solutions (old CFL and new LED lighting system) were operated in different ways. The old CFL system was a turn ON/OFF system operated via a manual switch in each patient suite. In contrast, there were several options with the new LED lighting system. With the LED lighting system, it was possible to change illuminance levels and spectral distribution depending on time of day and activity. The electric lighting system was programed to follow a daily schedule for circadian lighting, so that the correlated color temperature (CCT) and spectrum were automatically changing over the course of the day. It was also possible to manually change the electric lighting via wall switches in the patient suite entry hall to three different settings, depending on the purpose. The three light settings were: light therapy, calming and night care as shown in Figure 2-13. The lighting conditions could be programed, controlled and changed via a central touchscreen, as illustrated in Figure 2-14.

Figure 2-13 - Different electric lighting scenarios that can be set in the patient bedroom. Left: “Old lighting system (CFL)”, left, middle: "light therapy", right, middle: "calming" and right: "night care".

Figure 2-14 - Touch panel for central electric lighting control

Table 2-2 - Luminaires installed in the patient bedrooms and bathrooms with the new installed LED lighting system

BEDROOM	
Round ceiling-mounted LED luminaire **Name: BASECARE Ambient CW-RGB 4000 K** **Light source:** LED **Luminous flux:** 4590 lm **CCT: 4000 K (1582-6793) K** **CRI (R_a):** 90 **Power:** 45 W **Efficacy:** 102 lm/W	
Linear LED wall washer **Name: Matric A3 CW-RGB 1835 mm** **Light Source:** LED **Luminous flux:** 4465 lm **CCT: 4000 K (1582-6793) K** **CRI (R_a):** 90 **Power: 40 W (4000 K)**	

Table 2-3 - Luminaires installed in the patient bedrooms and bathrooms with the old lighting system

BEDROOM	
Round ceiling-mounted CFL luminaire **Name: ENSTO AVR400.218** **Light source: Compact fluorescent** **Luminous flux:** 2400 lm **CCT: 2884 K** **CRI (R_a):** 83 **Power:** 36 W **Efficacy:** 66 lm/W	

2.4 Illuminance

2.4.1 Horizontal Illuminance

According to DS/EN 12464-1 - Light and lighting - Lighting of work places - Part 1: Indoor work places [5], 100 lux are needed in wards in healthcare 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 and 1000 lux for treatment. For reference, Table 1-3 includes the recommendations of DS/EN 12464-1 for illuminance levels in the wards of healthcare facilities.

The horizontal illuminance was measured across a 0.5 m x 0.5 m grid always located 0.85 m above floor level. Along the walls, a nearly 0.5 m wide zone was not included in the measurements. In the rooms with the old fluorescent luminaires, the average horizontal illuminance was 80 lux (median 71.3 lux), which was much less than the suggested 300 lux, indicating that residents might find it difficult to read and nurses might have problems providing care.

In the rooms with the dynamic LED lighting, the illuminance levels changed throughout the day and therefore it was not possible to measure each individual setting. Instead, three distinct scenarios were assessed, that can be selected through a switch panel on the wall (“light therapy”, “night care” and “calming”). With this wall switch panel, the patients and staff could override the dynamic daily schedule based on their preference or a specific need. For example, a nurse could select “light therapy” to achieve light levels necessary for an examination, or a patient could select “calming” lighting while watching TV at night. From the wall panel, the electric lighting could also be turned off. The average horizontal illuminance was 430 lux (median 446.2 lux) with the “light therapy” setting, which was well above the recommendation of 300 lux and aimed at activating patients’ alertness. With the “night care” and “calming” setting, the horizontal illuminance was less than 100 lux (on average 70 and 47 lux, median 73.9 and 48 lux respectively).

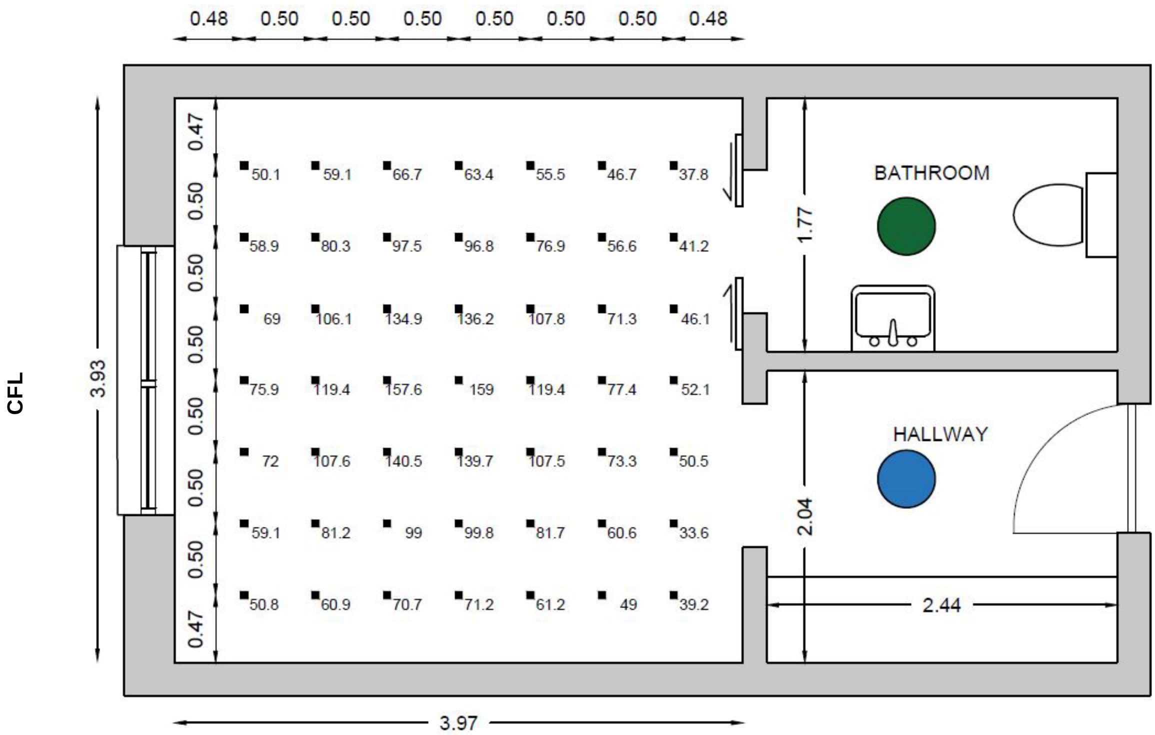


Figure 2-15 – The measured horizontal illuminance for the old CFL lighting system at a height of 0.85 m

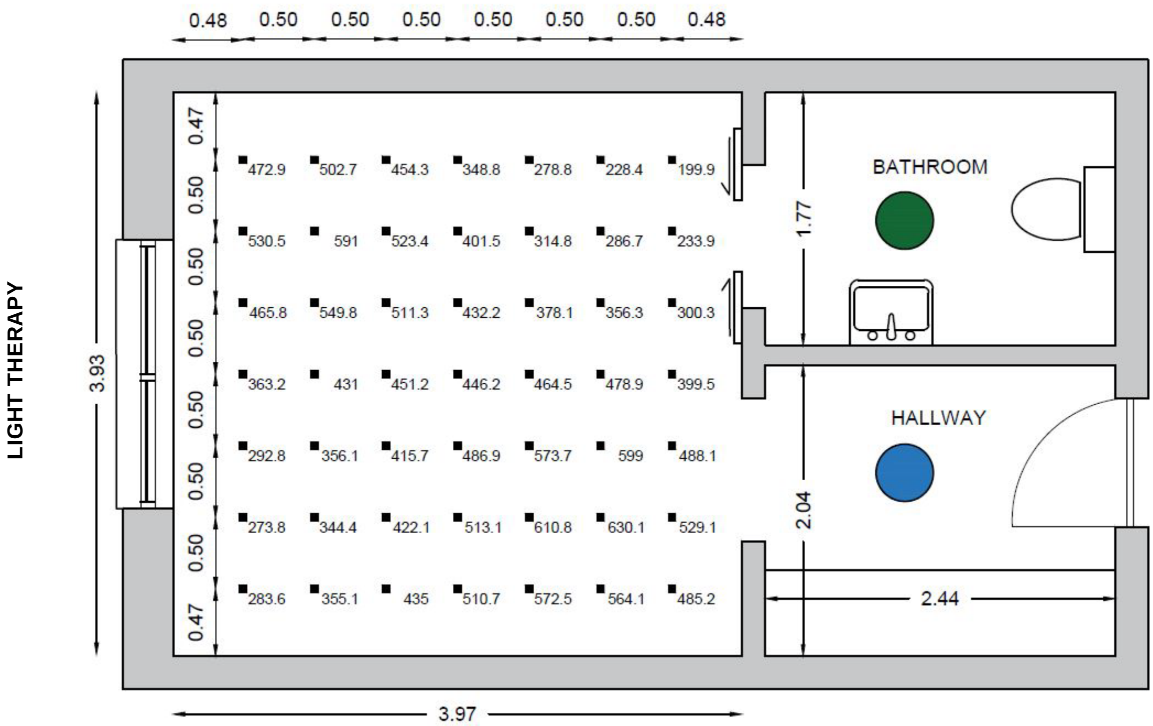


Figure 2-16 - The measured horizontal illuminance for “Light Therapy” at a height of 0.85 m

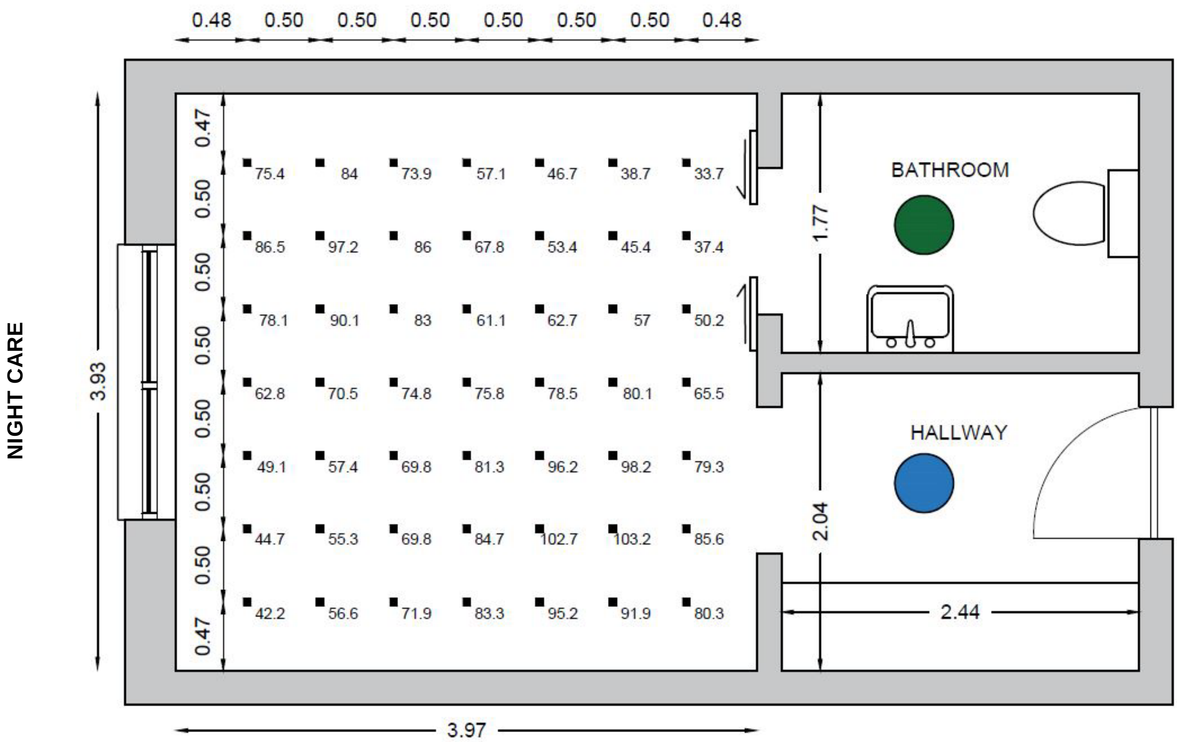


Figure 2-17 - The measured horizontal illuminance for “Night Care” lighting system at a height of 0.85 m

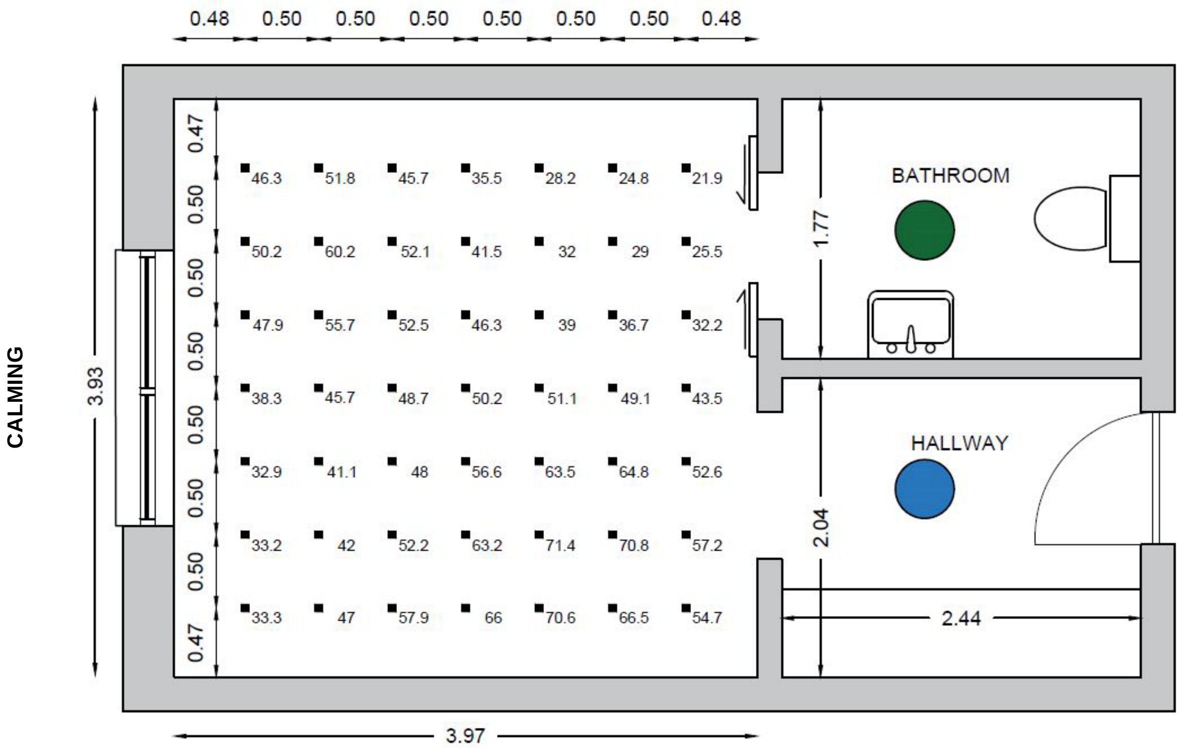


Figure 2-18 - The measured horizontal illuminance for “Calming” at a height of 0.85 m

Table 2-4 - Horizontal illuminance distributions for the four switchable lighting scenarios

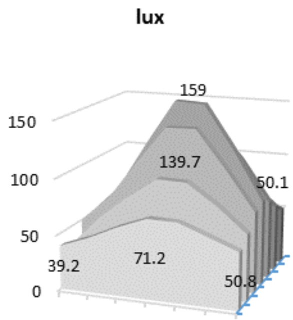
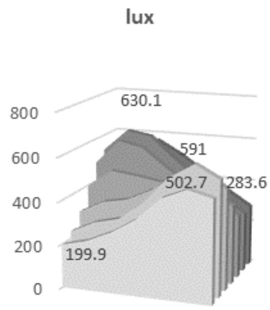
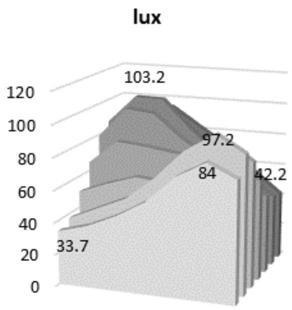
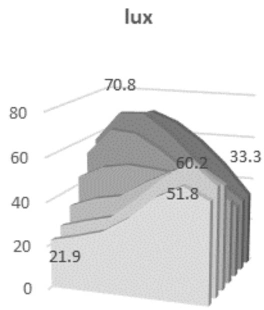
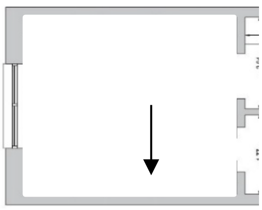
CFL	Light Therapy	Night Care	Calming
			
			

Table 2-5 - Summary of maximum, minimum and average values of the vertical illuminance measured for each switchable lighting scenario

Horizontal Illuminance [lux]				
Scenario	Min	Max	Average	Median
CFL	33.6	159	80.2	71.3
Light Therapy	199.9	630.1	431.4	446.2
Night Care	33.7	103.2	70.9	73.9
Calming	21.9	71.4	47.5	48

2.4.2 Vertical Illuminance on the Wall

Measurements of vertical illuminance were taken on the wall opposite from the bed where the TV is located, across a 0.5m x 0.5m grid. The vertical illuminance was meaningful for this case study because the patients in the facility spent a significant portion of their day in bed, facing that wall. It was therefore important to provide a uniform illumination and avoid possible visual discomfort sources. The initial installation of the dynamic LED system created a quite uneven illumination of that wall (from 0 to 700 lux with the “light therapy” setting), with a very bright patch of light on the part of the wall next to the luminaire. Therefore, the modification that was implemented to avoid this problem was 1) to move the luminaires further away of the wall and towards the center of the room and 2) to add a linear wall washer behind the TV. The purpose of the wall washer was to make TV watching in the evening more comfortable by decreasing glare and the contrast. At other times, the wall washer added a brighter surface, letting the whole room appear lighter. The final LED installation had a much more uniform vertical illumination on the wall. The distributions of the vertical illuminance for each of the three lighting scenarios and the case with the old CFL system are illustrated by Figure 2-19, Figure 2-20, Figure 2-21 and Figure 2-22. Here the vertical illuminance at each grid point is stated for the wall opposite from the bed.



CFL

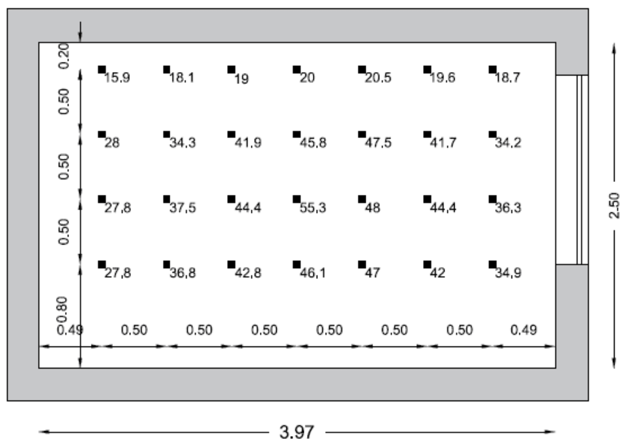


Figure 2-19 – Measured vertical illuminance at the wall opposite from the bed with the old lighting system.

NIGHT CARE

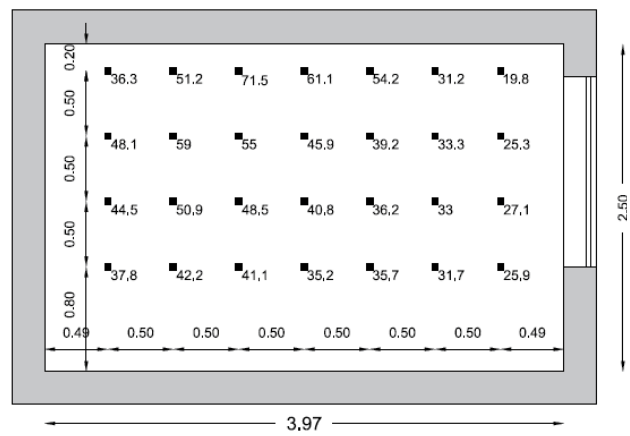


Figure 2-20 – Measured vertical illuminance at the wall opposite from the bed with the setting "Night Care".

CALM

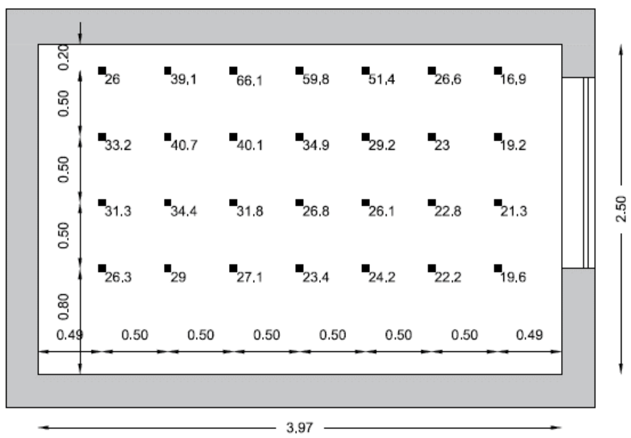


Figure 2-21 – Measured vertical illuminance at the wall opposite from the bed with the setting "Calming"

LIGHT THERAPY

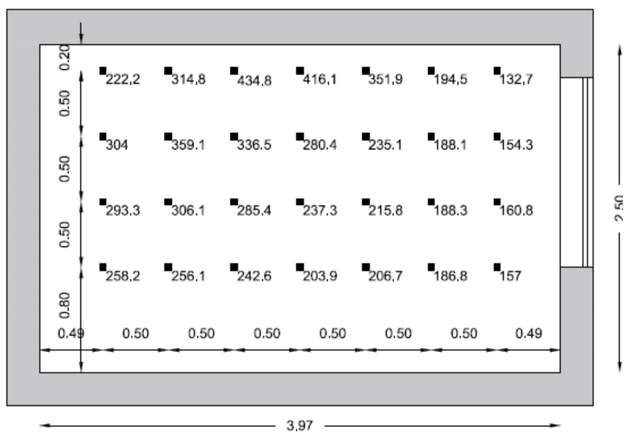


Figure 2-22 – Measured vertical illuminance at the wall opposite from the bed with the setting “Light Therapy”

The difference in vertical illuminance on the wall for the two cases – before and after modification described previously in Section 2.4.1- can be seen in Table 2-6 .The values are given for both the case before (CFL) and after the modification of the lighting system.

Table 2-6 - Summary of maximum, minimum, median and average for the vertical illuminance measured for each lighting scenario

Vertical Illuminance [lux]				
Scenario	**Min**	**Max**	**Average**	**Median**
CFL	15.9	55.3	36.4	36.9
Light Therapy	119.2	434.8	244.0	235.1
Night Care	19.8	71.5	40.3	39.3
Calming	14.6	66.1	28.8	26.7

2.5 Luminance and Glare

Luminance (cd/m^2) is the absolute brightness of direct or reflected light emitted in the direction of an observer by a surface or a light source. Therefore, assessing the luminance distribution from the perspective of a patient or staff member makes sense. For this purpose, a calibrated Canon EOS 60D DSLR camera with a 180-degree fisheye lens was used. The images were taken from four positions in the room for the four different lighting scenarios: CFL lighting, light therapy, night care and calming light. The four different positions of the camera are shown in

Figure 2-23. The positions are in two of the corners, in front of the TV facing the bed and at the bed facing the TV.

A way of evaluating potential glare issues under electric lighting conditions is via the Unified Glare Rating (UGR), which is an index of discomfort related to the experience of glare. According to DS/EN 12464-1 [5], the UGR in the wards of health care facilities should be below 19 for general lighting, reading lighting, and examinations. Only the electric lighting can be assessed with UGR, therefore the curtains were shut during the luminance mapping procedures.

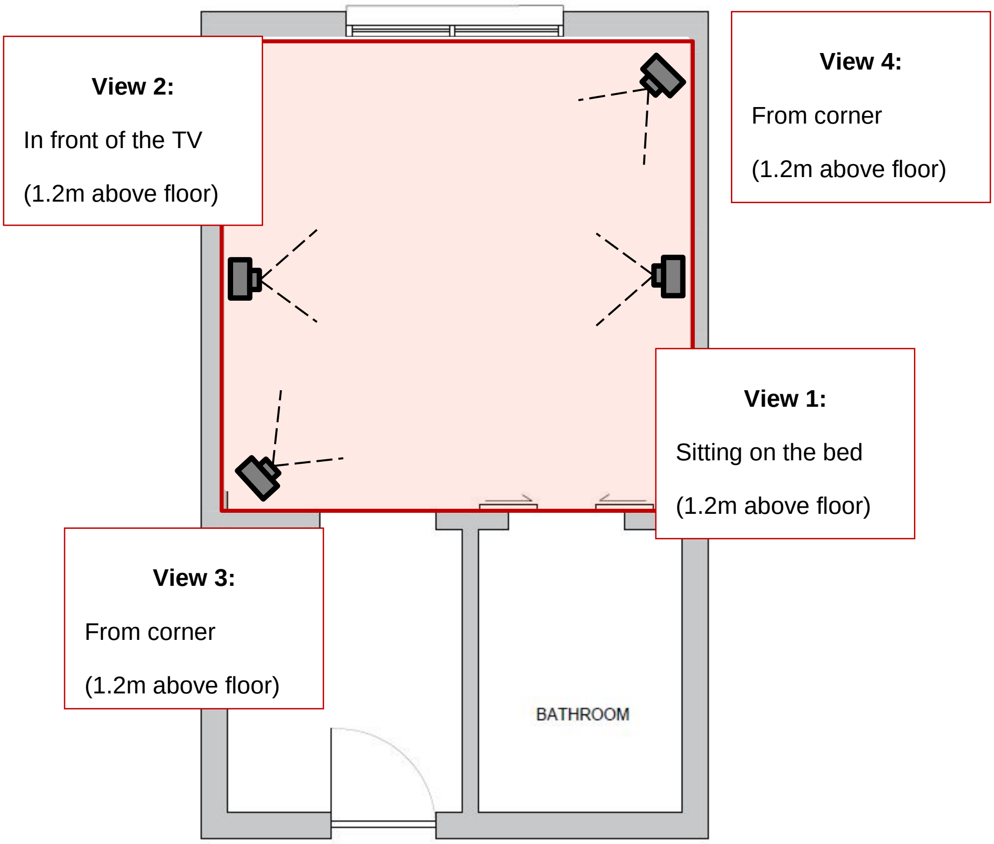
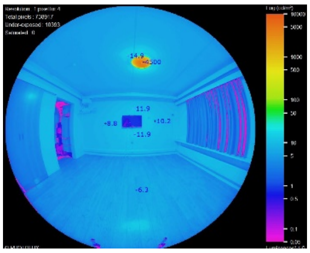
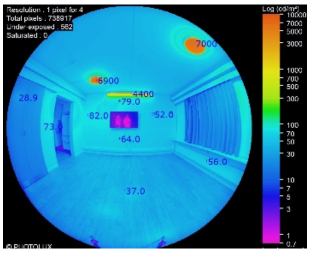
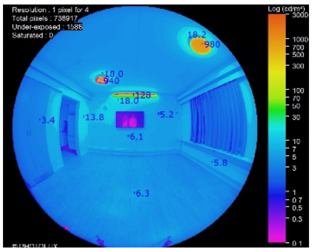
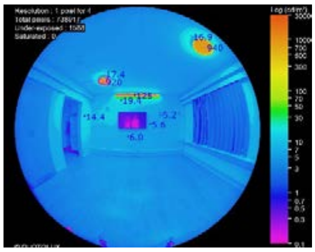


Figure 2-23 - Floorplan of the room showing the camera positions

A set of luminance maps created from the images taken from the bed view is shown in Table 2-7. The position of the camera was the same as that a person sitting on the bed (height 1.2m) would have experienced. The luminance maps were used for detecting any potential glare issues related to the current lighting installations. The luminance maps generated from the other viewpoints can be seen in Appendix A. All luminance maps were generated from HDR images with a program called “Photolux”.

