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Evaluation of staff's perception of a circadian lighting system implemented in a hospital

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ABSTRACT

Natural and electrical lighting have received attention in hospital environments due to their ability to increase hospital staffs' performance, improve shift workers' circadian rhythm and improve patients' recovery. Researchers have investigated health care staffs' satisfaction with their lit work environment in real-life settings; however, staff members' perception of a circadian lighting system (CLS) that operates automatically has yet to be researched. This paper presents the implementation of a CLS installed in a newly built hospital between June 2021–February 2022. Two surveys ($n^1 = 63$, $n^2 = 48$) and 10 interviews were conducted with staff. Wilcoxon rank-sum test was conducted to compare staff members' responses between the pre-existing lighting (PeL) and circadian lighting system (CLS) at Neuro Intensive Care Unit and Postanesthesia Care Unit. The results showed a statistically significant satisfaction with the CLS compared with the PeL ($p = 0.0003$), and the staff found the CLS easier to use ($p = 0.0011$) and to adjust ($p = 0.0023$). The staff working in rooms with multiple patients appreciated the ability to adjust the lighting to the individual patient. These results supplement the existing body of research by presenting a field-study that illuminates barriers and advantages to consider when implementing CLS in hospitals. We conclude that CLS can complement a complex work environment in hospitals, but it requires close collaboration with occupants and continuous adjustments to the lighting settings for a successful implementation, and long-term use of the lighting system.

1. Introduction

In built environments, health care employees' satisfaction and visual comfort are important for the quality of the general health care provided [1–6]. Besides thermal, acoustics and air quality comfort, visual comfort and light play an important role in carrying out tasks correctly and providing the right treatment for patients [7–9]. Recent research has established a correlation between the lit environment and job satisfaction. For example, poor illuminance and flicker can cause physical eye strain, discomfort glare, eye fatigue, affect sleep quality and safety [10–12]. The effectiveness of health care work can also be affected by poorly designed lighting when excessive time is spent on finding the right lighting setting appropriate for the task at hand, using medical penlights to shield patients or finding alternative ways of using light sources [13]. At night, bright, short-wavelength lighting, or blue light as low as 40 lx [14], has been linked to serious health issues [14,15] because it can suppress melatonin and create misalignment in the biological clock [15]. As a response to the issue at hand, researchers have stressed the need for attention to the design of lighting for individuals who do shift work and sleep at atypical hours to enhance performance and circadian regulation [15–17]. Research has also highlighted individual differences in light sensitivity and preferences, suggesting implementation of individual lighting solutions at work [9,15,17,18]. On the other hand, carefully designed lighting has the potential to affect staff members' performance [11], productivity, visual performance, alertness [14], risk of medical errors and satisfaction with their workplace [8]. In particular, red lighting during the night has been demonstrated to improve visual performance and alertness [14]. Moreover, exposure to lighting that imitates natural daylight has been shown to improve visual comfort and alertness in the morning and evening

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compared to regular LED [19].

Besides photometric measures, attention has been given to the factors of lighting that may impact staff members' and patients' satisfaction with a space. Researchers have also addressed the importance of visual ergonomics, and several methods have been suggested to mitigate the work environment's negative effects [20,21]. Such factors include daylight access, window view and solar blind positions [22], which have been determined to be important factors in occupant satisfaction and stress levels [23–28]. Daylight access and window view have been shown to shorten patients' hospital stays [26,29]. Other factors, such as task lighting, accessibility and lighting for navigation as well as absence of light during the night, have been rated as important among hospital staff [5,9,30,31]. Well-being, productivity and satisfaction are interlinked with control of occupants' environment and experience of lighting [32]. For example, being able to control the light in the surroundings is recommended in some hospital studies because it increases satisfaction with one's workspace [23,33]. One study found that controllability of the lighting affected med-surge nurses' satisfaction [6], while another study showed that nurses working in a room with zone-divided luminaires with separate controls, nighttime lighting and dimming, reported higher quality lighting, fewer complaints and needed fewer additional light sources to perform tasks compared to a lighting system with simple switching controls without dimming [31].

Arguably, it can be concluded that the lit environment affects the staff's work and health. With the increasing body of scientific evidence demonstrating the potency of lighting by its non-visual effects on occupants' biological rhythm, circadian lighting is a growing demand in building commissioning [34] Terms such as "human-centric lighting" and "circadian lighting" have become popular in the building practice and research communities [34]. However, designing lighting that meets visual and non-visual needs of health care staff in a hospital building for various complex activities and occupants is not an easy task and still needs much research [35,36].

There is little evidence of health care staff's perception of lighting systems that entrain biological rhythms and imitate the qualities of natural daylight (referred to in this paper as circadian lighting) in relation to variables of subjective visual comfort, satisfaction and overall acceptance of the lighting system. The lack of research on this topic might be due to the challenge of studying a lighting system that changes over the course of the day, various cofounding variables and the challenges involved in collecting data in a hospital environment [13], nevertheless, some researchers have conducted studies on health care staffs' satisfaction with aspects of circadian lighting [14,19,37]. The current literature includes recommendations for exposure to light during night shifts, e.g., maximum 10 lx Melanopic Equivalent daylight illuminance (M-EDI), preferably less than 1 lx M-EDI during the night, to prevent circadian misalignments [38], but how is the work environment perceived at night under these conditions? Moreover, an automatic lighting scheme is suggested for simulated daylight because of its potential to support our biological rhythms through a 24-h light-dark cycle offering the occupants' a recurring sense of time, creating a structure to the day, as well as reducing the number of things that the occupants have to remember to adjust [36]. However, there is little evidence that an automated lighting scheme affects occupants' satisfaction with the lighting [39].

This experimental study focuses on the satisfaction of health care staff working at a Neuro Intensive Care Unit (neuro-ICU) and a Post-anesthesia Care Unit (PACU) with a CLS compared to an existing lighting solution installed prior to the circadian lighting. The aim of the study is to document health care staff's visual comfort at all hours of the day, their perceived satisfaction with the work environment, ease of use of the lighting control