Table 2-7 - The four different lighting scenarios and with their luminance maps and UGR values

CFL LIGHTING	LIGHT THERAPY	NIGHT CARE	CALM
			
			
UGR: 18.3	**UGR: 18.5**	**UGR: 10.8**	**UGR: 10.8**

2.6 Spectral Information

The spectral power distribution (SPD) of the two electric light settings was measured by a spectrophotometer (Konica Minolta CL-500A), right below the two different light sources – the ceiling luminaire and the wall washer, as described in Table 2-2. The measurements included information about the Correlated Color Temperature (CCT) and the Color Rendering Index (R_a). The CCT indicates if the light appears "warm or cold" to the observers, and the R_a indicates how well a person can likely identify 8 standard reference colors under the light source. The graphs below show the SPD, CCT and R_a measured below the ceiling luminaire. Similar values were obtained from the wall washer as well. When viewed from the four observer viewpoints, the resulting spectrum at an observer's eye would be slightly modified by the reflectance properties of the room surfaces.

Table 2-8 - The four different lighting scenarios and measured spectral power distributions (SPDs) for each of them

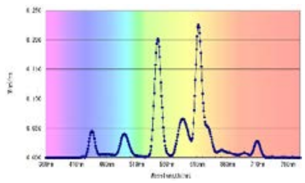
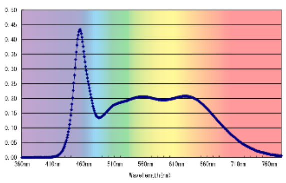
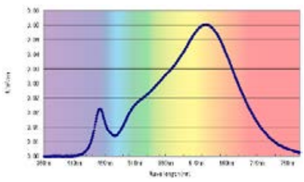
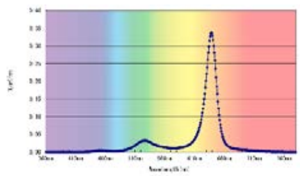
CFL LIGHTING	LIGHT THERAPY	NIGHT CARE	CALM
			
			

Table 2-8 shows that settings which at increasing alertness (like the “light therapy”), have a larger short-wavelength component (towards the blue side of the spectrum). In contrast, the settings which aim at creating a calming environment, occupy a larger part of the long-wavelength part of the spectrum (red side of the spectrum, like the “calming” and “night care” settings). The changing SPDs of the daily schedule used with the dynamic LED lighting contained therefore more blue light in the morning and more red light in the evening.

Similarly, the correlated color temperature (CCT) followed a daily schedule that features cooler light in the morning and after lunch (to provide an afternoon boost) and moved towards warmer values in the evening (See Figure 2-24). The daily schedule was running when none of the manual scenarios were used in the patient rooms. Continuous spectral measurements were not performed, but the schedule is illustrated here to indicate how the correlated color temperature was changing over the day.

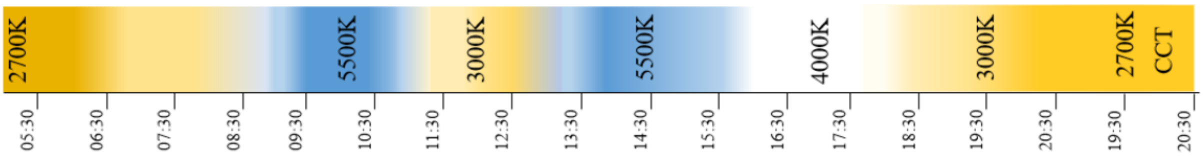


Figure 2-24 – The daily schedule for CCT implemented at Vikærgården.

2.7 Circadian Potential

When there is access to spectral information, it is possible to assess whether a specific lighting condition contributes with sufficient spectrum and intensity to stimulate the photoreceptors of the residents to absorb appropriate amounts of light at the appropriate time [11]. The circadian potential was evaluated for this project by using two circadian metrics: Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) and Circadian Stimulus (CS). The two circadian metrics are the current state-of-the-art metrics for this purpose. Both are calculated using the SPDs as input in their own purpose-made Excel spreadsheets. M-EDI indicates the melanopic illuminance received at the eye [12] and is calculated via a toolbox developed by the CIE [13]. Circadian Stimulus (CS) is the effectiveness in suppressing the nocturnal melatonin production of the spectrally weighted irradiance of the lighting condition at the cornea of the eye from threshold (CS = 0.1) to saturation (CS = 0.7). CS is calculated via a spreadsheet developed by the Lighting Research Institute (LRI) [14]. While these are fairly new metrics and experience with them is still limited, some initial recommendations exist.

As stated above, the WELL Building Standard v2 has published recommendations for M-EDI values. To obtain good circadian conditions for increasing alertness and suppressing melatonin production, the WELLv2 standard recommends a M-EDI of 218 lux at eye level for a good target between 9:00-13:00 [10]. Regarding CS, values between 0.1 and 0.7 show an influence on the circadian system. In the evenings and at night, CS should thus be kept below 0.1. At times, when melatonin production should be suppressed in order to increase alertness, a value between 0.3 and 0.4 is proposed. The results for CS and EDI can be seen in Figure 2-26 and Figure 2-27 with reference to the defined target zones and limits provided in the literature.

The measurements of the SPDs were conducted individually right below the 2 different types of luminaires. This kind of measurement does not give clear results for the metrics, as it is not the light that reaches the eyes. The lux levels are measured too high in comparison to what the lux levels would be in a height of 1.2 m above the floor (positions of a person sitting in bed). To obtain more realistic results for the circadian potential measured at the eye of an observer, a vertical illuminance (E_v) is simulated by using DIALux. The vertical point is placed at a height of 1.2 m above the floor, at the position of the bed and facing the television on the opposite wall as illustrated by Figure 2-25. Then the ratio between E_v for the 4 lighting scenarios (CFL is simulated and calculated as well) and the measured vertical illuminance for the ceiling luminaires ($E_{v,e,\ Ceiling\ luminaire}$) is calculated.

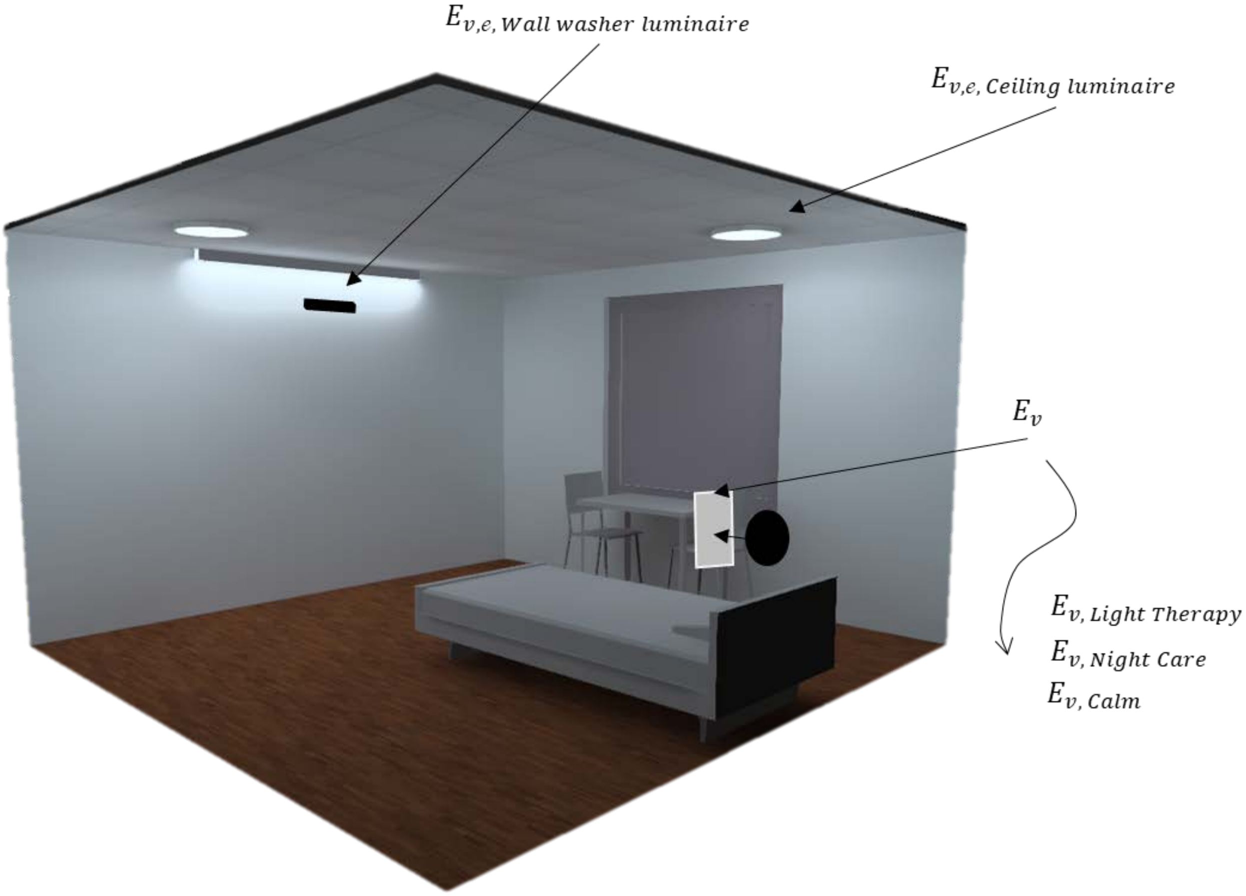


Figure 2-25 – Illustration of the new lighting system installed at Vikærgården. Here the terms used for the calculations of the ratio between the measurements and simulations are stated. Ev indicates the position of a person sitting in bed. It is only the new lighting system, which is illustrated, but the simulations and calculations are done for the old system as well.

The calculation of the ratios between the measurements and the simulations are given by equation [1]:

$$Ratio_{Light\ Therapy} = \frac{E_{v,\ Light\ Therapy}}{E_{v,e\ \ ceiling\ luminaire}},\quad Ratio_{Night\ Care} = \frac{E_{v,\ Night\ Care}}{E_{v,e\ \ ceiling\ luminiare}},\quad Ratio_{Calming} = \frac{E_{v,\ Calming}}{E_{v,e\ \ ceiling\ luminaire}} \qquad [1]$$

Then, the spectral measurements were multiplied by the ratio, to transform the spectral information to the situation of the observer.

The vertical point defined in DIALux was used for calculation of the two circadian metrics. The results of CS are shown in Figure 2-26 and results of M-EDI in Figure 2-27. CS is split to two zones – the evening target zone and the daytime target zone. This metric is included because it is possible to see if an evening/night situation reaches the target zone. This is not possible with M-EDI now. Calculated M-EDI is only compared with the target zones for “good” and “ok” between 9:00-13:00.

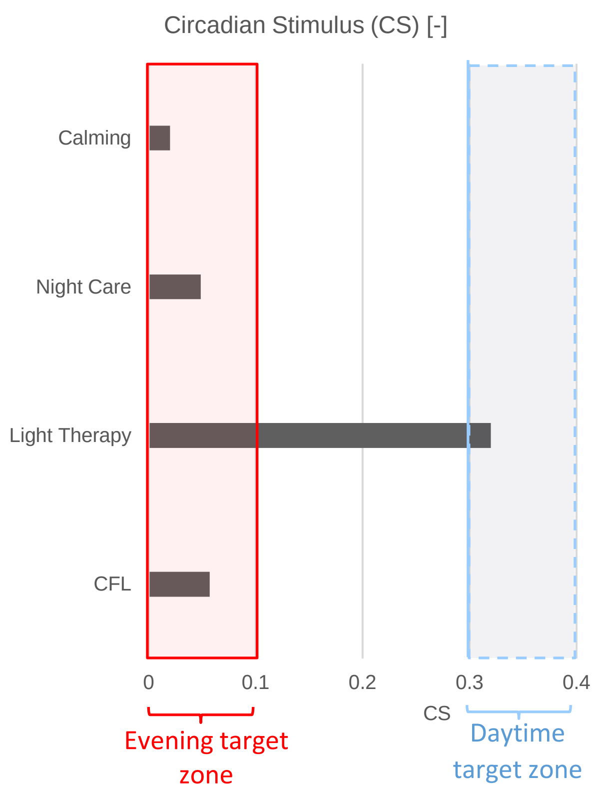


Figure 2-26 – Circadian Stimulus (CS) calculated for a vertical illuminance simulated by DIALux at a height of 1.2 m above the floor for the four lighting scenarios illustrated in Figure 2-13. The target zones refer to the recommendations of the Lighting Research Institute [14]

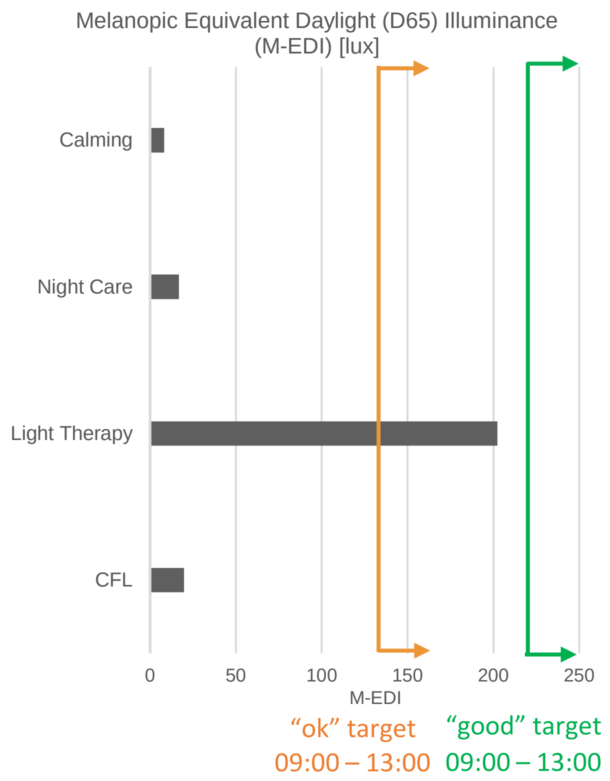


Figure 2-27 - Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) calculated by CIE Toolbox for a vertical illuminance simulated by DIALux at a height of 1.2 m above the floor for the four lighting scenarios illustrated in Figure 2-13. The target limits for "ok" and "good" refer to the recommendations of the WELL building standard v2 [10]

The results showed low values for both CS (0.02 for "calming" and 0.05 for "night care") and M-EDI (8.2 lux for "calming" and 17 lux for "Night Light") in Figure 2-26 and Figure 2-27. This makes sense for the purpose of these two settings, as they want the patients to be more relaxed and to fall asleep easier. Both CS (0.32) and M-EDI (202.3 lux) was calculated as being higher for the light therapy, which suits the purpose of the lighting scenario, as the patients should get a mood boost and get more energetic. The therapy light did not fulfil the recommendations for "good" target from WELLv2 of 218 lux M-EDI, but reaches the "ok target" of 136 lux M-EDI.

2.8 Opinion of Staff

The working group conducted a series of structured interviews with thirteen members of the medical staff at Vikærgården to evaluate how they perceived the electric lighting system operation and resulting lighting conditions, as well as the impact of the lighting system on their work and their patients. A questionnaire guide with a series of predefined questions was used. The more informal atmosphere of the semi-structured interview procedure also allowed for staff members to add additional comments they felt were important. They were encouraged to discuss and share their thoughts without being restricted in their responses by the interview guide.

The interviewees' answers and personal comments were recorded and later transcribed for analysis in an Excel sheet. The interview guide was structured into the following sections:

- **Personal Information**
- **Light Settings and Operation**
- **Visual Experience**
- **Perceived Effect of Circadian Lighting on Staff**
- **Perceived Effect of Circadian Lighting on Patients**
- **Emotional Effect**
- **Instruction and Implementation**

A more detailed description of each categories can be seen in Table 1-2.

2.8.1 Personal Information: Age, Gender and Occupation

Seven of the interviewees were working in the ward where the circadian lighting is established and six in the ward with the old lighting system. Their work schedule was divided into day, evening and night shift. Their shifts, age, gender and occupation are included in Table 2-9.

Table 2-9 - Overview of the interviewees´ working schedule

Circadian Lighting Ward							
	A1	A2	A3	A4	A5	A6	A7
Day shift	x		x		x		
Evening shift	x		x	x	x		
Night shift		x				x	x
Age	30-39	30-39	30-39	20-29	30-39	50-59	40-49
Gender	Female	Female	Female	Female	Female	Female	Male
Occupation	nurse	social and health assistant	social and health assistant	social and health assistant	nurse	nurse	social and health assistant
Fluorescent Lighting Ward							
	B1	B2	B3	B4	B5	B6	
Day shift	x	x	x		x		
Evening shift	x	x	x		x		
Night shift				x		x	
Age	>60	>60	20-29	50-59	30-39	20-29	
Gender	Female	Female	Female	Female	Female	Female	
Occupation	social and health assistant	nurse	nurse	social and health assistant	social and health assistant	social and health assistant	

As one can see in the table, the employees worked either night shift or a combination of day and evening shift. During the interviews, each participant evaluated only the lighting conditions that correspond to the shifts they have.

2.8.2 Light Settings and Operation

A. <u>Circadian lighting ward</u>

The staff members used the electric lighting settings, mostly from the individual room switch and some of them also from switches in the common spaces or the touch screen in the staff room. Most of them had an idea why circadian lighting was established in the ward, mentioning reasons such as better sleep for employees and occupants and increased calmness. The interviewees indicated that some or most of the patients found it confusing to operate the lighting, which might be due to the difficulty of understanding the controls or the patients' cognitive abilities.

B. <u>Fluorescent lighting ward</u>

Most of the staff members indicated that they did not use the electric lighting settings (there was only an on/off choice in this ward). Four of them said that some of most of the patients could figure out how to operate the lighting, one staff member said that all the patients could figure it out and another said that no one could. The difficulty of the control here seemed to be that the patients could often not leave their bed and the switch was too far away from it.

2.8.3 Visual experience

A. <u>Circadian Lighting Ward</u>

The distribution of light was perceived as comfortable by most of the interview participants, with the exception of a person who said that it was perceived as annoying and another person who said that it was comfortable during the day but annoying during the evening. Three out of seven people said that they experienced glare from the electric lighting in the following situations: during the night when going from the ward with the circadian lighting to the ward with the old CFL lighting system, in the morning when the sharp morning light turned on, or generally sometimes during the morning.

The following graphs show the opinion of the interviewees about how appropriate the lighting was for each room together with the comments of the people who thought it was not appropriate.

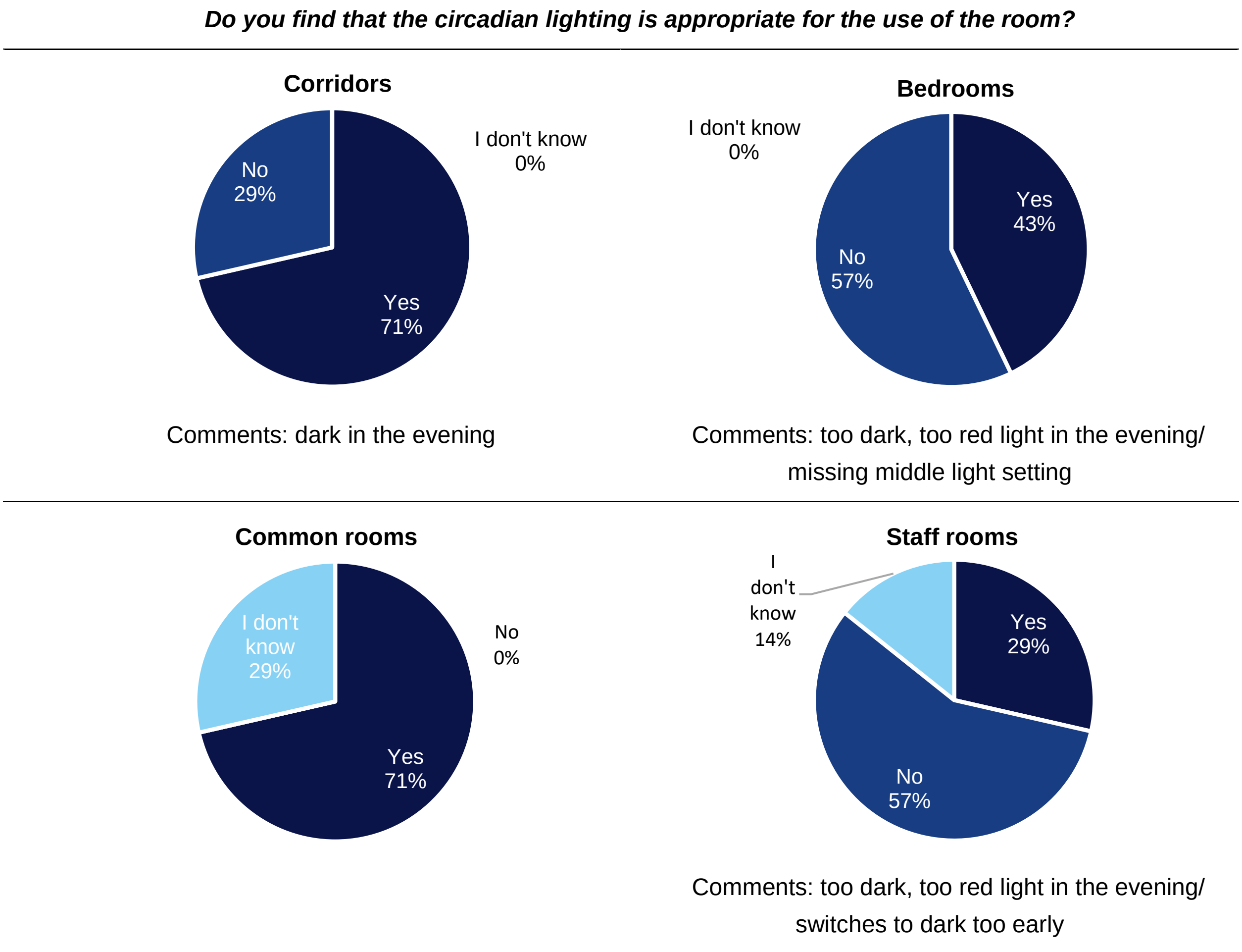


Figure 2-28 – Staff assessment of the appropriateness of the circadian lighting system for different rooms in their facility

Nobody thought that the light felt too warm. One person thought that the light felt too cold in the morning in the staff room and another person said that it felt too cold when the “light therapy” setting was turned on at night.

The participants were also asked about their ability to work easily under the electric lighting. During the day, they all agreed to a high degree that they could recognize color, see the patients, see the PC/TV screen, read, write and perform their work tasks. They also agreed to high or some degree that the lighting was comfortable to stay in.

During the evening, half of the results changed from “high” degree to “some” or “small” degree with respect to color recognition, ability to see the patients, ability to read, write and perform work tasks, ability to see the PC/TV screen and their comfort. This indicated at least some level of difficulty to perform visual tasks.

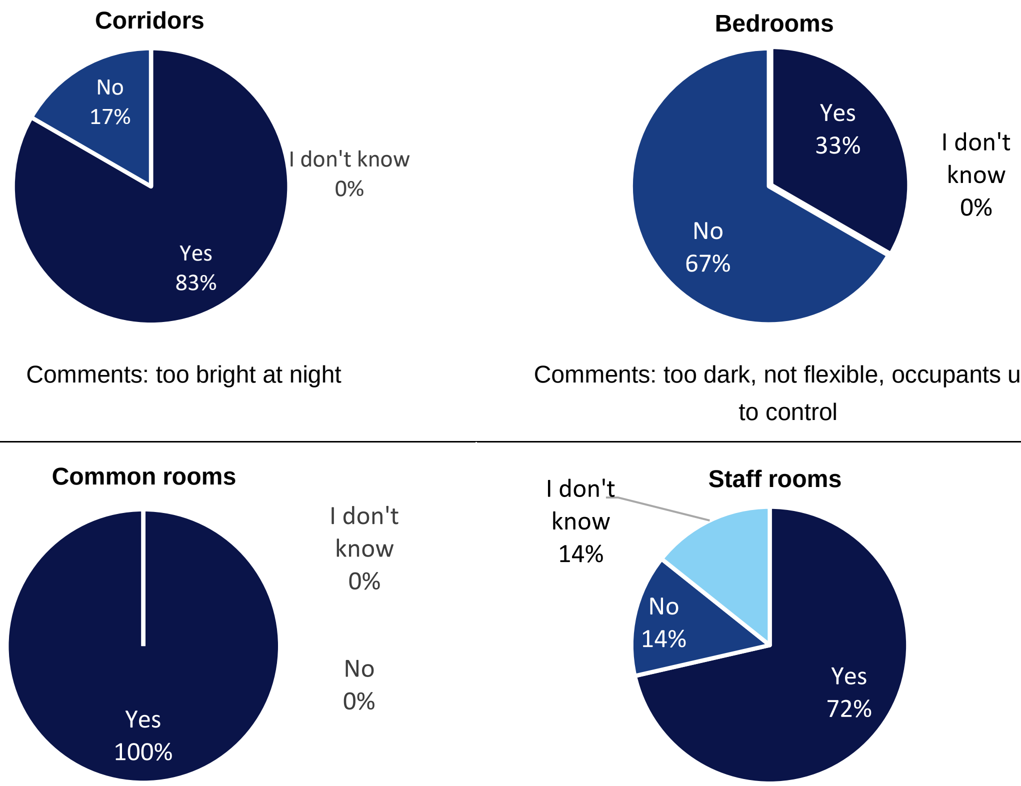
During the night, their visual ability results were like the afternoon ones. However, they all said that the light was comfortable to stay in at night to a high degree.

B. Fluorescent Lighting Ward

The distribution of light was perceived as comfortable or very comfortable by four out of six interviewees. Two of them said it was perceived as annoying, mentioning that it could be too dark and that there might not have been enough light for nursing tasks. Nobody perceived any glare from the electric lighting.

The following graphs show the opinion of the interviewees about how appropriate the lighting was for each room together with the complaints of the people who thought it was not appropriate.

Do you find that the lighting is appropriate for the use of the room?



Comments: too bright at night

Comments: too dark, not flexible, occupants unable to control

Comments: table lamps are nice

Figure 2-29 - Staff assessment of the appropriateness of the lighting system for different rooms in their facility

Two people thought that sometimes the light felt too warm. Also, two people thought that sometimes the light felt too cold, specifically in the evening.

The participants were also asked about their ability to work easily under the electric light. During the day, they all agreed to a high degree that they could recognize color, see the patients, see the PC/TV screen, read, write and perform their work tasks. They also agreed to a high or some degree that the light was comfortable to stay in.

During the evening, half of the results changed from “high” degree to “some” or “small” degree regarding color recognition, ability to see the patients, ability to read, write and perform work tasks. Their ability to see the PC/TV screen remained “high”. Regarding comfort, three of them said that it was to some degree comfortable and one answered that it was comfortable to a small degree.

The results for night lighting are only based on two interviews. During the night, the two interviewees said that they could see colors to some or a small degree, that they could see the patients to a small degree (and one “I don’t know”), that they could read and write to some degree or not at all, and that they could see the PC/TV screen to some degree. They said that the lighting was comfortable to stay in at a high or some degree.

The participants were asked to what extent they experienced that the lighting had a positive effect on them in relation to sleep quality, calmness in the ward, energy levels, voice volume when speaking, physical well-being and security. The ward with the circadian lighting was rated more positively compared to the ward with the old fluorescent lighting, to small or large extend, in all the topics.

A. Circadian Lighting Ward

The opinions of the staff regarding effect the circadian light had on them were mixed. Many of the participants answered that the light had a positive effect on them to a “high” or “some” degree in relation to good sleep quality, calmness in the ward, lower voice volume and better physical well-being. Their detailed answers are presented in the following graphs.

To what extent have you experienced that the circadian lighting has a positive effect on you in relation to

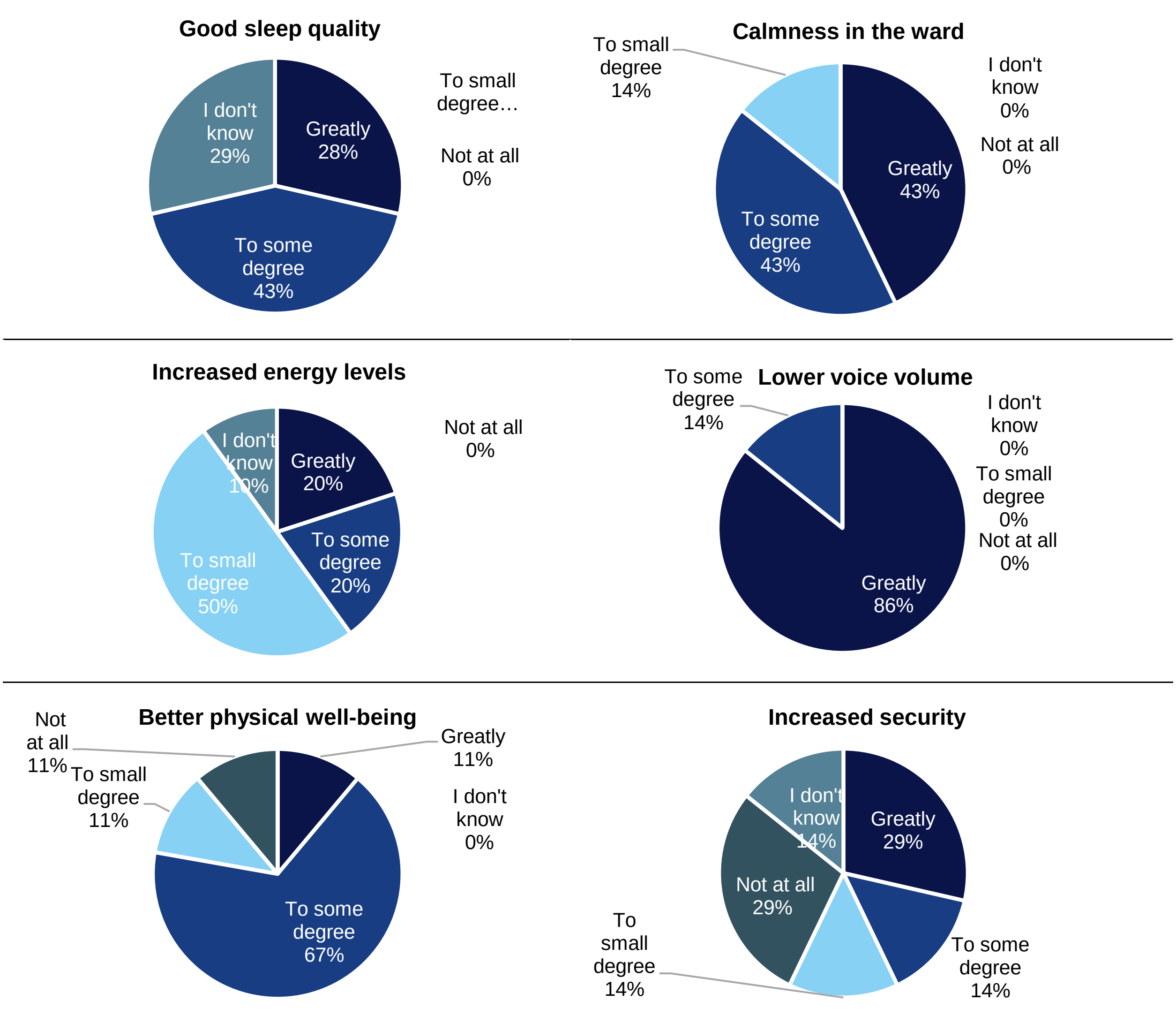


Figure 2-30 - Indications of staff on the experience of perceived positive effects of the circadian lighting on them

B. Fluorescent Lighting Ward

The opinions of the staff regarding effect of the circadian lighting on them were mixed. Their detailed answers are presented in the following graphs.

To what extent have you experienced that the lighting has a positive effect on you in relation to

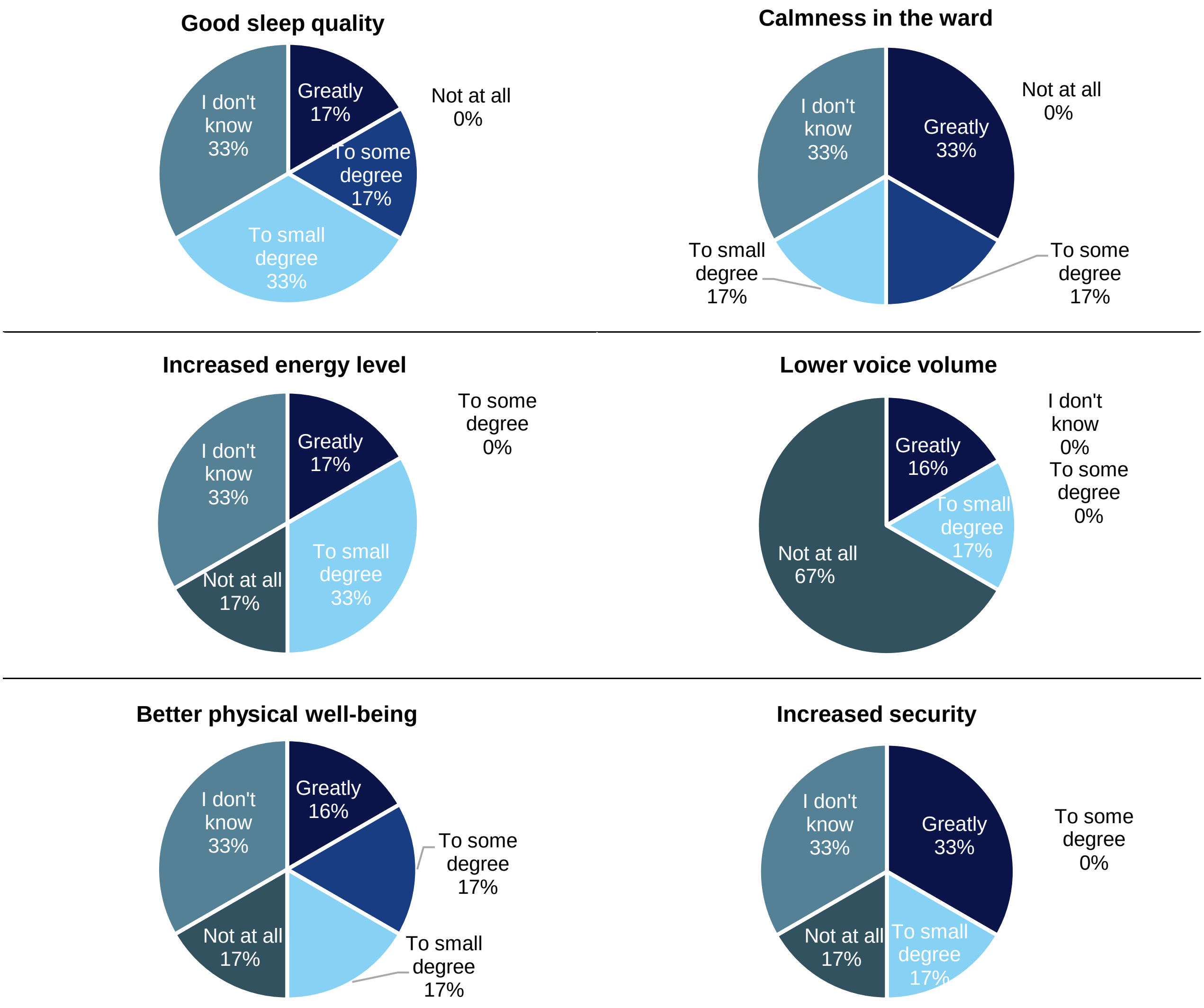


Figure 2-31 - Indications of staff on the experience of perceived positive effects of the lighting on them

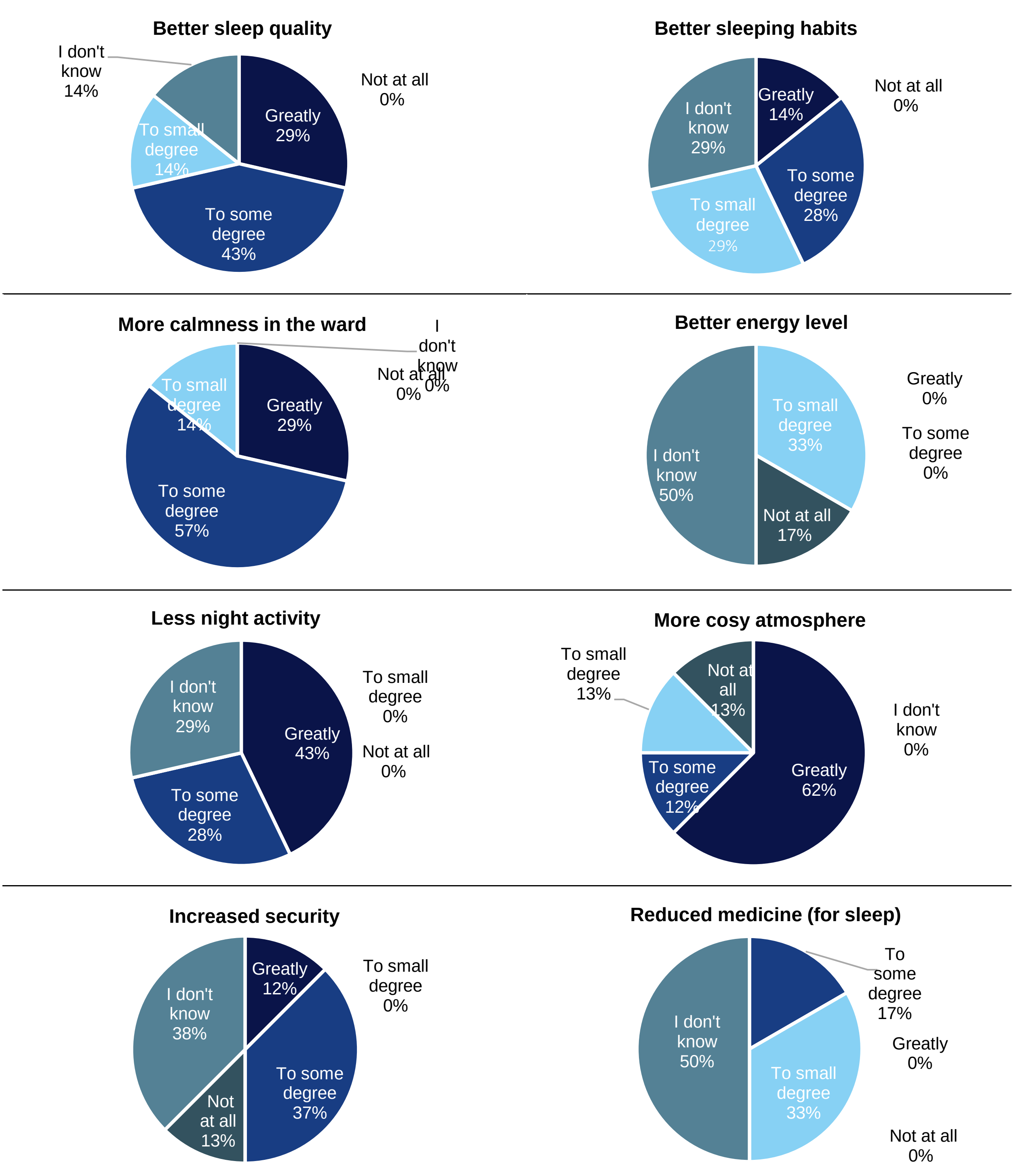
2.8.4 Perceived Effect of Circadian Lighting on Patients

The participants were asked to what extent they experienced that the lighting had a positive effect on the patients' experience. The ward with the circadian lighting was rated more positively in relation to calmness in the ward and a feeling of a cozier atmosphere. The ward with the old fluorescent lighting was rated more positively in relation to increased feeling of security. For the rest of the questions, it was not that easy to judge which ward was rated more positively.

A. Circadian Lighting Ward

In relation to sleep quality and sleeping habits, the participants' answers were divided. They mostly agreed (to "high" or "some" degree) that the circadian lighting ward was experienced by the patients as calmer and cozier and that it resulted in less night activity. In relation to patients' energy levels, one third of the participants answered, "to a small degree" and the rest "not at all" or "I don't know". In relation to medicine use, half of them reported a reduction in medicine for sleep and one third of them reported a reduction in medicine for other purposes to "some" or a "small" degree. The rest of them responded "I don't know" and one of them commented that their impression was that the medicine use was constant in all the wards. Two thirds of them thought that the patients received a better quality of treatment to some degree. Their detailed answers are presented in the following graphs.

To what extent have you experienced that the circadian lighting has a positive effect on the patients in relation to



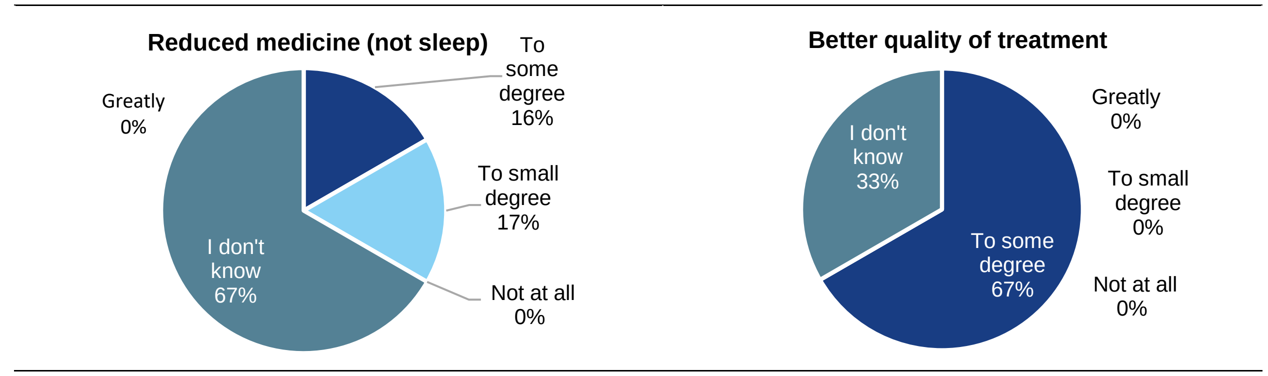
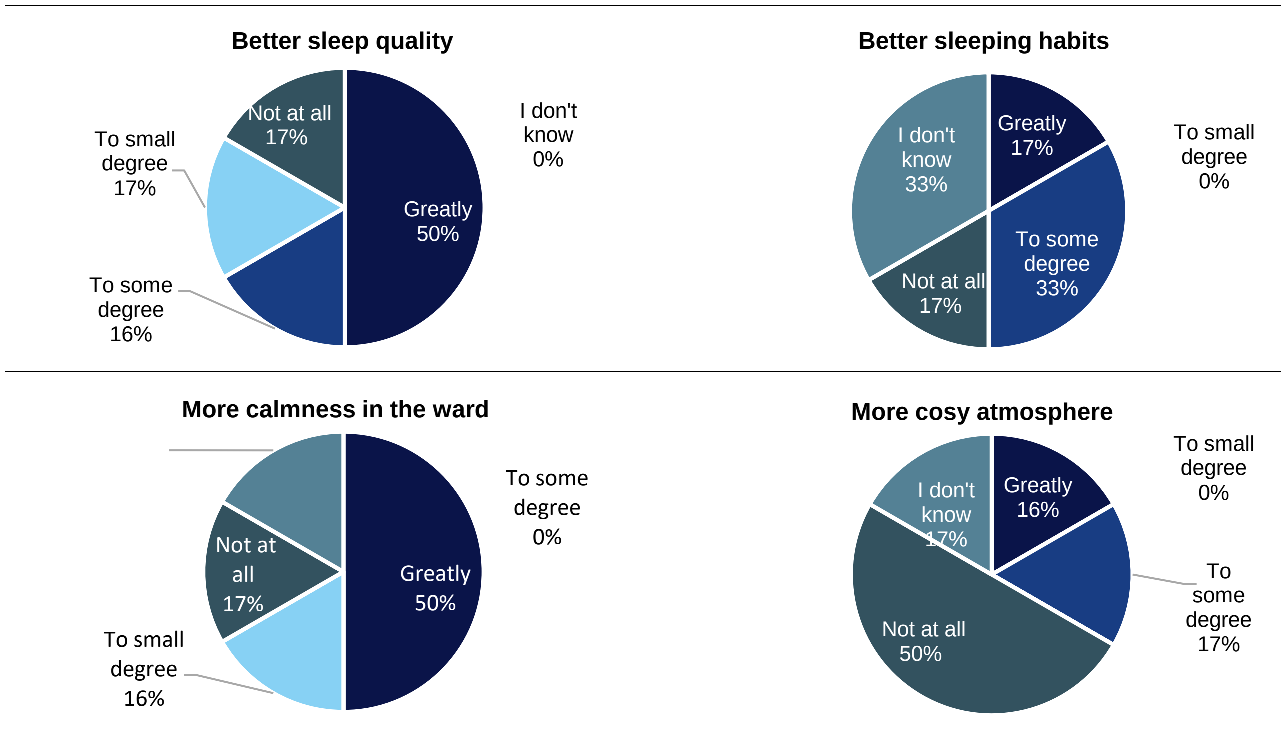


Figure 2-32 - Indications of staff on the experience of perceived positive effects of the circadian lighting on patients

B. <u>Fluorescent Lighting Ward</u>

Half of the interviewees responded that the patients had a better sleeping quality and that they experienced a calmer ward to a high degree. In relation to sleeping habits, the participants' answers were divided. Half of them thought the patients did not experience a cozy atmosphere (not at all), but all of them thought that the security was increased (too high or some degree). Their detailed answers are presented in the following graphs.

To what extent have you experienced that the lighting has a positive effect on the patients in relation to



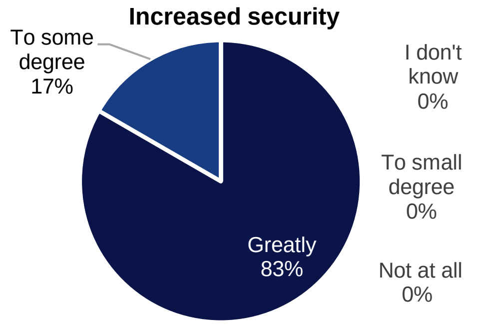


Figure 2-33 - Indications of staff on the experience of perceived positive effects of the lighting on patients

2.8.5 Emotional Effect

The interviewees were asked if they thought that the light had a positive or negative impact on them and how they experienced the evening and night lighting. When comparing the answers for the two wards, there was not a big difference, except a small tendency for a slightly more positive rating for the evening lighting in the circadian lighting ward.

A. <u>Circadian Lighting Ward</u>

Regarding the emotional effect of the lighting installation, most of them thought that it had a positive influence (from small to high degree) and some mentioned that it felt nice to be in the ward and that they slept better. However, some thought that the emotional effect was negative at night because it felt too dark and that the lighting switched to a dark setting too early.

Their view of the evening light was that it was soothing (from a small to a high degree), created a calm atmosphere (to some or high degree), influenced them to talk more quietly (from a small to a high degree) and experienced that the eyes could easily get used to it (from small to high degree). In relation to feeling fresh and being able to fall asleep easily after the evening shift, their answers were mixed with some replying “I don’t know” and some agreeing to it from a small to a high degree. In relation to the patients’ experience with the lighting, the general impression was that some people liked it, and some did not.

Their view of the night light was that it was soothing (to high degree), created a calm atmosphere (to a high degree), influenced them to talk with a lower volume (to some or a high degree) and experienced that the eyes could easily get used to it (to some or a high degree). They did not feel fresh after the night shift (not at all, or they did not know) and they mostly did not know if they felt asleep more easily after it.

In relation to patients’ experience with the evening and night lighting, the general impression was that some people liked it, and some did not. Some mentioned that patients have some difficulties with operating the lighting controls.

Most of them agreed that the lighting made sense for their everyday activities, but a few said that the night settings did not make sense because it was too dark. They would all recommend it to others because they thought it was better for their sleep quality, cozier and helped patients calm down in the evening. They were generally very positive about the daytime lighting settings with some concerns for the evening and night settings.

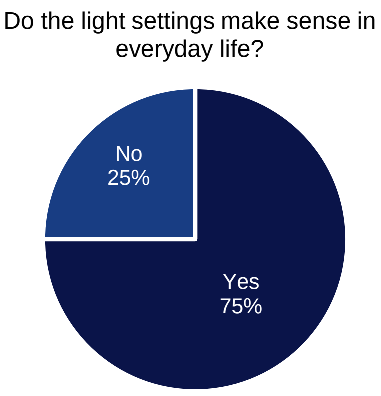


Figure 2-34 – Staff response to whether the circadian light settings made sense in their everyday life

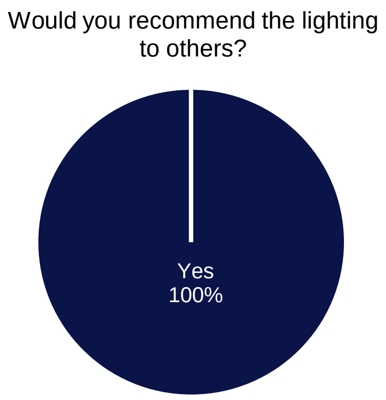


Figure 2-35 - Staff response to whether they would recommend the circadian lighting system to someone else

B. <u>Fluorescent Lighting Ward</u>

Regarding the emotional effects of the lighting installation, two thirds of the interviewees said that the influence of the lighting was positive to some or a high degree. One person said that there was no influence and mentioned that it was difficult to relax at home after returning from the evening shift.

Their view of the evening lighting was mixed. One of the interviewees was very negative towards the evening lighting, replying “not at all” to all the questions about it. The rest (three people) thought it was soothing and created a calm atmosphere (too a small or some degree) and influenced them to talk more quietly (to some degree). Most of them did not feel fresh after the evening shift. Their answers were mixed about being able to sleep easily after the evening shift, with some replying “not at all” and one replying “to a high degree”.

The view of the two interviewed people working the night shift was that the night lighting was soothing and created a calm atmosphere (to a high degree). They disagreed about whether the lighting influenced them to talk with a lower volume (one answered, “to high degree” and one “not at all”) and about feeling fresh after the night shift (one answered “to small degree” and one “not at all”). Moreover, they said that they could fall asleep easily after the night shift to a small or high degree.

We should mention here that there was no difference in the light settings between evening and night lighting. The only difference was which shifts the interviewees were working. Those who were working the evening shifts evaluated the evening lighting and the people who were working the night shifts evaluated the night lighting.

In relation to the patients’ experience with the evening and night lighting, two thirds of the interviewees said that they were ok with the lighting and nobody complained about it, but one third said that there are some problems.

A bit more than half of the interviewees agreed that the lighting made sense for their everyday activities, mentioning that it was easy to control because the light only turns on and off. The people who disagreed with that said that there was not enough light for nursing activities and there was need for more functions. Some of them would recommend this system to others and some would not.

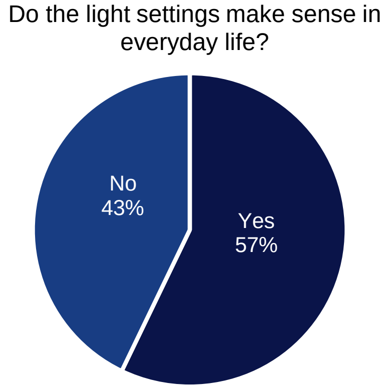


Figure 2-36 - Staff response to whether the CFL light settings made sense in their everyday life

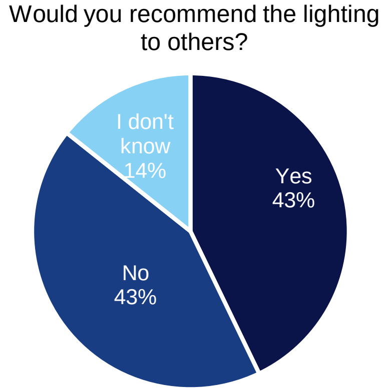


Figure 2-37 - Staff response to whether they would recommend the CFL lighting system to someone else

2.8.6 Teaching and implementation

A. <u>Circadian Lighting Ward</u>

Some of the staff members received instructions about how to use the lighting settings and some did not. The ones who received the instructions were satisfied or very satisfied with them and the ones who did not receive such instruction were dissatisfied or very dissatisfied about it. The facility had a user manual about the operation of the lighting, but nobody mentioned using it. Half of them felt sure about knowing and understanding the functions of the lighting control.

Half of them mentioned that they had daily challenges when using the lighting. Their challenges were related to control from the touch screen and the light turning on too bright when a person would select the “light therapy” or the “night care” setting. Nobody mentioned maintenance problems or challenges in emergency situations. One mentioned that in emergency situations, a person would use the “light therapy” setting.

Some general comments were:

- *There is a need for one extra setting in the morning between night light and sharp morning light*
- *The light switches too early to the dark settings in the evening*
- *The night light is too dark*

B. <u>Fluorescent Lighting Ward</u>

There was no user manual for this lighting installation, but the staff felt mostly sure about how to operate the controls (since it was a simple on/off).

Half of the participants mentioned that they had daily challenges when using the lighting, because it was too dark and there was a lack of extra light for special nursing tasks. Some mentioned challenges with the maintenance of the system, due to the small number of available sockets for bedside or reading lighting. One mentioned problems during emergencies, because there was not enough light for certain situations.

Some general comments were:

- *There is not enough light for some activities*
- *Dimming at night could be good / the corridors are too bright at night*
- *There is a lack of flexibility*

3

PSYCHIATRIC HOSPITAL IN SLAGELSE

EVALUATION OF DAYLIGHT AND ELECTRIC LIGHTING INSTALLATION IN PATIENT ROOMS

https://godtsygehusbyggeri.dk/inspiration/cases/helende-arkitektur-psykiatrisygehuset-i-slagelse - Photograph: Karlsson Arkitekter VLA

3 PSYCHIATRIC HOSPITAL IN SLAGELSE

Slagelse Psychiatric Hospital is the largest psychiatric facility in Denmark. The 44.000 m^2 building was completed in 2015 and includes general and forensic psychiatry wards, a high-security ward, training facilities, a swimming pool and research facilities. The building was designed as a network of clusters that provides good connections between the hospital's different functions. The patient rooms are facing garden-like courtyards that allow the occupants to feel closer to nature. The project was awarded a DGNB silver certification.

Figure 3-1: Aerial (left) and top (right) view of the Psychiatric Hospital

Figure 3-2: The central staircase (left) and corridor in the hospital ward (right)

Figure 3-3: Common spaces

During the monitoring for this project, LED lighting was used in the building with different settings for day and night, with the aim to support the circadian system of patients and staff (Figure 3-4). The purpose of this report is to present the characteristics of the electric lighting system and evaluate them based on photometric measurements and subjective opinions of the employees.

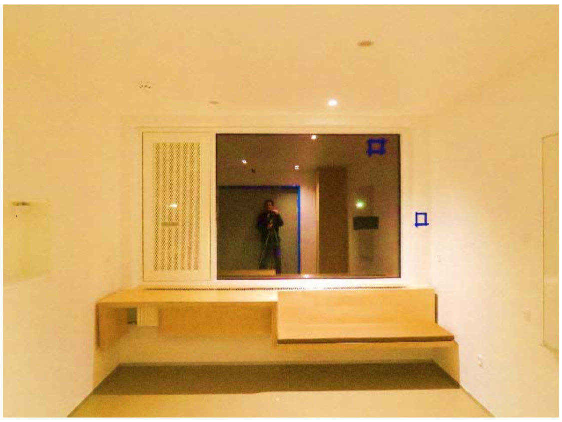


Figure 3-4 - Different electric light settings in patient bedroom. The day setting on the left and the night setting on the right. Both pictures were taken at night.

The lighting group of Aarhus University conducted measurements in one of the patients' rooms during one day in February 2020. A series of on-site interviews with members of the staff took place in order to assess their experience with the lighting system.

3.1 Description of the Measured Patient Suite

The measurements were conducted in an empty patient suite on the west side of the hospital. The orientation of the façade was towards north-west and the windows were facing a courtyard. The patient bedroom was approximately 15m2 in area with a room depth from the window of slightly less than 5m. Beds were movable. The window area was around 60% of the façade and the visual transmittance of the glass was 61%. Part of the window was openable to the outside with a perforated metal sheet in front of it that did not allow someone to exit the room through the window. Adjacent to the bedroom, there was a personal bathroom of about 3.5m2.

Figure 3-5 – Patient bedroom

Figure 3-6 – View of the bathroom

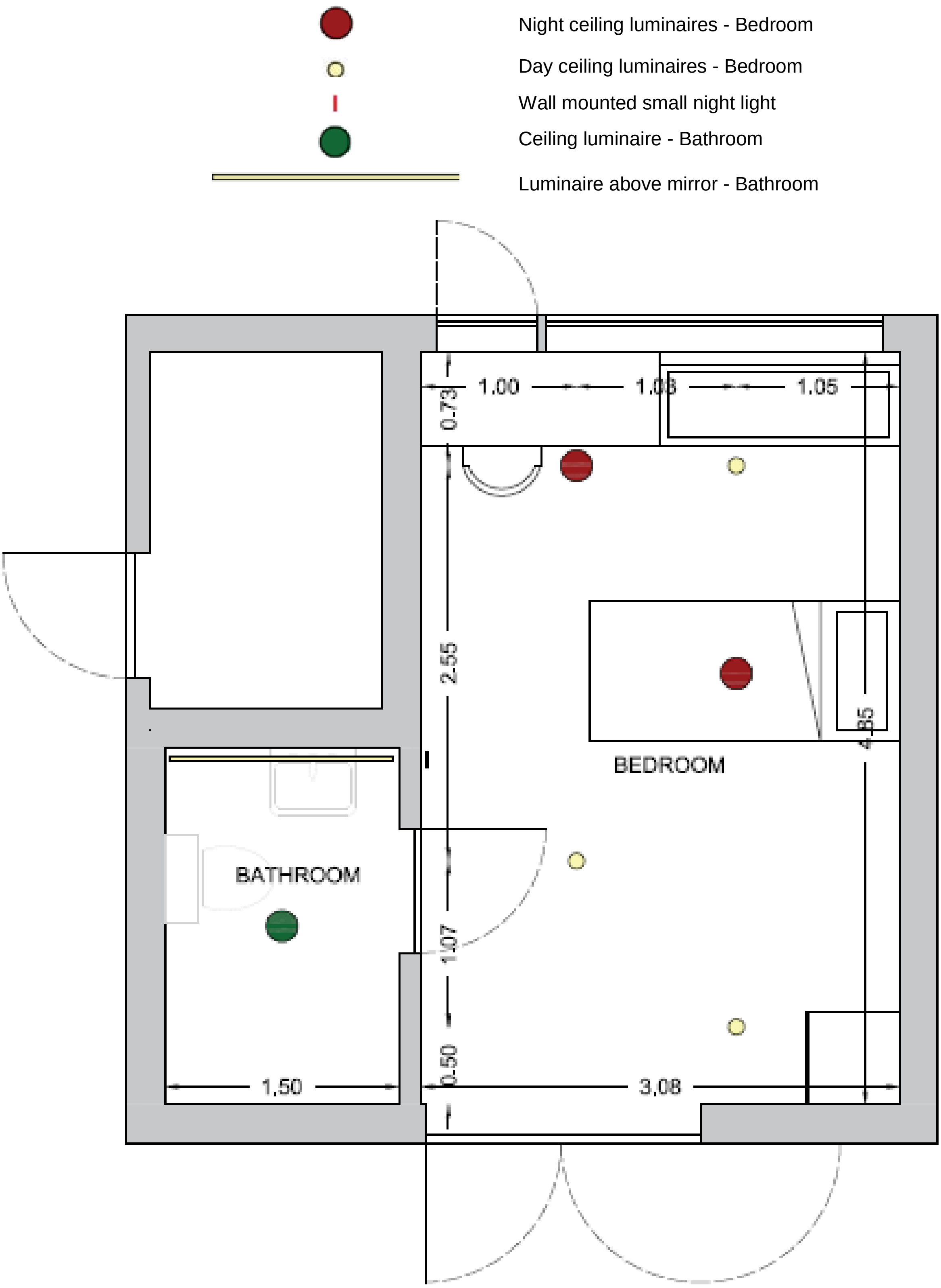


Figure 3-7 - Floor plan of patient bedroom with illustrated placement of the different luminaires in the room.

The reflectance of the interior surfaces was measured with a spectrophotometer Konica Minolta CM-600d. The measured reflectance values from the Physical Hospital in Slagelse are specified in Table 3-1.

Table 3-1: Reflectance of interior surfaces.

Bedroom		**Bathroom**	
Surface	**Reflectance [%]**	**Surface**	**Reflectance [%]**
Ceiling	84	**Ceiling**	84
Wall	84	**Wall**	73
Floor	28	**Floor**	47
Seat cushion	15	**Sink**	75
Table	52	**Door frame (blue)**	23
Wardrobe	52	**Door**	45
Window glass	7	**Window frame**	5

Although the measured room did not have any shading devices on the windows during the time of the measurements, most of the other rooms had semi-transparent white curtains as solar shading. An example of a curtain is illustrated in

Figure 3-8. The curtains were placed in both office and patient rooms, but in some cases the curtains were removed because of safety concerns for patients.

Figure 3-8: Curtain in patient bedroom.

3.2 Daylight Factor

The daylight in the patient rooms was evaluated using the daylight factor (DF), which is the ratio of the illuminance indoors to the horizontal illuminance outdoors under an unobstructed overcast sky. Typically, a minimum DF of 2.1% is required for adequate daylight for at least 50% of the room area. To calculate the daylight factor of the room at several different points, first the outdoor illuminance had to be determined under overcast sky conditions. It needed to be measured at the highest accessible point of the building. In the meantime, the horizontal illuminance values of the daylight were measured inside at previously located grid points. The measurement points were along the centerline of the room, perpendicular to the window and one meter apart from each other.

The daylight factor in the patient room was deemed sufficient (the average of the four points was 4%), mostly because the room was not too deep. Figure 3-10 shows that on the desk (placed by the window) and on the bed (placed approximately 2m from the window) there was enough daylight for patients and staff to see clearly and perform basic activities, as DF was above 2.1%.

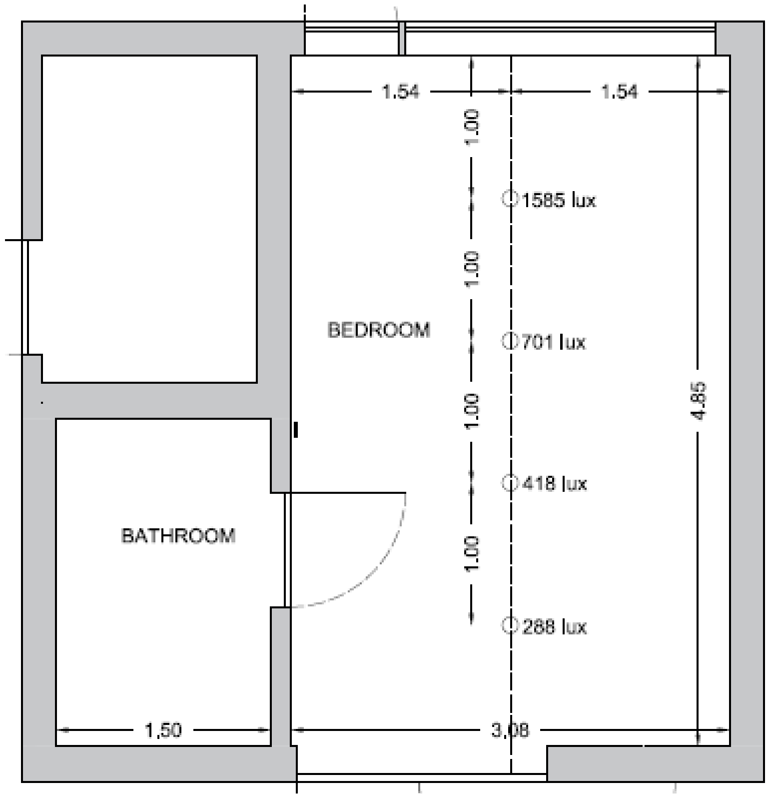


Figure 3-9 - Illuminance level at the center line during daylight

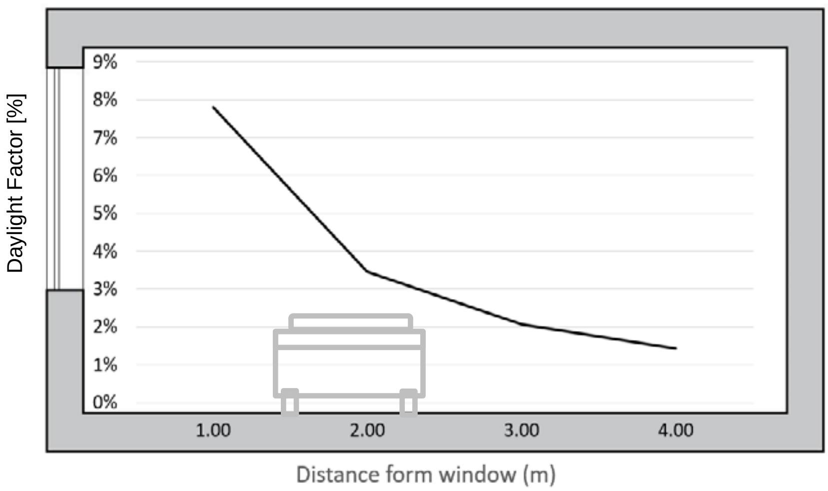


Figure 3-10 - Daylight factor in the patient room

3.3 Electric Lighting

There were two electric lighting scenarios for the room, one to be used during the day and one during the night. The day setting consisted of three round ceiling-recessed LED luminaires. The night setting consisted of two different ceiling-recessed LED luminaires at different locations and a small wall-mounted safety and orientation luminaire adjacent to the lower right corner of bathroom door as seen from the room. In the bathroom, there were two luminaires, one placed in the center of the ceiling, which was of the same type as the ones in the bedroom night scenarios, and one above the mirror, which was an LED strip luminaire. The bathroom light should also have had different settings for day and night, but that was not the case in the bathroom of the patient suite monitored.

The luminaire type that was installed for both the bedroom night lighting and the bathroom lighting was using two drivers connected to two of the four wires of the luminaire and thus allowing for mixing the spectrum as desired. Nevertheless, the luminaire in the bedroom was only used at night and with only one setting. In the room we assessed, the spectral distribution and correlated color temperature settings were very close to those of the daytime setting (see Section 3.6 below).

There was no daylight-dependent control for dimming the electric lighting when sufficient daylight would have been available, nor a motion sensor in the bedroom. There was, however, a PIR sensor installed in the bathroom.

For the staff there was a touch panel in the staff room (see Figure 3-11), from which the lighting of each room type or specific room could be changed manually. There were more options for changing the lighting from the touch panel, than what was possible via the buttons in the room (Figure 3-12). Also, at the touchscreen it was possible to override the light settings – for example during emergency situations. The reading light was not installed at the time we inspected the room and it was only used if patients asked for it and the extra light source would not be considered a safety concern for the psychiatric patients.

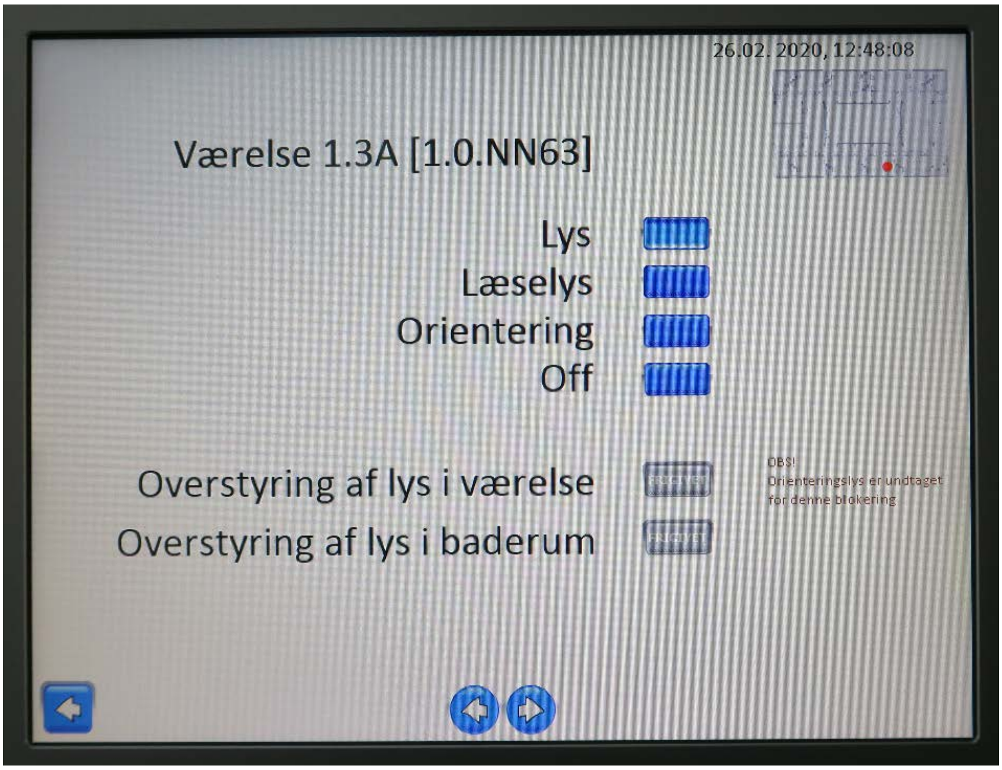
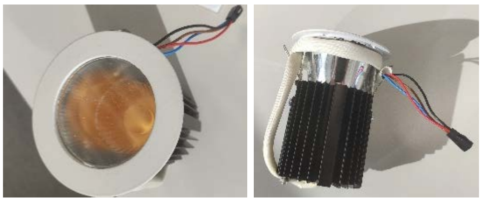


Figure 3-11 - Interface for central electric lighting control.

Table 3-2: Luminaires installed in patient bedrooms

Bedroom	
Recessed LED luminaire in ceiling (for day setting): **Lamp Power:** 15.5 Watt Driver Power: 4 Watt **R_a:** 90 **CCT:** 2700K	
Recessed LED luminaire in ceiling (for night setting): **Lamp Power**: - 6 Watt Driver Power: 4 Watt **R_a:** 90 **CCT:** 2190K/ 2790K *(2790K was connected)* *(*)*	
Wall-recessed LED orientation luminaire **Watt:** 1.0 W **R_a:** 80 **CCT:** 2200 K	

(*) Presumably, the intention was to connect 2190K or lower CCT for the night setting. However, we measured around 2700K. It is unknown whether this was intentional (perhaps because the room was temporarily used as an office) or by accident.

The luminaires were placed in the ceiling and the edge of the luminaires was flush with the ceiling as a safety precaution in each patient room.

There is no switch in the room that allows the residents to change between day and night settings. One can shift between the two settings through a central control interface, available to staff but not the patients.

In the room, the luminaires could be controlled through a switch placed on the wall that could turn the light on and off but had no dimming function. The functionality of the switch changed when the light setting changed from day to night. Figure 3-12 displays the installed switch. Basically, the switch-panel consisted of two on and off buttons during the day setting, and during night setting one of the off buttons allowed the operator to only turn off the ceiling luminaires. Its design was not very intuitive without labels or guidelines; therefore, it took some time until people, including us, could figure out what each button controlled.

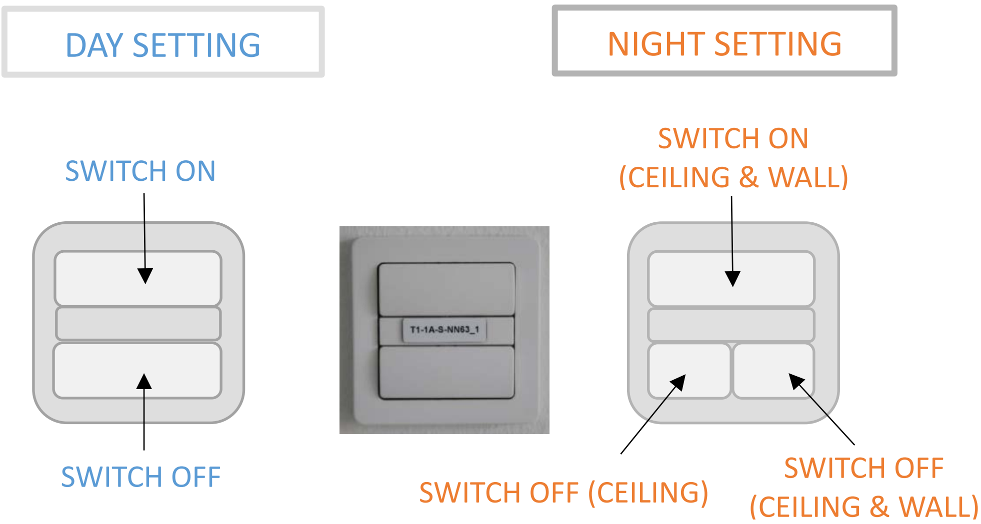


Figure 3-12 - Wall switch that controls the electric lighting

3.4 Illuminance

The horizontal illuminance provided by the two settings was measured in the bedroom at the center line perpendicular to the window and 0.85 m above the floor. The measurements were taken at 1.0 m intervals and took place during nighttime, so no daylight was present. In the bathroom, horizontal illuminance was measured on the floor and at a height of 0.85 m right under the central luminaire (see Figure 3-13 (right) and Figure 3-14 (right). Additionally, the same figures show that the vertical illuminance was measured at 1.7m above the floor and facing the bathroom mirror to represent the illuminance a person would receive at eye level. For reference, Table 1-3 includes the recommendations of EN 12464 for illuminance levels in the wards of health care facilities.

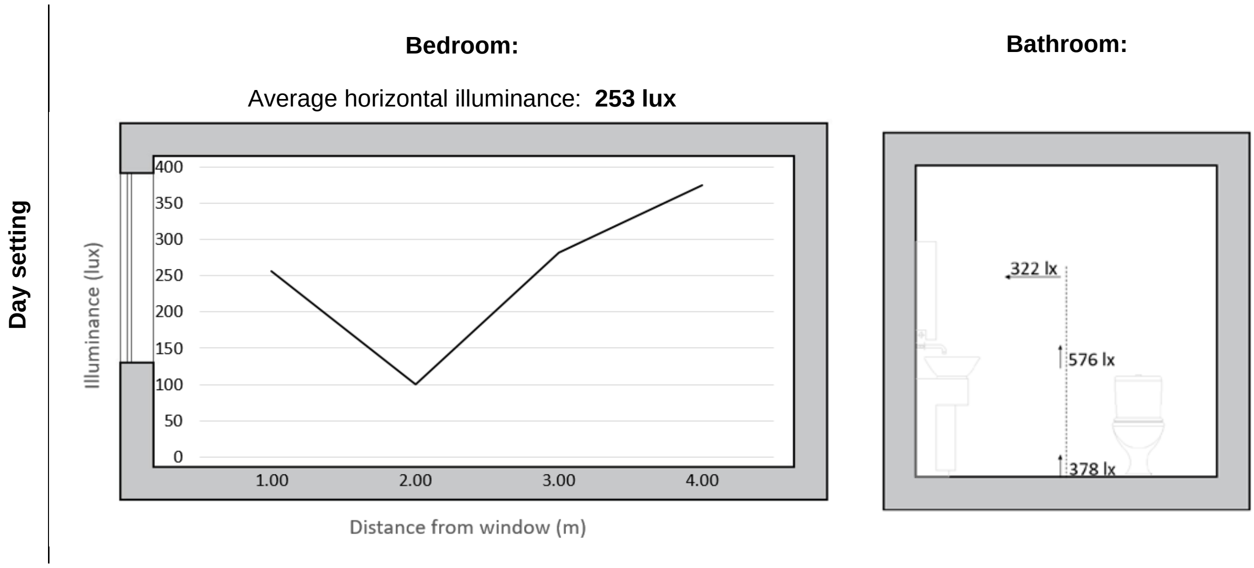


Figure 3-13 -Measured Illuminance in patient room and bathroom for the day setting of the electric lighting

Night setting

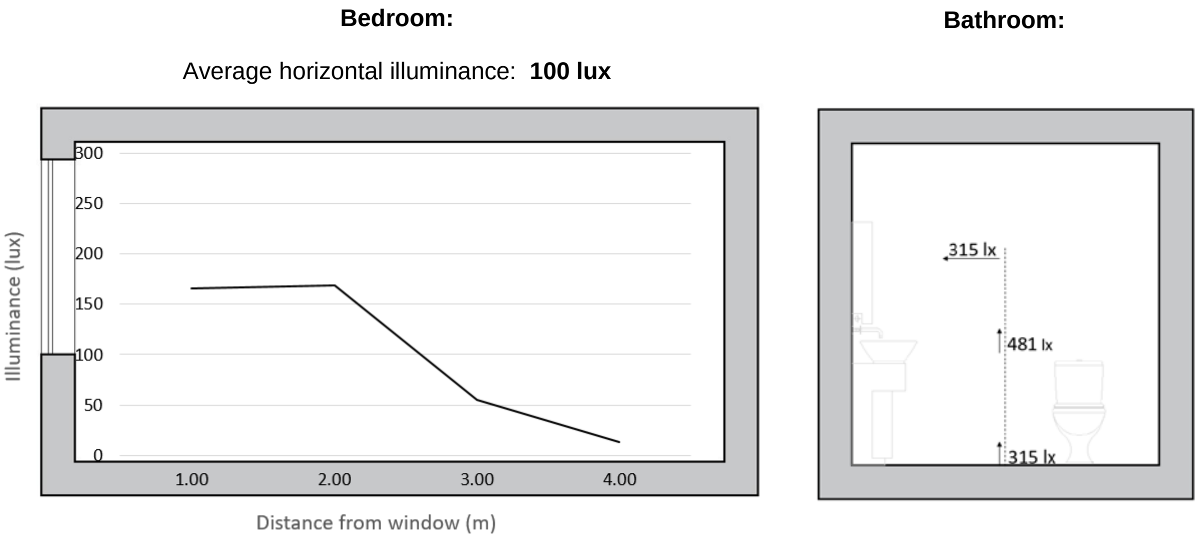


Figure 3-14 - Measured Illuminance in patient room and bathroom for the night setting of the electric lighting

Small night orientation light

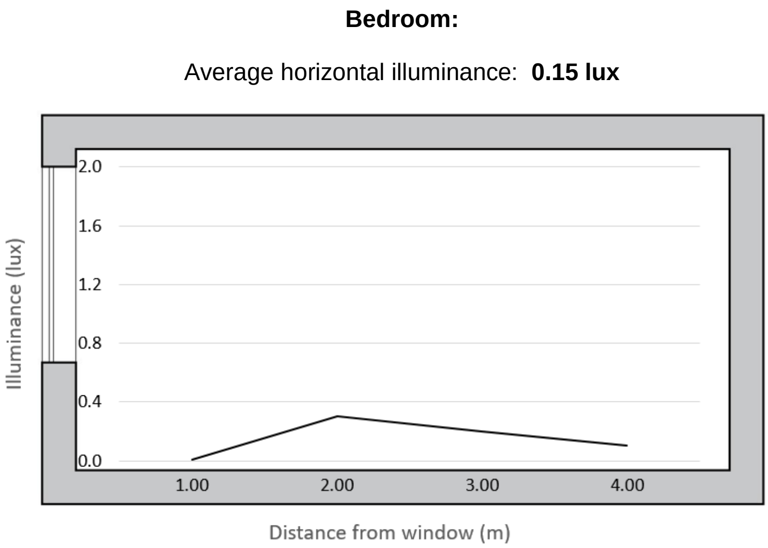


Figure 3-15 - Measured Illuminance in patient room with the small night light with night setting

3.5 Luminance and Glare

Luminance maps were generated from HDR images using a calibrated Canon EOS 60D DSLR camera with a 180-degree fisheye lens. The images were taken from two positions in the room for the three different lighting scenarios: daylight and the daytime and night settings of the electric lighting. The different positions of the camera are displayed in Figure 3-16. The distance from the floor to the lens was 1.2 m for both views. The two camera views correspond to the view of a person sitting on the bed (View 1) and the view of a person entering the room (View 2). The luminance maps help to identify potential sources of glare and high contrast spots. Glare should be minimized, especially for View 1, where a person would probably spend more time.

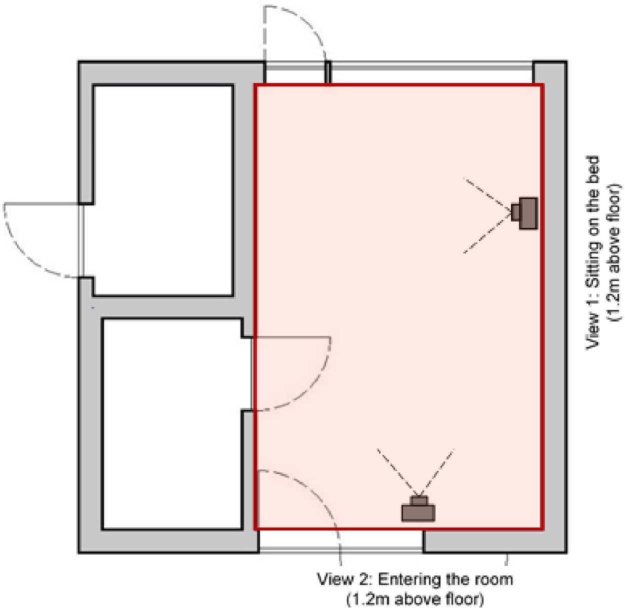


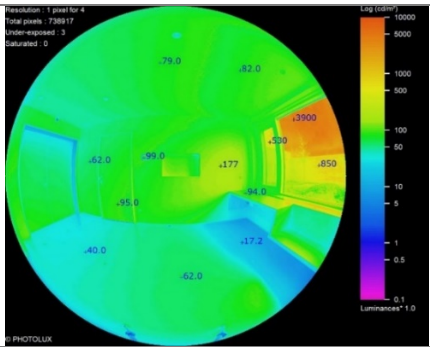
Figure 3-16 - HDR images were captured from two views to generate luminance maps

The luminance maps presented in Figure 3-17 show that glare due to daylight can be of concern. The Daylight Glare Index (DGI) values calculated by Photolux from these maps are 22.4, i.e. just above the limit of 22 for comfortable conditions, for the view towards the bathroom door and wall and 31.1 for the view directly towards the window, indicating potentially intolerable glare. The latter will normally only be a problem when entering the room. As the observer moves closer to the window, his/her eyes will likely adapt to the lighter conditions there, thus reducing the experience of discomfort glare. It is important to note that the luminance maps were captured under an overcast sky without direct sun visible through the window, and therefore the situation can be different under sunlit conditions, when sun at low altitude angles might directly shine into the room. Curtains at the window (not shown in these images) will allow for sun and glare control should this be necessary.

DAYLIGHT

View 1

DGI: 22.4
(DGP estimated to be just above 0.35)



View 2

DGI: 31.1
(DGP estimated to be far above 0.45)

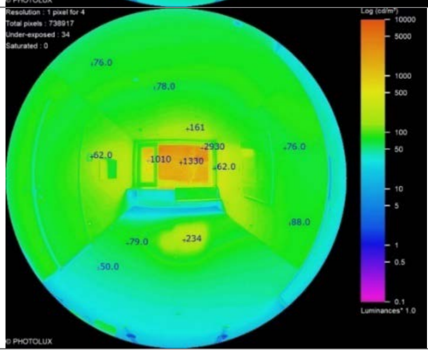


Figure 3-17 - Luminance maps for the patient room in daylight from both views

According to Figure 3-18, discomfort glare due to electric lighting for the day setting is higher for View 2 than the upper limit of 19 for the Unified Glare Rating (UGR) recommended by DS/EN 12464-1. This is due to the bright luminaire in the upper field of view being rather close to a position representing a person sitting on the bed. However, the available daylight will normally raise the adaptation luminance of the observer by adding more light to the room, thus potentially mitigating the effect during daylight hours. For View 1 it is within the acceptable range.

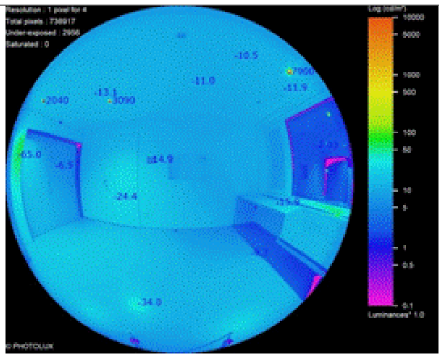
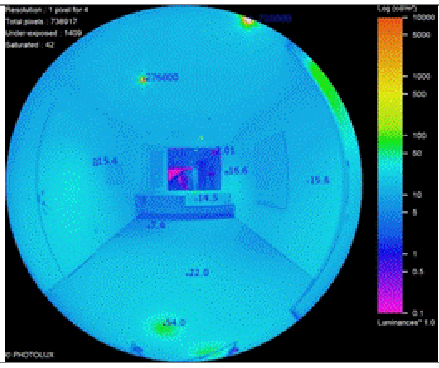
DAY SETTING		
View 1 UGR: 16.4		
View 2 UGR: 28.1		

Figure 3-18 - Luminance maps for the patient room in daylight from both views

For the night setting illustrated in Figure 3-19, the discomfort glare is below the limit for UGR, but View 1 is close to the limit with a value of 18.8.

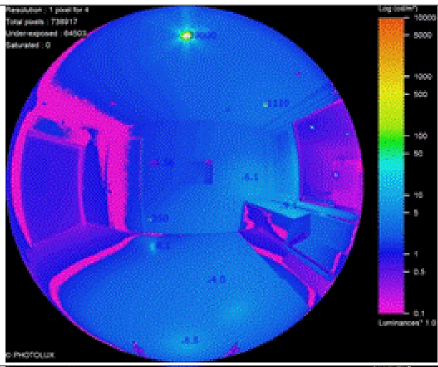
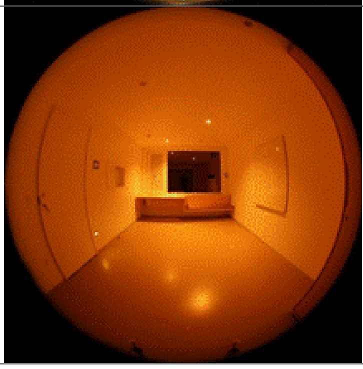
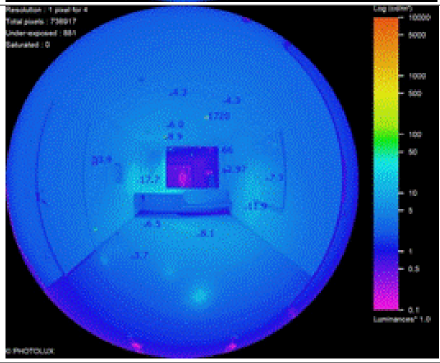
	NIGHT SETTING	
View 1 UGR: 18.8		
View 2 UGR: 7		

Figure 3-19 - Luminance maps for the patient room with night setting for electric lighting from both views

3.6 Spectral Information

The spectral power distributions (SPDs) were measured on different monitoring days – on 26 February 2020 and on 23 November 2020. The measurements from 26 February did not show the expected differences in the spectral data between the night setting and daytime setting. Therefore, repeated SPD measurements were performed in another patient room on 23 November 2020. The measurements on 26 February 2020 of the two electric light settings were taken with a spectrophotometer (Konica Minolta CL-500A) at the two investigated positions – View 1 and View 2 as displayed in Figure 3-16. The measurements on 23 November 2020 were taken with another type of spectrophotometer (UPRtek MK350N premium LED). The next to identical measurements for the daytime setting suggests that the differences are not due to the use of different measurement equipment.

The measurements included information about the Correlated Color Temperature (CCT) and the Color Rendering Index (R_a), which allow us to assess whether the light appears warm or cold and how well the light source represents a set of standard color swatches. The SPDs measured on 26 February and 23 November 2020 for the night setting are presented in Figure 3-20 and Figure 3-21 and for the day setting in Figure 3-22 and Figure 3-23.

There are inconsistencies between the lighting installations in the different patient rooms we assessed. It is our impression that the measurements of 23 November better represent the purpose of the lighting installation. As the patient rooms we assessed on 26 February were used as office spaces prior to our monitoring activities, we suspect that the night settings had been changed at some point to reflect the nature of the office tasks, rather than the needs of patients wanting to rest. Technical staff had probably just forgotten to return the lighting settings to the originally programed scenario for the night setting. This, however, could not be confirmed.

26 February 2020

Day Setting, View 1

CCT = 2363K

R_a = 89

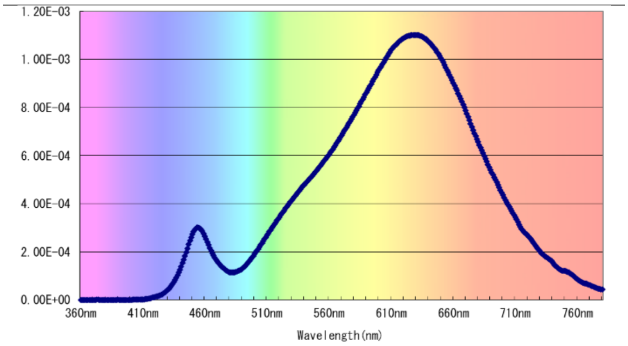


Figure 3-20 – SPD for day setting (View 1)

23 November 2020

Day Setting, View 1

CCT = 2471K

R_a = 91

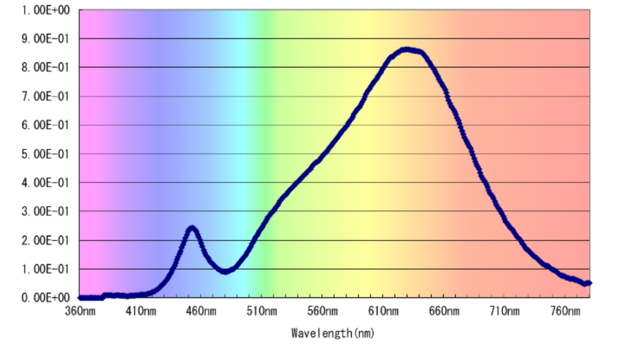


Figure 3-21 - SPD for day setting (View 1)

26 February 2020

Night Setting, View 1

CCT = 2317K

R_a = 88

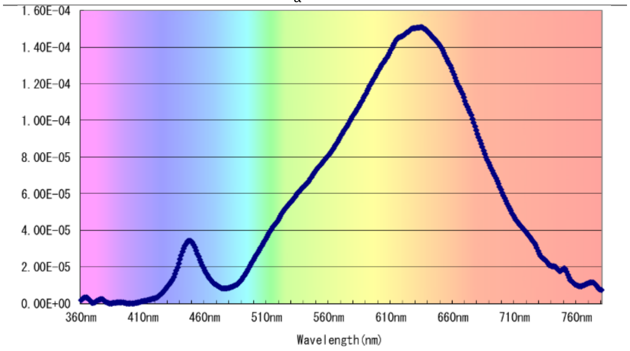


Figure 3-22 - SPD for night setting (View 1)

23 November 2020

Night Setting, View 1

CCT = 1753K

R_a = 65

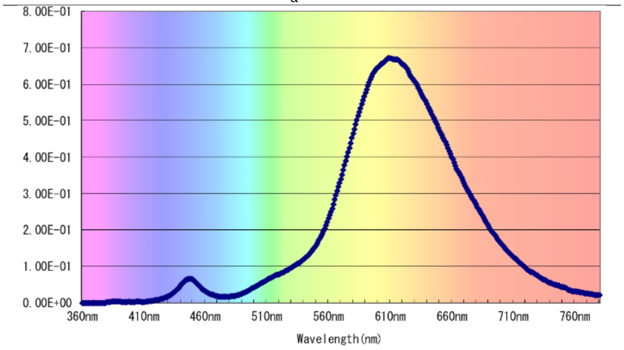


Figure 3-23 - SPD for night setting (View 1)

Spectral and luminous intensity distribution measurements of the two luminaires were also conducted in the lighting laboratory at Aarhus University in order to create IES files of the luminaires for simulations. The results are listed in Table 3-3. CCT and R_a values measured in the laboratory with black, light absorbing surfaces were different compared to the ones measured on location, because the spectrum was not modified by the surrounding colored surfaces of the room of the actual patient room.

Table 3-3 – Measured CCT [K] and R_a at the location and in the lighting laboratory

	Setting				**View 1**		**View 2**
		CCT [K]	**R_a [-]**	**CCT [K]**	**R_a [-]**	**CCT [K]**	**R_a [-]**
On location	**Day**			2451	90	2363	89
	Night			2457	89	2317	88
Laboratory	**Day**	2770	90				
	Night	2779	93				
On location 2nd time	**Day**			2471	91.1	2474	93.4
	Night			1753	65.3	1746	65.9

3.7 Circadian Potential

In order to evaluate the circadian potential of the lighting installation and different settings, the same two metrics calculated for Vikærgården, Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) in lux and Circadian Stimulus (CS), were also calculated for the Psychiatric Hospital in Slagelse. For a detailed description of the calculation method and metrics, see Section 2.7. Figure 3-24 and Figure 3-25 show the calculated CS and M-EDI compared to the target zones and limits.

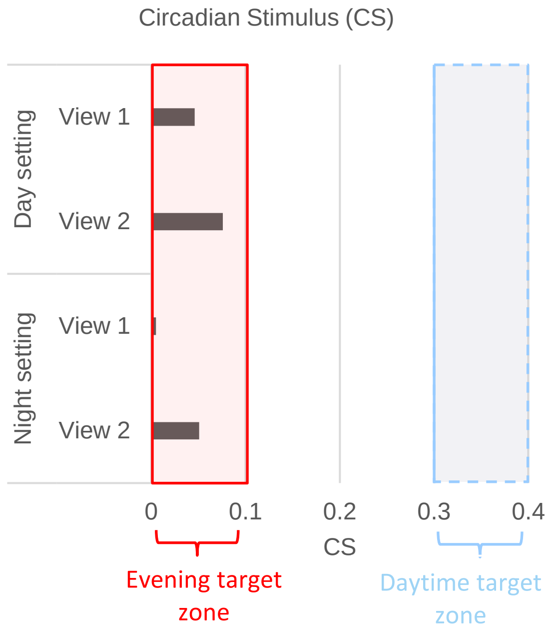


Figure 3-24 - Circadian Stimulus (CS) measured on 26 February 2020 at the eye of a hypothetical observer, 1.2 m above the floor from the two viewpoints illustrated in Figure 3-16. The target zones of evening and daytime refer to the recommendations of the Lighting Research Institute [14]

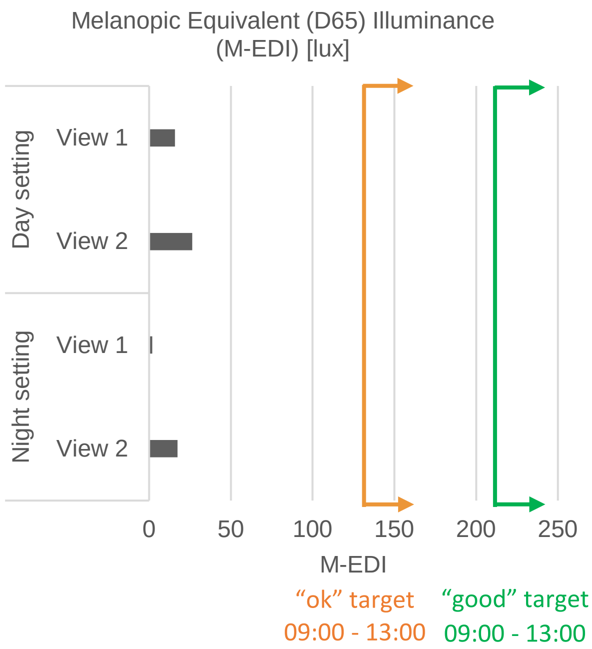
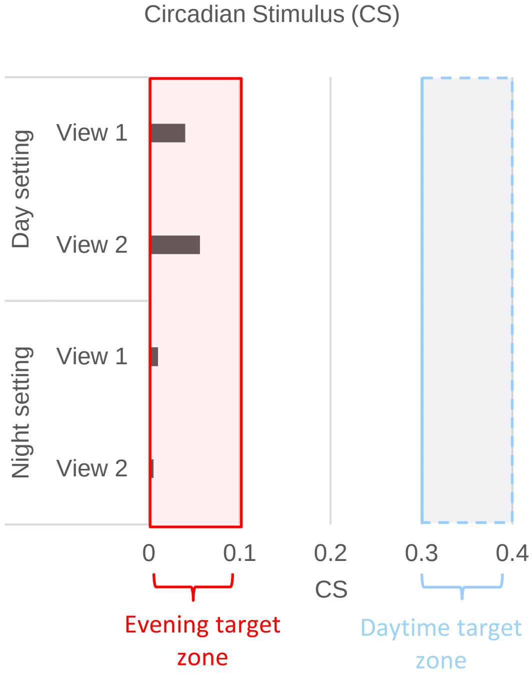


Figure 3-25 – Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) measured on 26 February 2020 at the eye of a hypothetical observer, 1.2 m above the floor from the two viewpoints illustrated in Figure 3-16. The target limits for “ok” and “good” refer to the recommendations of the WELL building standard v2 [10]

The calculations show quite low values of CS and M-EDI for View 1 and View 2 for both day and night settings. The night setting reaches the target zone for an evening/night situation. Preferably, the CS values needs to be below 0.1 not to interrupt melatonin levels and to support peaceful sleep during the night. During the day, we want increased CS and M-EDI to provide an energy boost at a certain point of the day. However, the day setting of the electric light cannot provide an increased stimulus, so the occupants need to rely on daylight. While Figure 3-24 and Figure 3-25 are showing the results of CS and M-EDI on 26 February, it was necessary to investigate the CS and M-EDI for the spectral information from 23 November. This is documented in Figure 3-26 and Figure 3-27.



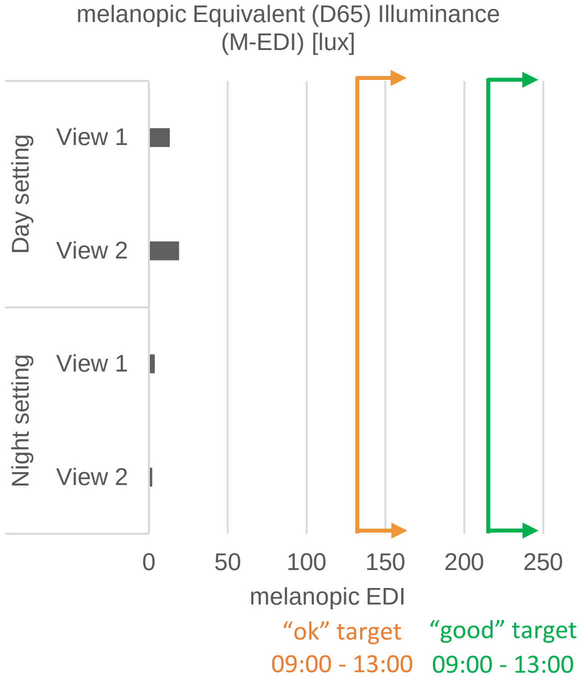


Figure 3-26 – Circadian Stimulus (CS) measured on 23 November 2020 at the eye of a hypothetical observer, 1.2 m above the floor from the two viewpoints illustrated in Figure 3-16. The target zones of evening and daytime refer to the recommendations of the Lighting Research Institute [14]

Figure 3-27 - Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) measured on 23 November 2020 at the eye of a hypothetical observer, 1.2 m above the floor from the two viewpoints illustrated in Figure 3-16. The target limits for "ok" and "good" refer to the recommendations of the WELL building standard v2 [10]

The results for CS and melanopic EDI (M-EDI) shown in Figure 3-26 and Figure 3-27 are not deviating markedly from the previous results. Only the night settings for View 1 and View 2 show a difference. Here both the CS and melanopic EDI are lower than previously and this coincides with the changes in the spectral data. The CS value is not reaching the target zone for daytime, which is between 0.3 and 0.4. The same can be said about M-EDI. The results are far away from both the "ok" at 136 lux M-EDI and "good" target at 218 lux M-EDI. The results indicate that daylight is necessary during daytime to obtain an adequate circadian stimulus.

3.8 Opinion of Staff

We conducted a series of semi-structured interviews with six members of the staff of the Psychiatric Hospital that worked primarily the evening and night shifts to evaluate their perception of the electric lighting conditions and how the lighting conditions affect their work and the patients. During the personal interviews at the hospital, we used a questionnaire guide and recorded the interviewees' responses to the questions, as well as their personal comments and observations they shared with us.

The interview guide was again structured into the following sections:

- **Personal information**
- **Light Settings and Operation**
- **Visual Experience**
- **Effect of Circadian Lighting on Staff**
- **Effect of Circadian Lighting on Patients**
- **Emotional Effect**
- **Instruction and Implementation**

A more detailed description of each category can be seen in Table 1-2.

3.8.1 Personal Information: Age, Gender and Occupation

The interviewees were one nurse, one occupational therapist and four social/social education workers. Five of them were female and four over the age of 50. Their work schedule was divided into the day, evening, and night shift as shown in Table 3.4.

Table 3-4 - Overview of shifts during which the six staff members interviewed worked

Shift	P1	P2	P3	P4	P5	P6
Day	X	X		X		X
Evening	X	X	X	X	X	X
Night		X	X		X	

3.8.2 Light Settings and Operation

All the participants said that they operated the circadian lighting system through the touchscreen in the staff room. There did not seem to be a common understanding of the staff regarding the reason for the implementation of the circadian lighting system, with some stating that they had no information about it. Five of the interviewees said that most or some of the patients could figure out how to operate the lights, indicating that some patients had difficulty operating the room light switches.

3.8.3 Visual experience

Half of the interviewees stated that they experienced glare from the electric light in the staff room. Regarding the color of light, one person thought that the light in the staff room felt too blue/cold when it turned on and another person said that the light felt too blue/cold because it instantaneously switches in the morning to the day setting. Three people said that sometimes the light felt too yellow/warm.

The following graphs show the opinion of the interviewees about how appropriate the lighting was for each room together with the comments of the people who thought it was not appropriate.

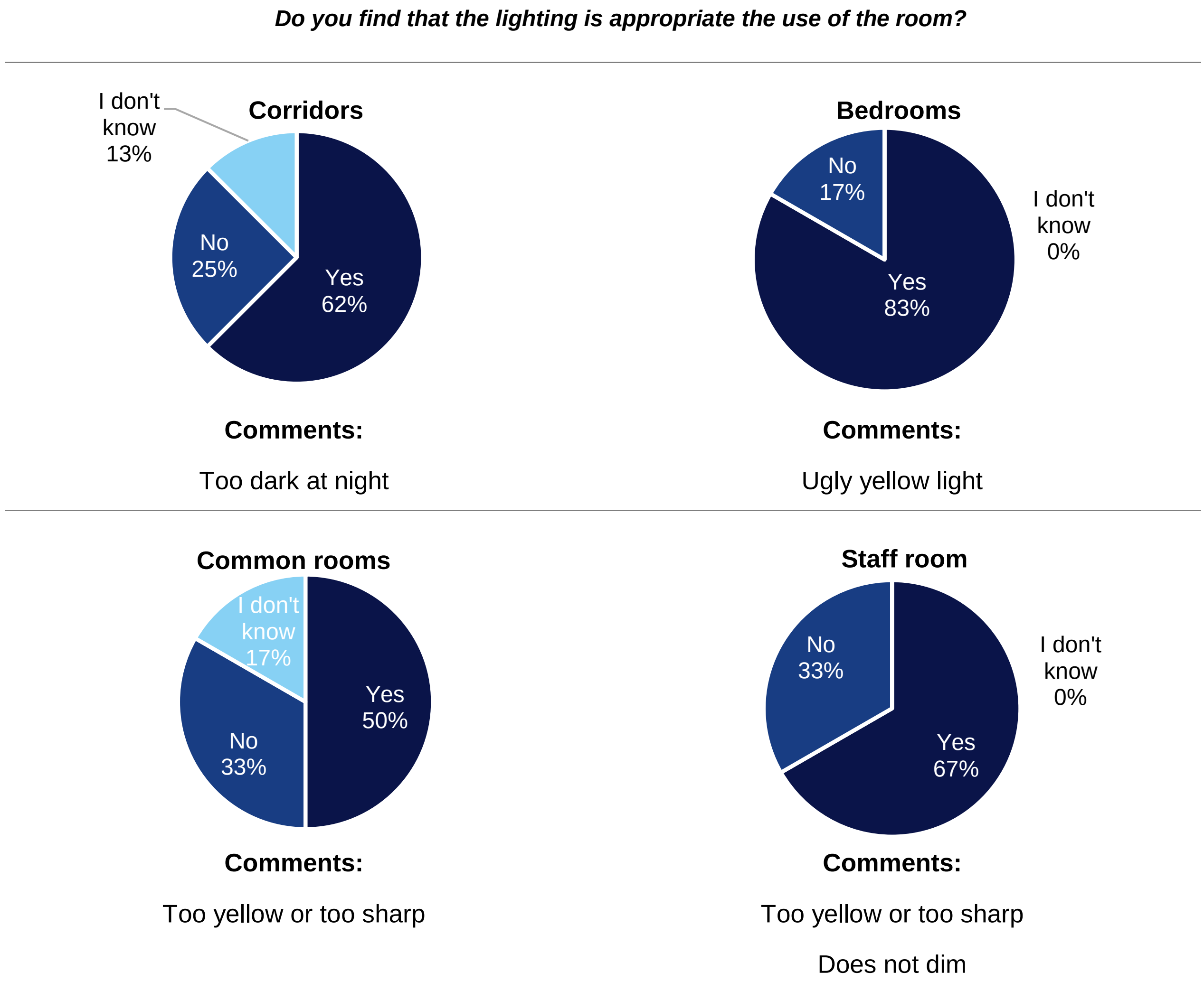


Figure 3-28 – Staff assessment of the appropriateness of the circadian lighting system for different rooms in their facility

The participants were also asked about their ability to work easily under the electric lighting. During the day, they mostly claimed to have no problems with color recognition, ability to see the patients, ability to see the PC/TV screen, and with comfort, although some reading difficulty in the patient bedrooms was expressed. Similar answers were given for the evening light. For the night light, the ability to recognize colors was rated slightly worse.

3.8.4 Effect of Circadian Lighting on Staff

Staff were asked, whether they believed that they experienced a circadian effect of the lighting systems. This was a difficult question to ask, as other factors might also have contributed. Nevertheless, some respondents believed that the lighting system had affected them. Most of the interviewees responded that they did not experience, or they did not know if they experienced, a circadian effect. However, the opinions were mixed and caution is definitely advised with respect to the responses and any conclusions drawn from them.

To what extent have you experienced that the circadian lighting has a positive effect on you in relation to

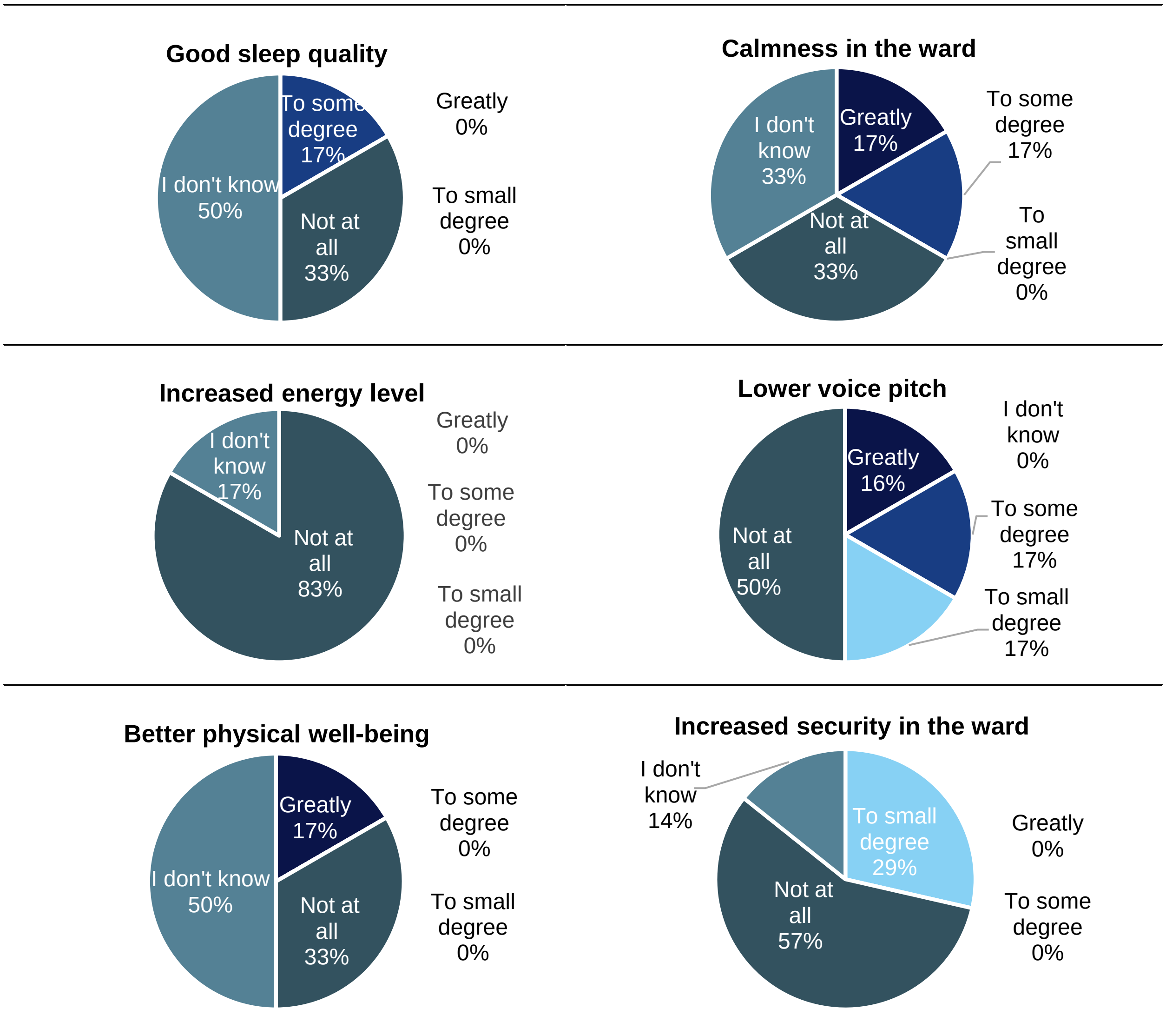
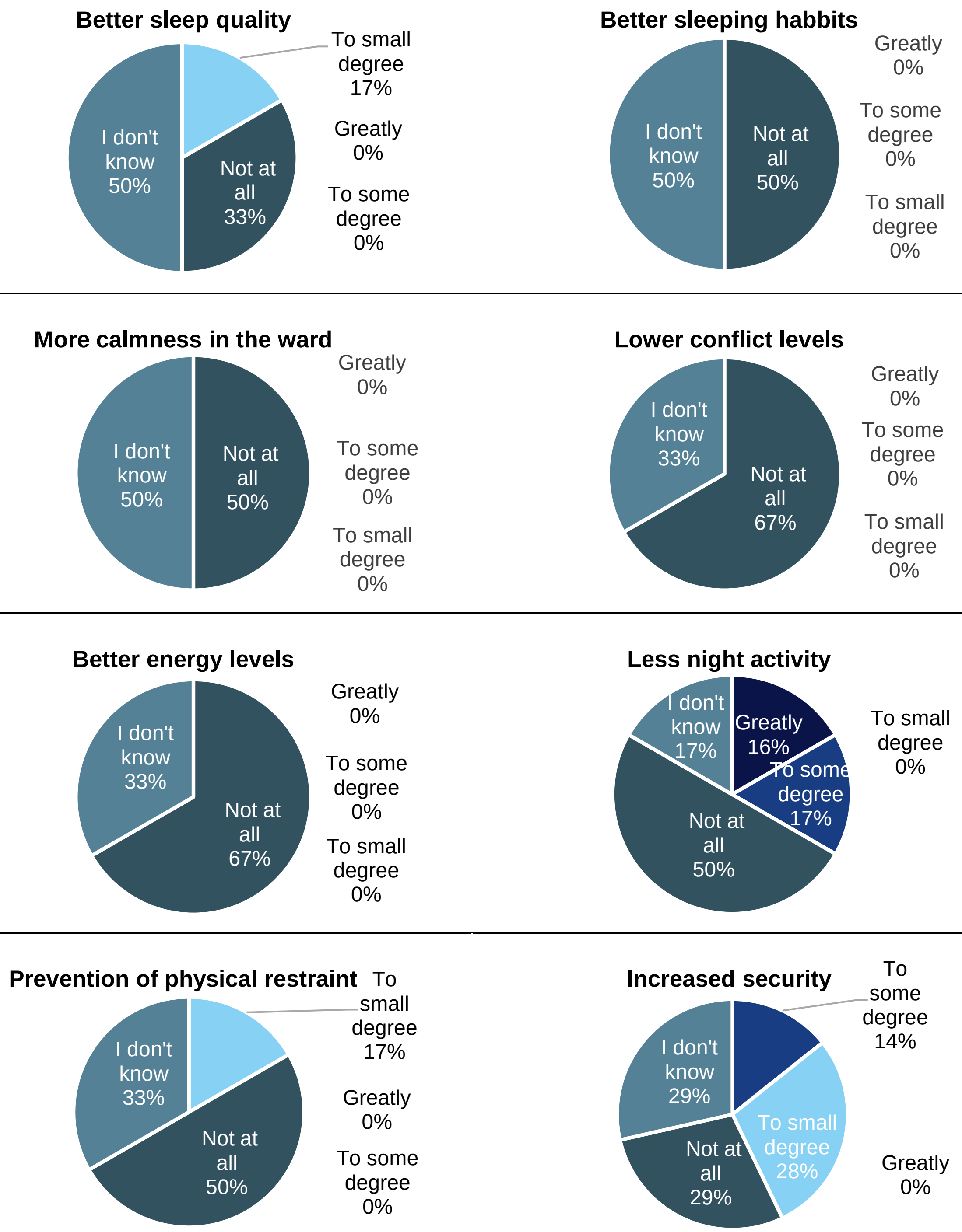


Figure 3-29 - Indications of staff on the extent of experiencing positive effects of the circadian lighting

3.8.5 Effect of Circadian Lighting on Patients

Most of the interviewees responded that the patients did not experience, or that they did not know if they experienced, an effect due to the circadian lighting. Areas where they might have observed a possible positive effect were reduced night activity and increased security in the psychiatric wards, as well as a small reduction in the need for physical restraint. They did not express any positive effect on sleeping habits, calmness in the ward, conflict levels, energy levels, or medicine use.

To what extent have you experienced that the circadian lighting has a positive effect on the patients in relation to



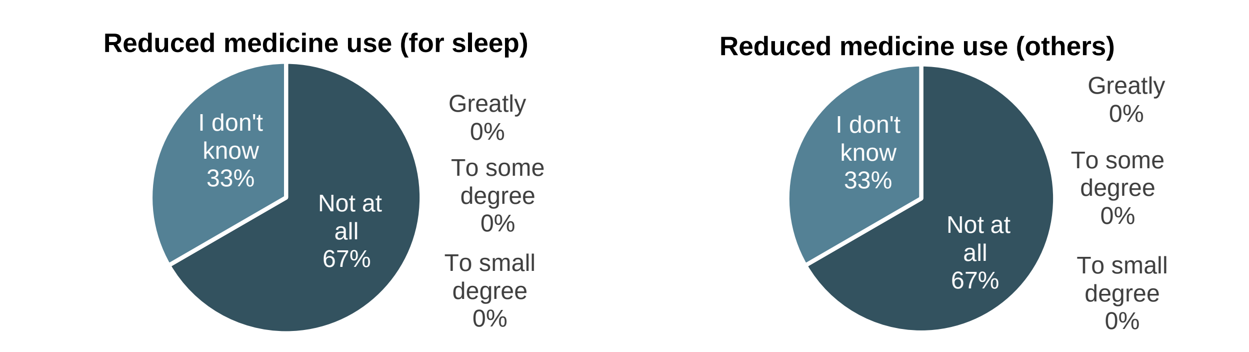


Figure 3-30 – Indications of staff on the experience of perceived positive effects of the circadian lighting on patients

3.8.6 Emotional Effect

Regarding the emotional influence of the lighting installation, half of those interviewed said that there was no influence while the other half said that it had a positive effect (too a high or moderate degree). Nobody agreed with feeling fresher after a night shift, and only one said that it was easier to fall asleep after the night shift (to some degree). However, all of them believed that it was easier for the eyes to get used to the evening light (from small to high degree).

Most of them believed that the lighting made sense in their everyday activities and that they would probably recommend it to others, but they also had suggestions for improvements or adjustments. From their comments, the general impression seems to be, that this type of lighting system is a good thought, but that the implementation was not ideal.

The interviewees' opinions regarding the patients' experience with the lighting system were mixed. Some said that they did not notice any dissatisfaction of the patients with the system and that the lighting made it easier for the patients to maintain calm. However, others commented that it was difficult for the patients to operate the light and that the switch with four push button functions was far too complicated.

3.8.7 Instruction and Implementation

Staff had not been offered appropriate instruction on how to use the circadian lighting system unless they needed to receive it or personally asked for such instruction. Four of them said that they were dissatisfied with the introduction they received and the other two were satisfied or very satisfied. None of them used a user manual, and they did not know whether one existed, but four of them felt confident that they knew the functions of the system.

Half of those interviewed experienced challenges with the everyday operation of the system on a weekly or monthly basis, such as not being able to turn lights off from the touchscreen panel and problems with the PIR sensors in the bathrooms. Two of them experienced challenges with the operation during emergencies, including the light turning off because of an error.

Staff suggestions for improvements were:

- *Increase the light levels in the corridors*
- *Paint the black surfaces white (make the spaces feel more secure)*
- *Change the yellowish light at night*
- *Make the operation of the switch in the patient room easier (there are too many buttons without an indication of what they do)*
- *Add a dimming function*
- *Offer better technical info about the lighting to staff*
- *Offer an illustrated guide on the operation of the lighting system to patients*

4

LIGHTING ENERGY USE

4 LIGHTING ENERGY USE

A major factor in this project has been the aim to get a good understanding of the energy use associated with operating circadian lighting systems in practice. Concerns have been raised with the project team at the start and throughout the project about the energy use of the lighting installations investigated. Administrators and users in the healthcare facilities expected that the circadian lighting systems would perhaps use significantly more energy than typical standard lighting solutions for hospitals. We intended to measure the actual energy use of the various lighting systems installed in the buildings visited. However, due to the COVID-19 pandemic, we could not perform such measurements as access to the buildings was prohibited.

At the Vikærgården Rehabilitation Center in Aarhus, the luminaire manufacturer was on site for a few days to complete some work in the fall of 2020. We asked the manufacturer's technical staff to take measurements of the connected power of individual luminaires for the different spectral power distribution (SPD) and dimming/illuminance settings, so we would at least have some basic information for calculating likely energy consumption values. However, as the settings typically moved gradually from one setting to another over a certain period of time to make the changes as imperceptible as possible to the users (fading time), the resulting calculations are only an approximation of the actual energy use. We applied the simulation tool DIALux and Excel calculations in the absence of real energy measurement data.

For Vikærgården, we did not compare the estimates for the new circadian lighting systems installed in selected wards with the actual energy consumption of the still existing compact fluorescent lighting (CFL) in other wards. We made this decision, because the CFL system no longer met current standard requirements and exhibited serious issues with deferred maintenance. The lamps were way past their useful lifetime and provided an inadequate lighting distribution and level in the room.

For Slagelse Psychiatric Hospital, we were able to measure the maximum power (W) of the individual luminaire and driver combinations ourselves off-site, but had to estimate the dimming values based on spectral and illuminance measurements taken on-site during a one-time visit in February 2020 and subsequent DIALux simulations and Excel computations.

For Skejby Psychiatric Hospital in Aarhus, we had access to the technical specifications and plans for the lighting installation, but no on-site or off-site measurements at all. Estimated energy use figures are therefore based on DIALux simulations of the lighting installation for selected scenarios and subsequent Excel calculations.

All energy data, on which these discussions and conclusions are based, are thus only our best estimates using the simulations and additional calculation methods described in DS/EN 15193:2017 – Energy Performance of Buildings – Energy Requirements for Lighting – Part 1: Specifications [15]

We compared the healthcare facilities studied though simulations of standard reference lighting installations for typical rooms in each of healthcare facilities. The standard references were set up with current building and lighting regulations in mind (providing average general illuminance levels at a working plane 0.85 m above the floor of 300 lux during the day and 100 lux during night – normally measured at floor level and not at working plane height) and represented our best approximations of the actually installed lighting systems.

The standard reference case always included a daylight-dependent control system, dimming the electric lighting when sufficient daylight was present. However, two of the three actual lighting installations did not include such an option. They therefore could not benefit from potential energy savings due to the available daylight.

The lighting designers, in both cases manufacturers of circadian lighting systems, regarded the installed lighting as special lighting installations with a medical purpose and thus not having to fulfil the requirement for daylight-dependent dimming.

In our view, a great opportunity was missed in both of these installations, especially since daylight provides the best circadian lighting available for suppressing the sleep hormone melatonin during the day and serves as the reference light source for assessing the non-image forming (NIF) circadian aspects of lighting.

For the two dynamic lighting installations at Vikærgården and Skejby Psychiatric Hospital, we calculated the estimated energy use for a lighting scenario schedule that was as close as possible to the programed schedule. We also estimated the energy use for these same lighting schedules adjusted for the use hours established in the standard reference case (3000 hours during the day and 1000 hours during the night across the whole year), thus allowing a comparison on equal footings. Actual schedules of the lighting scenarios varied between the facilities, but it was difficult to get good data on how often the programed lighting scenarios were actually in operation. While the programed schedules always remained active in the control system, both staff and patients could override the settings manually via switches (both groups) or touch panels (staff only) and either turn lighting off completely or, as with Skejby Psychiatric Hospital and Vikærgården, select a different setting than the scheduled scenario.

4.1 Vikærgården Rehabilitation Centre

In order to assess the lighting energy use of the patient rooms a spreadsheet tool was used that calculates the energy consumption based on DS/EN 15193 [15]. Three different lighting scenarios were considered: one standard reference, which presents a typical scenario that complies with the current Danish standards, therefore it includes a daylight dependent control system; one for the current light settings in the rooms and one for a proposed system, which could potentially further improve the existing situation. The three scenarios are presented below, with the layout of the luminaires. The standard one uses four recessed flat LED lighting panels, the other two have two different types of luminaires, two pieces of a round RGB LED lamp and a wall washer above the TV with similar properties, these are described in detail above in Section 2.3. The proposed scenario uses PIR motion sensor  and a daylight dependent control system .

At Vikærgården Rehabilitation Center in Aarhus, the luminaire manufacturer was on site for a few days to complete some work in the fall of 2020. We asked the manufacturer's technical staff to take measurements of the connected power of individual luminaires for the different spectral power distribution (SPD) and dimming/illuminance settings, so we would at least have some basic information for calculating likely energy consumption values. However, as the settings typically moved gradually from one setting to another over a certain period of time to make the changes as imperceptible as possible to the users (fading time), the resulting calculations are only an approximation of the actual energy use. We applied the simulation tool DIALux and Excel calculations in absence of real energy measurement data.

For Vikærgården, we did not compare the estimates for the new circadian lighting systems installed in selected wards with the actual energy consumption of the still existing compact fluorescent lighting (CFL) in other wards. We made this decision, because the CFL system no longer met current standard requirements and exhibited serious issues with deferred maintenance. The lamps were way past their useful lifetime and provided an inadequate lighting distribution in the room.

Standard Reference | **Existing** | **Proposed**

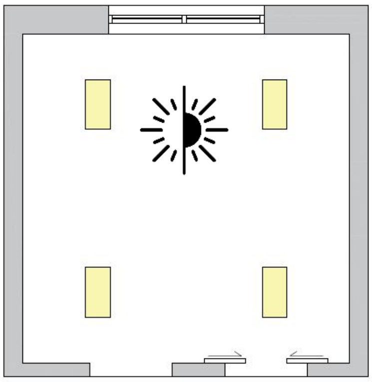


Figure 4-1 - The standard reference lighting with four ceiling-recessed LED panels placed in two rows in the patient bedroom and a daylight-dependent control system

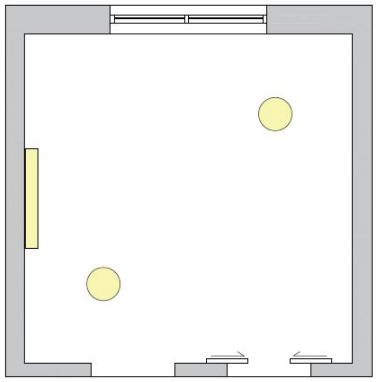


Figure 4-2 - The existing lighting with two different types of luminaires - two circular LED luminaires and a linear wall washer

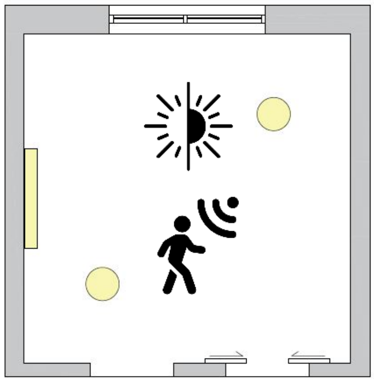


Figure 4-3 - The proposed lighting contains the same light sources as the existing case, but with daylight-dependent control system and PIR motion sensor

Table 4-1 - Calculated lighting energy use for Vikærgården in Aarhus based on DS/EN 15193 [15] with the different specifications for different scenarios. Please note, that for the existing and proposed cases, different lighting scenarios will be active at different times of the day and night to support the circadian rhythm of the patients: hence the varying lux levels and power values.

	Standard Reference	Existing	Proposed Change	Existing Adjusted	Proposed Change Adj.
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 4 Ceiling	3 2 Ceiling + 1 Wall		3 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 Watt	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 15.65 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%

* indicates 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

At Vikærgården, the installed circadian lighting system as implemented would likely use 83% more energy than the standard reference case, if the lighting remained on for the entire time of the programed hours as provided by the luminaire manufacturer who installed the system, as there is no daylight-dependent dimming control function. With a measured daylight factor of only 1.4% (compared to 2% for the two other facilities), the standard reference room at Vikærgården used significantly more electric lighting energy than those at the other two facilities. With daylight-dependent dimming (daylight dependency factor of 0.56 for the room) and occupancy sensors in place (absence factor of 0.2), we estimated energy savings of 16.4% compared to the standard reference (despite significantly longer operating hours) and 54.3% energy savings over the currently installed system without daylight-dependent dimming and occupancy sensors. When adjusting the use hours to the same schedule as the standard reference, 39.4% electrical energy could be saved over the standard reference case.

4.2 Psychiatric Hospital in Slagelse

At Slagelse Psychiatric Hospital, the installed circadian lighting system used different luminaires during the day than at nighttime. The system was very simple and switched at programed times, but could also be manually adjusted for each room to suit the needs of patients as determined by medical staff. The standard reference in this case used four ceiling-recessed LED panels, the existing and proposed solutions have two different types of ceiling-recessed LED luminaires with different color temperature and power, as described in Table 3-2. The proposed scenario uses a PIR motion sensor and a daylight-dependent control system for dimming.

Standard Reference

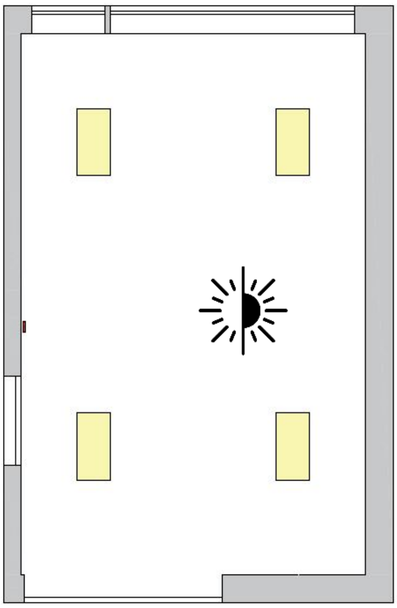


Figure 4-4 - Standard reference with four recessed flat LED lighting panels placed in two rows in the patient bedroom and daylight-dependent control

Existing

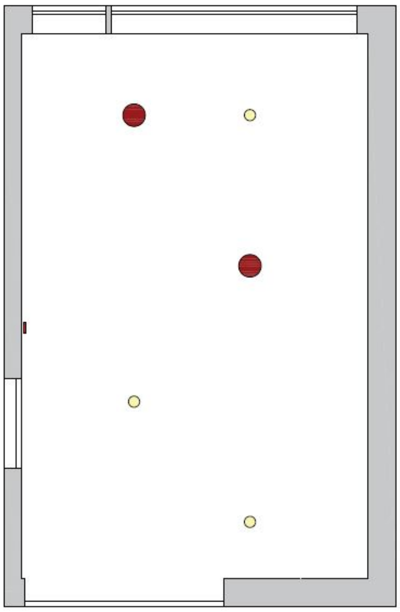


Figure 4-5 - Existing lighting with the two different types of luminaires - two LED spotlights with different color temperature and power

Proposed

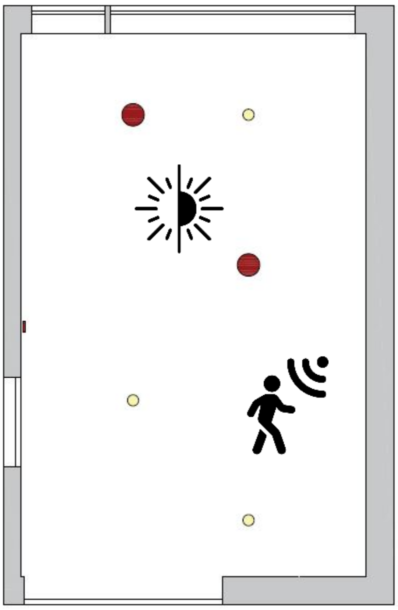


Figure 4-6 - Proposed lighting containing the same light sources as the existing system, but with daylight-dependent control and PIR motion sensor added

For the Psychiatric Hospital in Slagelse, the existing lighting scenarios would likely have resulted in a 60.5% higher energy use than the standard reference case as no daylight-dependent dimming was implemented. Added daylight-dependent dimming and occupancy sensors (absence factor of 0.2) would have resulted in 33.3% energy savings compared to the standard reference. After adjusting the use hours to the same number as the standard reference, the existing system would have used 109.9% more energy than the standard reference without daylight-linked dimming or occupancy sensors, and 14.7% less energy than the standard reference with the additional installation of daylight-linked dimming and occupancy sensors.

Table 4-2 – Calculated lighting energy use in a room in the Psychiatric Hospital in Slagelse based on DS/EN 15193 [15] with the different specifications for different scenarios

	Standard Reference	Existing	Proposed Change
Day (DF = 2%), (Average Illuminance -->)	300 lux	218 lux	218 lux
Hours	3000 Hours	3000 Hours	
Number of Luminaires	4 Ceiling	3 Ceiling	
Power per Luminaire	18.1 W	19.5 W	
Daylight-Dependent Control	yes	no	yes
Occupancy Sensor	no	no	yes
Total Annual Energy Use Day	98.5 kWh	175.5 kWh	64.9 kWh
Night (Average Illuminance -->)	100 lux	135 lux	135 lux
Hours	1000 Hours	1000 Hours	
Number of Luminaires	4 Ceiling	2 Ceiling	
Power per Luminaire	6 W	10.5 W	
Total Annual Energy Use Night	24.0 kWh	21.0 kWh	16.8 kWh
Total Annual Energy Use	122.5 kWh	196.5 kWh	81.7 kWh
LENI (for Room of 15 m^2)	8.2 kWh/m^2	13.1 kWh/m^2	5.4 kWh/m^2
Energy Savings compared to Standard Reference		-60.5%	33.3%
Energy Savings compared to Existing			58.4%

Note: If possible, the actual energy use at Slagelse Psychiatric Hospital should be measured after COVID-19 is over.

If ave. 300 lux during day and 100 lux at night	Standard	Existing	Proposed Change
Total Annual Energy Use	122.5 kWh	257.1 kWh	104.4 kWh
LENI (for Room of 15 m^2)	8.2 kWh/m2	17.1 kWh/m2	7.0 kWh/m^2
Energy Savings compared to Standard Reference		-109.9%	14.7%
Energy Savings compared to Existing			59.4%

Calculation done on 16Dec 2020 - WO_IVE

4.3 Skejby Psychiatric Hospital in Aarhus

The psychiatric hospital in Aarhus should have been a part of these case studies were it not for the current access restrictions in hospitals. Nevertheless, technical information about the rooms and the lighting was provided to us, therefore a simple energy consumption assessment was made. The patient suite consisted of a bedroom and bathroom. The bedroom had a floor area of approximately 18 m^2. There were two recessed LED lighting panels with a frosted acrylic cover for more diffuse light. There was also an LED wall washer unit providing a different lighting quality and an additional reading light next to the bed. The lighting system was fitted with a daylight dependent control system, which dimmed the electric lighting present in the daily lighting schedule when there was adequate amount of daylight in the room. The lamps had a preset for morning, afternoon and night settings, which resulted in changes in CCT and dimming level. These could also be adjusted for individual needs. Similarly, to the other two energy consumption assessments above, the existing system was compared to a standard reference case with two recessed LED luminaire panels, which were fitted with dynamic daylight control.

For Skejby Psychiatric Hospital, the almost around-the-clock lighting schedule would likely have resulted in an 89.4% higher energy use than the standard reference case – even with daylight-dependent dimming (daylight dependency factor of 0.53 for the room) – if the lighting was turned on during the entire scheduled time. This could have been reduced to just 66.8 % more with added occupancy sensors (absence factor of 0.2). After adjusting the use hours to the same number as the standard reference, the existing system could have used 7.3% less energy than the standard reference with just the daylight-linked dimming and 18.4% less energy than the standard reference with the additional installation of occupancy sensors.

Standard Reference | **Existing** | **Proposed Case**

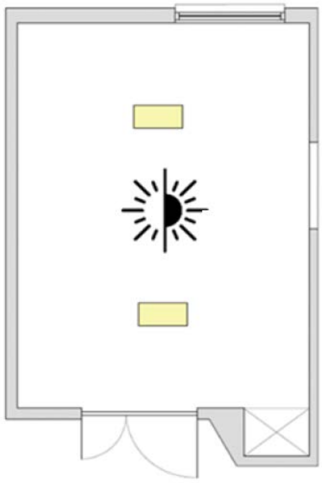


Figure 4-7 - Standard reference with two ceiling-recessed LED lighting panels placed in two rows in the patient bedroom and a daylight-dependent control system

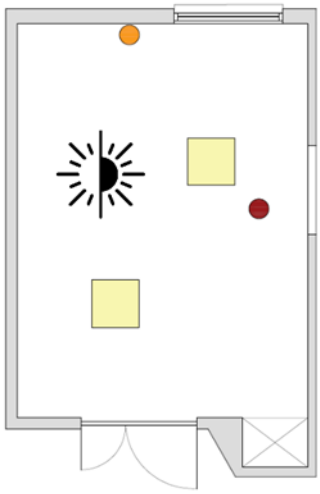


Figure 4-8 - Existing lighting with two ceiling-recessed LED luminaires, wall washer and a reading light next to the bed, and daylight-dependent control system

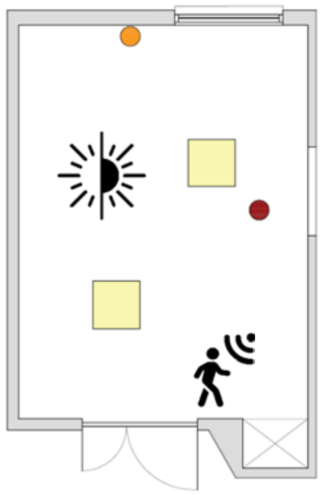


Figure 4-9 - Existing case with two recessed LED luminaires, wall washer and a reading light next to the bed, daylight-dependent control system and occupancy sensor

Table 4-3 - Calculated lighting energy use in a room in the Skejby Psychiatric Hospital in Aarhus based on DS/EN 15193 [17] with the different specifications shown for different scenarios

	Standard Reference	Existing	Proposed Change	Existing Adjusted	Proposed Change Adj.
Day (DF = 2%), (Average Illuminance -->)	300 lux	100 - 500 lux	100 - 500 lux	100 - 500 lux	100 - 500 lux
Hours	3000 hours	6205 hours	6205 hours	3000 hours	3000 hours
Number of Luminaires	2 Ceiling	4 Ceil. + Wall	4 Ceil. + Wall	4 Ceil. + Wall	4 Ceil. + Wall
Power per Luminaire	37 W	5 - 98 W	5 - 98 W	5 - 98 W	5 - 98 W
Daylight-Dependent Control	yes	yes	yes	yes	yes
Occupancy Sensor	no	no	yes	no	yes
Total Annual Energy Use Day	118.0 kWh	268.3 kWh	236.4 kWh	129.7 kWh	114.3 kWh
Night (Average Illuminance -->)	100 lux	10 - 100 lux	10 - 100 lux	10 - 100 lux	10 - 100 lux
Hours	1000 hours	730 hours	730 hours	1000 hours	1000 hours
Number of Luminaires	2	2 Wall + Bed	2 Wall + Bed	2 Wall + Bed	2 Wall + Bed
Power per Luminaire	12.3 Watt	5 -18 Watt	5 -18 Watt	5 -18 Watt	5 -18 Watt
Total Annual Energy Use Night	24.7 kWh	1.86 kWh	1.49 kWh	2.6 kWh	2.0 kWh
Total Annual Energy Use	142.6 kWh	270.18 kWh	237.89 kWh	132.3 kWh	116.3 kWh
LENI (for Room of 18 m^2)	7.9 kWh/m^2	15.01 kWh/m^2	13.22 kWh/m^2	7.3 kWh/m^2	6.5 kWh/m^2
Energy Savings compared to Standard Reference		-89.4%	-66.8%	7.3%	18.4%
Energy Savings compared to Existing (Existing Adj)			12.0%		12.1%

Note: If possible, the actual energy use at Skejby Psychiatric Hospital should be measured after COVID-19 is over.
Calculation done on 16 Dec 2020 - WO_IVE

4.4 Conclusions

This estimated analysis shows that current circadian lighting systems installed in Danish healthcare facilities could potentially use significantly more electricity than other common or standard reference lighting installations. Yet, there are rather simple solutions available.

The calculations conducted as part of the project show that daylight-dependent dimming and occupancy sensors can contribute significantly to the reduction of lighting energy use in buildings. We observed that these circadian lighting systems with very similarly sized rooms (15, 15.65 and 18 m^2) and identical operating hours achieved a Lighting Energy Numeric Indicator (LENI) value of between 6.5 and 7.0 kWh/m^2 when fitted with daylight-dependent dimming and occupancy controls.

If possible, we would really like to conduct actual and detailed measurements of lighting energy use in the near future. That would allow us to get a better understanding of the actual energy use figures for these healthcare facilities and offer a useful check on the provisions of DS/EN 15193. Such measurements would then enable a realistic comparison with the estimates provided here.

As far as energy cost savings are concerned, we would like to name one example. If the existing circadian lighting system at Vikærgården would be equipped with a daylight-dependent dimming system and occupancy sensors, this would result in approximately 212.5 kWh and DKK 425 less per room and year than used by the existing system when a cost of DKK 2.00 is assumed for each kWh of electricity. While this does not seem much, it is approximately 14.2% of the annual energy use of a single person household in Denmark at 1,500 kWh.

5

DISCUSSION

5 DISCUSSION

5.1 Intended Purpose for Installing a Circadian Lighting System

Any consideration for the installation of a circadian lighting system should include a serious discussion of the intended purpose. Establishing clearly articulated reasons for such a system is paramount so that appropriately selected expert advisors and lighting designers understand the needs of those being exposed to the lighting system. There are many options on the market, and it is difficult to select suitable solutions fit for the intended purpose. Good communication between the ultimate users – or as in the case of patients, their medical service providers – and the designers/manufacturers/installers of the lighting system seems a prerequisite for ending up with the best possible solution. The intended purpose should in any case be the most important driver for any decision, as different purposes usually call for different answers to the problem statement. For the two healthcare facilities studied in detail in this project, a key aim for the installation of a circadian lighting system was allowing patients in a psychiatric hospital (especially manic-depressive patients) and an after-surgery rehabilitation center to return to a normal and regular sleep/wake cycle. It was the hope that this would help speeding up their healing and recovery process and perhaps even reduce the need for some medication and avoid physical restraint (in psychiatric hospital). As the lighting in Slagelse offers only two different settings for the lighting – one during the day and one at night – circadian lighting is perhaps not the right descriptor.

5.2 Energy Use

That the fear of increasing energy use with circadian lighting systems had been raised by several of the participants involved in the planning process for some of the initially proposed case study facilities for this project, is probably not surprising. Too little seems to be known about actual energy use data for circadian lighting installations. This is one of the reasons for wanting to conduct this study. Diving into the technical data of the installed lighting systems we monitored and taking photometric measurements in various spaces allowed us to make some progress. The perception that the lighting systems installed to date might use more energy, appears to be supported by the data we collected.

However, daylight-dependent dimming control and presence detection sensors integrated in electric lighting systems can contribute significantly to a reduction in the electricity consumption for lighting in buildings. This had also been shown in the energy calculations we conducted as part of this project. The Danish Building Regulations require the installation of daylight-dependent controls for electric lighting in work environments. Occupancy sensors are, on the other hand, only required in spaces that are intermittently occupied for a short time. Because of the potential savings that can be achieved, planners of lighting installations in healthcare environments are strongly encouraged to add these control systems also when establishing circadian or other dynamic lighting systems, although circadian lighting installations in healthcare environments might in some cases be interpreted as special medical lighting.

Establishing separate groups and auxiliary meters for lighting systems and their controls could facilitate the process of measurements. It is expected that this would lead to further electricity savings, as building owners will be able to visualize the often hidden components of the building's electricity consumption.

5.3 Photometric Assessment

Photometric measurements provided a good sense of the lighting distribution and supported the calculation of circadian potential of the circadian lighting installations. The two investigated circadian lighting systems were rather different from each other and the purpose of the respective buildings was also different. The intended purpose of the lighting, however, was similar: supporting a better sleep/wake cycle of the patients and allowing for more alertness during the day.

Access to daylight mostly depended on the configuration of the façade, which greatly differed in the two cases, primarily in the width of the windows. That was reflected in the daylight factor results with 1.4% for Vikærgården and 2% for Slagelse Psychiatric Hospital. It was true in both cases that performing visual tasks at the table placed next to the window during daytime should have been effortless. Deeper in the room electric lighting might have been necessary, though mainly for examinations/treatment or reading in bed. The overall horizontal illuminance in both rooms provided sufficient light during the day to fulfil the requirements of the applicable standard (Table 1-3). However, in Slagelse it depended very much on the location of the bed, as the layout of the luminaires did not provide uniform lighting in the middle of the room. Some staff members, however, perceived illuminance levels at night, as being inappropriate for the room and too yellow.

There was no complaint about noticeable or disturbing glare in Slagelse from daylight or from the electrical lighting; despite luminance map analysis indicating that intolerable glare from daylight might occur when entering the room from the hallway (view 2). The same was true for the night settings of the electric lighting from view 1, because one of the luminaires was placed directly in the field of view when sitting on the bed. The SPD, CCT and R_a measurements show that the luminaries provided a rather warm light, which was appropriate for the afternoon and evening, but an option to switch to CCT values around 6500K could be desirable for providing more light for treatment and melatonin suppression. This option was provided at Vikærgården. However, it did not reach 6500K, but 5500K. As the luminaires could have become possible glare sources in their brightest settings, perhaps a different luminaire design would be more suitable. The color rendering of the lights was suitable for the activities, but some perceived the night settings as too red. That made it harder to recognize certain colors when treating patients at night.

5.4 Circadian Potential

In Slagelse, none of the luminaire settings could provide the necessary circadian stimulus (CS) or melanopic equivalent daylight [D65] illuminance (M-EDI) values that are suggested during daytime. On the other hand, that meant that they likely provided adequate CS values during the night at low illuminance and CCT. With only two settings and not able to reach the daytime exposure for suppressing melatonin production, the daytime illuminance for that purpose would need to be supplied by daylight entering the room through the windows. A desk in front of the window allowed this to happen.

At Vikærgården, the separate light settings were more tuned to the circadian needs. Therefore, some settings during morning hours and the light therapy setting could provide "okay" M-EDI values. However only the wall washer could reach the daytime target zone for CS, but the other luminaires could possibly also be tweaked to reach these values. In this case, requiring the lights to reach the EML and CS target was justifiable as they were meant to provide melatonin suppression during certain periods of the day, but not for the whole day.

5.5 User Perspective

The semi-structured interview survey aimed at finding answers to questions about the user experience with the respective lighting systems. Staff also attempted to provide some input on their perceived effects of the lighting on patients.

Vikærgården – 13 Respondents

Most of the staff indicated to have an idea about the circadian lighting and its effects on them and their patients. They often controlled the lighting from the switches in the rooms, the central touch screen was less preferred. Half of the staff had problems with operating the lighting controls through the touch screen, even though they had a manual for the system. The staff noticed that patients also had difficulties with operating the lighting controls. They usually found the desired lighting scene only after several failed interactions with the switch. The location of the switch was also identified as an issue due to immobility of some patients. For some patients, a bedside or remote switch would have been more suitable.

Generally, people liked the circadian lighting system, except for a few situations when they noticed glare, when they moved between different wards, and when the morning setting came on with far too bright lighting levels after the night.

Employees found it easy and well suited for work during daytime. For the evening, half of them found it rather too dark or too red for working and they needed to switch to another light setting to be able to perform visual tasks requiring higher light levels. However, the light was deemed adequate for resting, the main purpose for having the night setting.

Many participants felt that the circadian lighting made the ward more calm and less noisy so that patients slept better. They also noticed that there was less activity during the night.

Staff thought there was a need for an in-between setting before the light turned to morning light after the night lighting setting. Some people also noticed that the light turned too dark too early in the evenings, preventing them from properly assisting patients with personal care before the night. Regardless of the critical comments, many of them would still recommend this kind of lighting to others.

Slagelse – 6 Respondents

In Slagelse, the lights were mostly operated through a touch panel located in the nursing staff room. Staff noticed that some patients had difficulties with operating the lights in their room. Most of the time, people were satisfied with the lighting, however some of them thought it was too yellow and/or too dark at night. They had the same opinion about the lighting in different rooms, such as the bedrooms, corridors and nursing staff rooms. Therefore, some of them had difficulties with treating the patients at night, as well as recognizing colors properly, a potential danger while dispensing medication. They did not notice any change in the general activity levels, sleep quality or noise levels. Moreover, they did not notice any significant emotional effect change for staff or patients they would have attributed to the lighting.

An overall issue was reading under the ceiling lights, as they were not suited for this purpose. There were additional reading lights provided in both facilities, however they did not match the spectral properties of the ceiling luminaires at night, therefore they had the potential to disrupt badly needed regular sleep patterns. Some patients tended to use these reading lights excessively as night light, which counteracted the aim of helping patients returning to regular sleep routines.

5.6 Tangible Lighting Controls

Accessible lighting controls have been flagged by survey respondents as an important aspect in this study because patients in hospitals, unlike healthy individuals who can move to another location providing better lighting, can be limited in their mobility due to injury, illness, disabilities or old age. Simple and accessible lighting controls and intuitive and tangible switch design solutions for adjusting the lighting settings to suit the changing visual needs of a patient or a staff member caring for him/her are therefore imperative.

With the lighting installations described in this project, the users experienced difficulties when using the switch buttons to turn the lights on and off at the Psychiatric Hospital in Slagelse and to a lesser extent at Vikærgården as well. The exact functions of the buttons are not indicated on the switches or near them in Slagelse, but there are very small labels next to the switch buttons at Vikærgården. The switches at Vikærgården are unfortunately located in a dark corner in the entry hall of the patient suite and not accessible from the bed or other locations in the bedroom. An option is to change the controls in a more tangible and intuitive way, so the users can reach and understand the controls more easily. Providing more than one location for switches is one solution. Another is clearly presenting the lighting control options for fast identification and understanding. For this purpose, an easy and economical solution to address the problems would be to label the switches with some stickers around them, for example as shown in Figure 5-1. The controls could also be changed into a knob, which could turn to the left or right for choosing the desired light setting. Here some logos could indicate the different lighting settings. The knob could be pushed and pulled for other functions, such as an emergency lighting or just simply to turn off the lights (Figure 5-2). Either of these solutions would be suitable for the examined facilities.

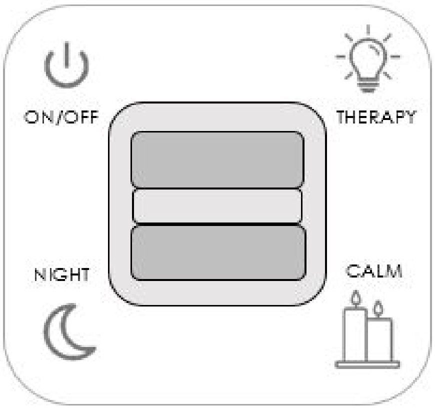


Figure 5-1 – Example for how logos could describe the different buttons and what light is turned on with each button. This example could be an option for Vikærgården.

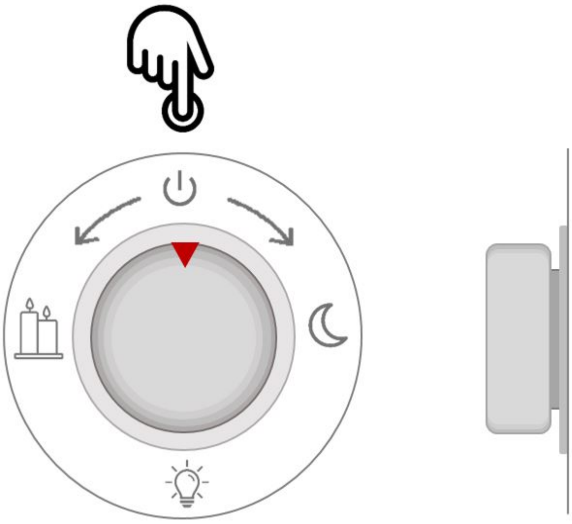


Figure 5-2 – A button which could be turned to the left or right and with the logos as explanation for the light settings.

For both of the current installations and the proposed controls, it would make sense for staff and patients to receive an instruction sheet when first arriving at the facility. The sheet can contain some recommendations to help with using the right kind of light at the right time of the day.

The placement of the controls could also be changed, so they would be placed close to the patients, because some of the patients cannot move from the bed. Alternatively, a remote control device could substitute for the current solution as well, so the patients could choose whether to have it with them or place it in the wall mount.

Sometimes medical staff need to work with the patients during emergency situations or personal care and need additional lighting or higher light levels. Additional switches/buttons that could only be operated by staff members could serve such a purpose.

5.7 Calibration and Commissioning

Any new lighting system needs to be properly calibrated and commissioned. When new luminaires and controls have been installed, the system should be carefully calibrated to ensure that it does what it is supposed to do as accurately as possible. As part of this process, the manufacturers and suppliers of lighting equipment and related components should provide calibration guides for all parts of the installation.

Afterwards, all functions should be rigorously tested by someone who is independent of the installation firm or manufacturer. Questions that arise during the tests should be investigated carefully and possible problems corrected. Instruction guides should be prepared for both operation by a variety of users and targeted to their specific needs, and for maintenance, so that technical service personnel understand what needs to be done when. With good instruction guides, staff turnover in critical positions might be less problematic, when the new employee arrives without understanding the system, but is able to read up and understand in a rather short time.

When changes of any kind are made to a system, clear procedures will go a long way.

5.8 Maintenance Strategies and Procedures

The survey and monitoring process conducted as part of this project also uncovered some relatively minor and easily solvable maintenance concerns, but other issues might not surface until later.

Regular replacement of the compact fluorescent lamps in the not yet retrofitted patient suites at Vikærgården had obviously been neglected for quite some time. The lumen output of some of the lamps had reached less than half of the original values for some of the light sources, resulting in very dark spaces. It is therefore not surprising that staff had difficulties with performing their tasks of examining and caring for patients during evenings and nights. The neglect might have been linked with the desire to roll out the new circadian lighting system across all wards over the coming months and not wanting to invest more money into the current system. We would like to emphasize that not conducting regular maintenance of the lighting system could possibly lead to unsafe conditions for both staff and patients.

New lighting solutions are almost entirely based on LED technology, as this provides significant benefits with respect to energy use, and flexibility for control of the desired light levels and spectral properties. On the other hand, LED technology is undergoing rapid development and products available today might not be there any more tomorrow. This fast pace affects the current installations, as replacing failed LED luminaires can become difficult, unlike with the well-known fluorescent sources that can be changed easily. The same is true for the drivers controlling the output of the LEDs. In some cases, entire luminaires need to be sent away to the manufacturer for re-fitting of new drivers and associated re-programming – if they can be repaired or changed at all. This might lead to increased costs for transport and temporary new installations. It seems therefore important that decisions for particular solutions need to include a good understanding of the issues to be considered. Clear maintenance strategies for replacing failed LED lighting components need to be set out from the start, preferably before the lighting system to be installed is chosen. Economic perspectives, repairs and the possibilities for future renovations and upgrades should be taken into account in the process.

6

CONCLUSIONS FROM CASE STUDIES

6 CONCLUSIONS FROM CASE STUDIES AND FUTURE RESEARCH

In the present project, we have examined selected lighting systems in order to collect data on how they perform, especially with respect to their purpose, ease of use, energy consumption and lighting technology aspects.

Various energy use and visual conditions have been mapped in two types of lighting systems at Vikærgården, a short-term residence for rehabilitation in Aarhus. Another type of circadian lighting system at the Psychiatric Hospital in Slagelse was investigated in the same way. Based on interviews with users, these facilities have also been examined for user-friendliness, degree of use, satisfaction with the subsequent daily use and the perceived impact on staff and patients.

At Vikærgården, the lighting installation was first tested through establishing on-site mock-up spaces and revising the lighting design after the initial tests before a larger ward of the facility was fitted with the new lighting system. Nevertheless, there remains room for improvement, as this study has shown. Generally, the new dynamic LED lighting system produces adequate illuminance levels and lighting distributions in the rooms and appears to provide some perceived support of some patients' and staff members' circadian rhythm. Analyzing the lighting system based on the few established circadian metrics available seems to indicate that the system is effective with respect to the aims of circadian lighting and can provide the suggested properties with respect to circadian stimulus or melanopic equivalent daylight illuminance. Both vertical and horizontal illuminance measurements confirm that the different lighting settings are suitable for their purpose. The luminance maps showed that the light therapy setting can cause glare for the occupants, which was also supported by the user opinions in the questionnaires. This could potentially be resolved with a different luminaire design providing better shielding. In addition, users suggested a gradual, rather than abrupt lighting transition from night to daytime lighting in the early morning and a later onset of the nighttime lighting.

In Slagelse, we saw a different approach to circadian lighting. The selected solution focused on simplicity in implementation and limited control options. This has advantages with respect to operation and maintenance costs. However, it cannot provide all the benefits of a more elaborate system. The chosen solution provided barely enough light for the rooms for basic visual tasks and could – according to the applicable standards – not provide sufficiently high illuminance levels for sustained reading or patient examinations. The only dynamic feature was the shift from three daytime LED luminaires with slightly higher CCT and illuminance values to two nighttime LED luminaires in different locations and lower CCT and illuminance. While add-on luminaires for reading could be made available on request, this would not always be possible because of potential safety concerns for some psychiatric patients. The circadian metrics show similar results. The lighting scenarios are adequate for supporting rest and general activities not requiring sustained visual work, but they do not provide any boost for alertness or circadian entrainment, or more flexibility and options than a regular dual setting lighting installation. The luminaires have the potential, so maybe a better layout and adjustments would improve the situation.

The selected options for controlling the available lighting scenarios is a concern in both facilities, which is why we addressed this aspect in some more detail above. There are easy and economic ways of handling this, which would immediately change the usability of the system and hence the satisfaction with it.

The maintenance of the system could be a future issue as well in both cases, especially as LED and control technologies are still rapidly developing, leading to systems potentially being outdated rather sooner than later. It might be advisable to plan and develop strategies for ongoing upgrades to the system as LED luminaires and control system components of the same type might be available only for several years, rather than decades.

For the Psychiatric Hospital in Skejby, it was possible to undertake energy calculations and evaluations of technical solutions based on the tender materials and information from technical managers by telephone. There remain problems with the operation of the system due to integration of the lighting controls with the building management system that seems to have gone a bit awry.

Examination of the case studies found that there is a great need for clear communication about the purpose and implementation of the respective lighting systems and that several rounds of calibration and adjustment appear to be necessary for goals to be achieved. When gradual changes in lighting levels and spectrum occur, minor failures with respect to controlling the scheduled scenarios might go unnoticed without regular checks. Without a clear understanding of what the lighting system is expected to do when, it is difficult for a technical service leader to implement appropriate tests and maintenance strategies.

We also noted that two of the three cases had not established daylight-dependent controls and motion sensors in the patient bedrooms, which had a great impact on energy consumption, as the lights might be providing unnecessarily high levels of illuminance during periods when this would not be needed due to available daylight or the space not being occupied. This means that the energy consumption for the installations in question would be greater. It would also significantly shorten the lifetime of the installation.

This project has just touched upon the practical challenges connected with the installation of circadian lighting systems. Much knowledge about the potential for energy savings of different design, operation and maintenance strategies for circadian lighting installations is still to be gained. Nevertheless, the results from the surveys, measurements and calculations presented here can clearly contribute with recommendations for future “best practice” solutions for circadian lighting systems. We have seen that not everything that might be labelled as circadian lighting lives up to this goal. There appear to be countless different approaches to the problem out there, and it is difficult to get a good overview of which technology and implementation strategies work best in which situation and for which purpose with respect to the needs of the individual seeking help in the healthcare system.

There is also a need for collecting more evidence on the human health and comfort benefits expected to be provided by lighting systems integrating visual and non-visual effects of lighting to support well considered goals for circadian entrainment and better sleep habits in a world rich in stimulation by lighting around the clock and little opportunity to find darkness. However, darkness at night is as vital to human health as light during the day. The natural cycle of light provided by the sun has set a standard for circadian lighting. The dream of mimicking this solely through electric lighting should, however, never let us forget about the excellent resource daylight provides to us. On the contrary, we should aim for making daylight the most used and valued light source in our buildings again and support any effort attempting to improve daylighting conditions in our work and living environments.

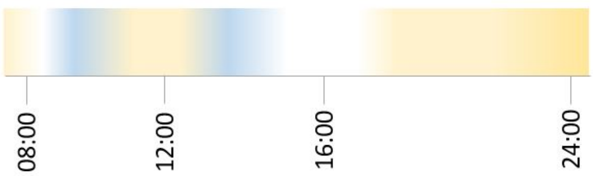
CASE STUDY	CIRCADIAN LIGHTING APPROACH	
VIKÆRGÅRDEN	Dynamic Daily Schedule	
SLAGELSE	Day and Night Set Points	

Figure 6-1 – The differences between the settings in the circadian lighting systems at Vikærgården and in the Psychiatric Hospital in Slagelse

It remains to be seen whether the currently debated melanopic equivalent daylight illuminance (M-EDI) values and timing schedules for circadian stimulation by electric lighting are indeed appropriate in the long term. There also is a need for addressing different health conditions and how circadian lighting can contribute to providing relief and healing for patients.

Evidence needs to be collected in systematic ways, and this could probably be best accomplished in interdisciplinary teams of researchers spanning the whole bandwidth of experts from lighting designers to building professionals, electrical and electronics engineers, and chrono-biologists and other medical specialists. Funding agencies might also join forces to allow for this type of research to occur in the not-too-distant future, as such work would likely speed up the process of gaining the necessary knowledge to advance circadian or integrative lighting.

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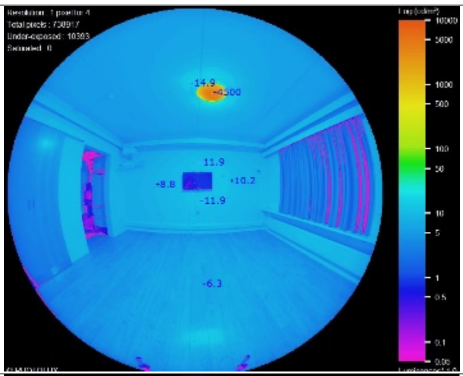
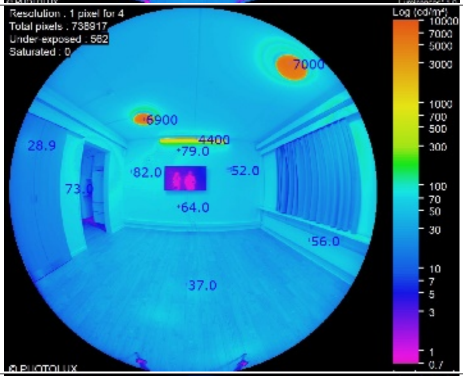
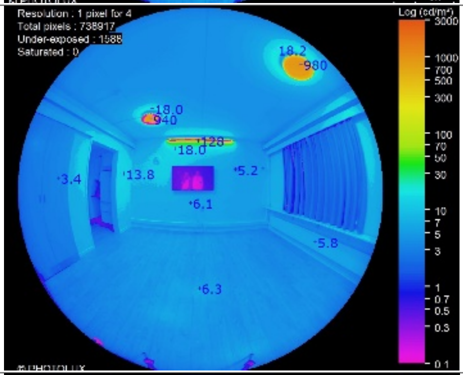
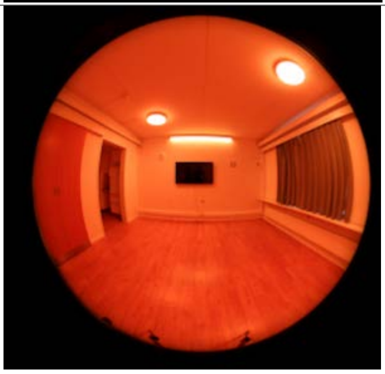
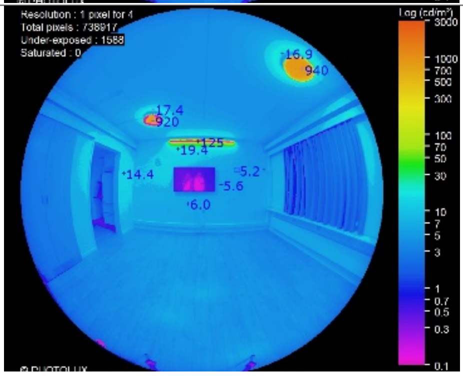
[15] Danish Standards Association, "DS/EN 15193-1:2017 Energy performance of buildings- Energy requirements for lighting - Part 2: Explanation and justification of EN 15193 Module M9," Danish Standards Association, Nordhavn, 2017.

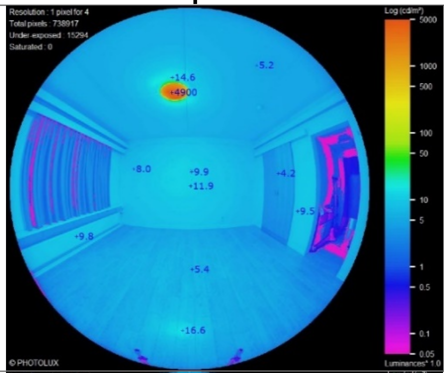
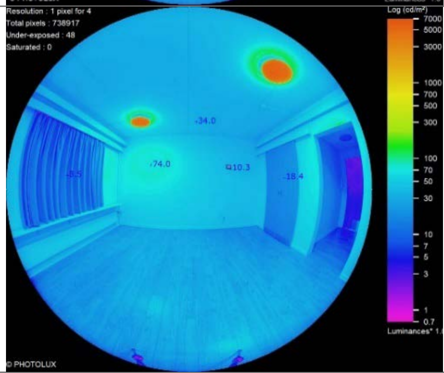
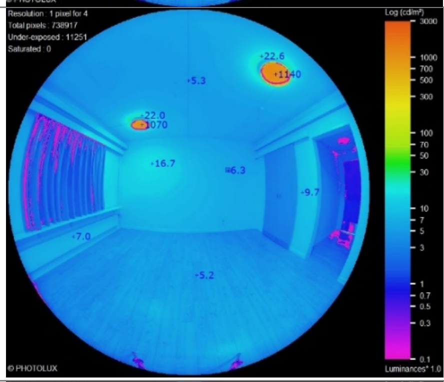
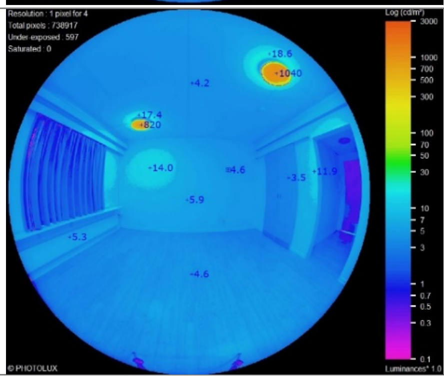
9

APPENDICES

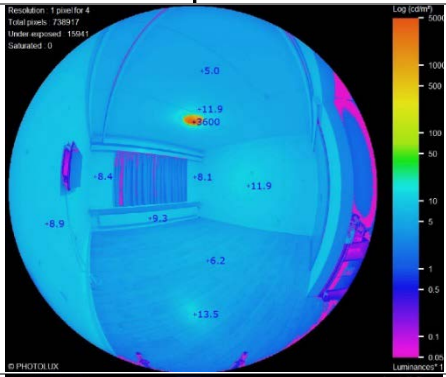
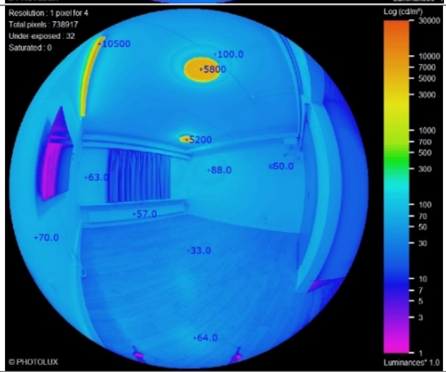
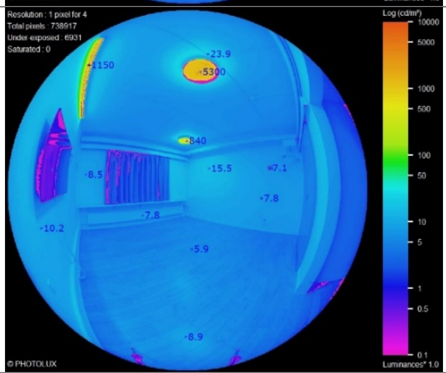
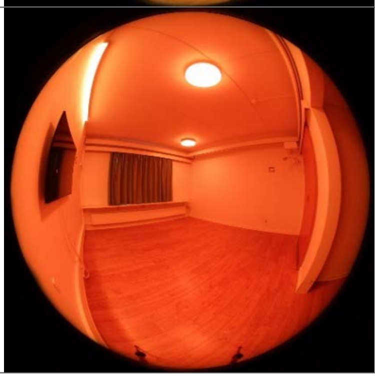
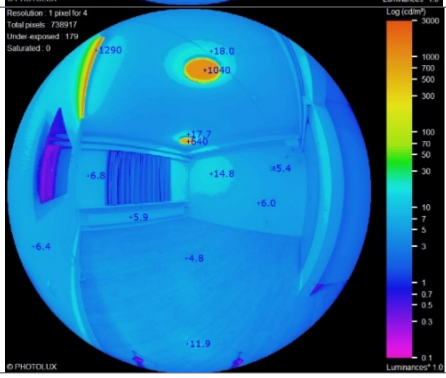
9 APPENDIX

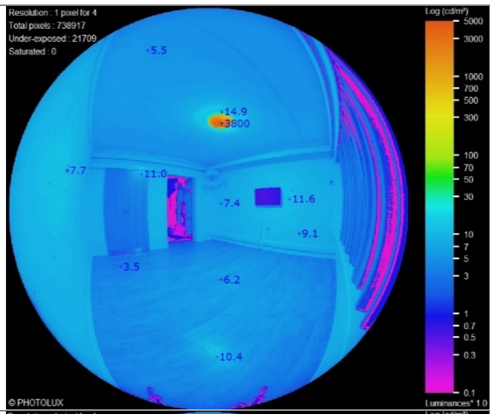
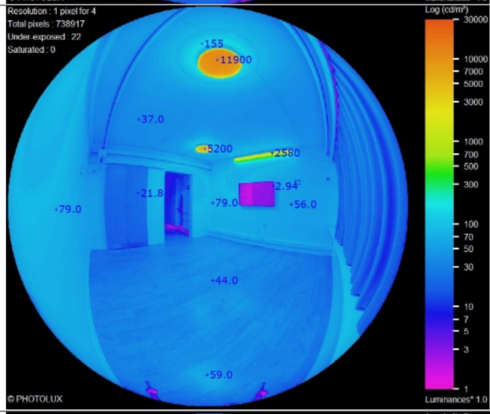
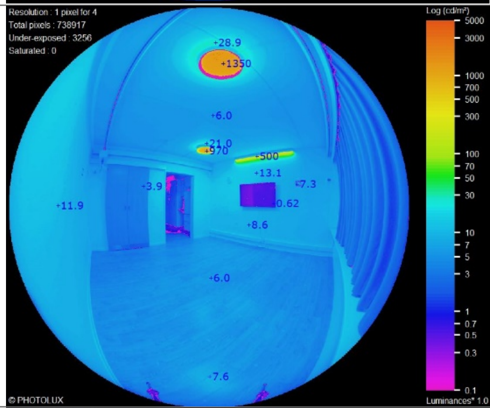
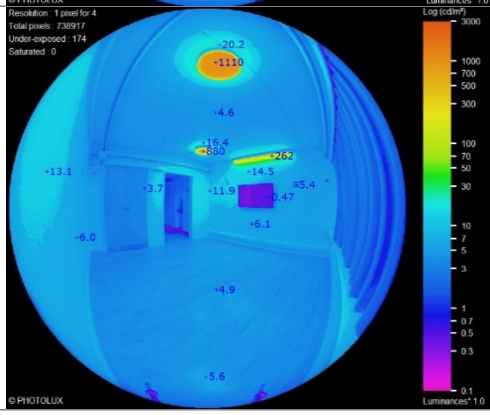
9.1 Appendix A

View 1		
Lighting Scenario	**Picture with fisheye-lens**	**Luminance Map**
CFL UGR: 18.3		
Light Therapy UGR: 18.5		
Night Care UGR: 10.8		
Calming UGR: 10.8		

View 2		
Lighting Scenario	**Picture with fisheye-lens**	**Luminance Map**
CFL UGR: 18.4		
Light Therapy UGR: 16.8		
Night Care UGR: 11.3		
Calming UGR: 10.6		

View 3

Lighting Scenario	Picture with fisheye-lens	Luminance Map
CFL UGR: 19.2		
Light Therapy UGR: 17.3		
Night Care UGR: 10.7		
Calming UGR: 10.9		

View 4		
Lighting Scenario	**Picture with fisheye-lens**	**Luminance Map**
CFL UGR: 19.0		
Light Therapy UGR: 18.5		
Night Care UGR: 11.9		
Calm UGR: 11.2		

9.2 Appendix B

Questionnaire on the perceived effect of circadian lighting among employees and patients.

PERSONAL INFORMATION

With this questionnaire, we would like to ask about the lighting you work under on a daily basis and how you and your patients feel about it.

Have you tried working in a department/section where circadian lighting has been established?

☐ Yes, please coment____

☐ No

What is your job/ work function?

☐ Doctor/ Psychiatrist

☐ Nurse

☐ Psychologist

☐ Physiotherapist

☐ Ergo therapist

☐ Social and health worker

☐ Administration

☐ Cleaning staff

☐ Social and health assistant

☐ Other (please indicate)

____

Sex

☐ Male ☐ Female ☐ Other (please indicate) ______________________

Age group

☐ 20 to 29

☐ 30 to 39

☐ 40 to 49

☐ 50 to 59

☐ 60 and over

During which shifts do you primarily work?

☐ Day shift ☐ Evening shift ☐ Night shift

LIGHT SETTINGS AND OPERATION

Do you use the lighting setting options in your everyday work?

☐ Yes

☐ No, please indicate why____

Do you know why dynamic circadian lighting has been established?

☐ No

☐ Yes, please indicate why____

Have you noticed how often the light settings change?

☐ Daily (Please indicate how many times) ____

☐ Weekly (Please indicate how many times) ____

☐ Monthly (Please indicate how many times) ____

☐ No, I have not noticed – (Never)

How often is the circadian lighting system used in the ward?

☐ Always ☐ Sometimes ☐ Rarely ☐ Never

Can patients find out how to use the lighting in their bedroom?

☐ Yes, all ☐ Yes, most of them ☐ Yes, some of them ☐ No, nobody

What is the most common way in which you operate the lighting?

☐ Touchscreen in the staff room/monitoring room

☐ Switch in the individual bedroom

☐ Switch in common areas

☐ I don't operate the light

☐ I do not know

VISUAL EXPERIENCE

Do you perceive the distribution of light and dark surfaces in the room as appropriate?

☐ Yes, very comfortable ☐ Yes, comfortable ☐ Annoying ☐ I do not know

Do you experience glare from the lighting?

☐ Yes From which source? ________________________ When? ______________________________

☐ No

☐ Other (please indicate) ____

Do you find that the lighting is appropriate for the use of the room?

Corridors

☐ Yes

☐ No (where/when?)____________________

☐ I don't know

Bedrooms

☐ Yes

☐ No (where/when?)____________________

☐ I don't know

Common rooms

☐ Yes

☐ No (where/when?)____________________

☐ I don't know

Staff room

☐ Yes

☐ No (where/when?)____________________

☐ I don't know

Are there times when the lighting feels too warm/yellow?

☐ Yes (where/when?) ____________________

☐ No

☐ I don't know

Are there times when the lighting feels too cold/blue?

☐ Yes (where/when?) ___________________

☐ No

☐ I don't know

How do you experience working and being under the circadian lighting?

	Day	Evening	Night
I can see colors clearly under the circadian lighting	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know
I can see the patients clearly	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know
I can read, write and perform my work tasks without a problem	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know

	Day	Evening	Night
The circadian lighting is comfortable to stay in	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know
I can clearly see the PC/TV screen	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know	☐ To high degree ☐ To some degree ☐ To small degree ☐ No at all ☐ I don't know

EFFECT OF CIRCADIAN LIGHTING ON STAFF

To what extent have you experienced that the circadian rhythm light has a positive effect on you in relation to

Good sleep quality

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

Calmness in the ward

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

Increased energy level

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

Lower voice volume

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

Better physical well-being

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

Increased security

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don’t know

EFFECT OF CIRCADIAN LIGHTING ON PATIENTS

To what extent have you experienced that the circadian rhythm lighting has a positive effect on the patients in relation to

Better sleep quality

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Better sleeping habits

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

More calmness in the ward

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Lower conflict level

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Better energy level

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Decreased night activity

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Prevention of patient restraint

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

More cozy atmosphere

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Increased security

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Reduced medicine use (for sleep)

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Reduced medicine use (other)

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

Better quality of treatment

☐ To high degree
☐ To some degree
☐ To small degree
☐ No at all
☐ I don't know

How do you experience the patients' satisfaction with the evening lighting?

Comment (short description) ____

How do you experience the patients' satisfaction with the night lighting?

Comment (short description) ____

How do you assess the experience of the patients with the lighting in general?

Comment (short description) ____

EMOTIONAL EFFECT

Has the circadian lighting affected you positively/negatively and to what extent?

☐ To high degree — Please indicate how ____

☐ To some degree — Please indicate how ____

☐ To small degree — Please indicate how ____

☐ Not at all — Please indicate how ____

☐ I don't know — Please indicate how ____

How do you experience the evening lighting?

The evening lighting is soothing and creates security

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The evening lighting creates a calm atmosphere

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The evening lighting causes us to talk at a lower volume

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

I feel more fresh after the evening shift

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

I can fall asleep easier after the evening shift

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The eyes easily get used to the evening lighting

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

How do you experience the night lighting?

The night lighting is soothing and creates security

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The night lighting creates a calm atmosphere

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The night lighting causes us to talk at a lower volume

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

I feel more fresh after the night shift

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

I can fall asleep easier after the night shift

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

The eyes easily get used to the night light

☐ To high degree

☐ To some degree

☐ To small degree

☐ No at all

☐ I don't know

Do the light settings make sense in everyday life?

☐ Yes (short description) ____

☐ No (short description) ____

☐ I do not know (short description) ____

INSTRUCTION AND IMPLEMENTATION

Has the staff been offered instruction on how to use the circadian lighting?

☐ Yes (short description) ____

☐ No (short description) ____

☐ I do not know (short description) ____

Are you satisfied with the instruction about the lighting?

☐ Very satisfied

☐ Satisfied

☐ Unsatisfied

☐ Very unsatisfied

☐ I do not know (comment) ____

Do you have a user manual?

☐ Yes

☐ No

☐ I do not know

Do you use the user manual?

☐ Yes

☐ No

☐ I do not know

Do you feel certain that you understand the functions of the lighting control system?

☐ Yes

☐ No

☐ I do not know

Do you experience challenges in everyday life when using the circadian lighting?

☐ Daily (Please indicate how many times) ____

Which challenges? ______________________________

☐ Weekly (Please indicate how many times) ____

Which challenges? ______________________________

☐ Monthly (Please indicate how many times) ____

Which challenges? ______________________________

☐ Never

Have you experienced problems with maintenance of the lighting system?

☐ Daily (Please indicate how many times) ____

Which challenges? _________________________________

☐ Weekly (Please indicate how many times) ____

Which challenges? _________________________________

☐ Monthly (Please indicate how many times) ____

Which challenges? _________________________________

☐ Never

Do you experience challenges in emergency situations when using the circadian lighting?

☐ Daily (Please indicate how many times) ____

Which challenges? _________________________________

☐ Weekly (Please indicate how many times) ____

Which challenges? _________________________________

☐ Monthly (Please indicate how many times) ____

Which challenges? _________________________________

☐ Never

Would you recommend the circadian lighting to others?

☐ Yes (short description) ____

☐ No (short description) ____

☐ I do not know (short description) ____

Do you have any suggestions for changes/adjustments? ______________

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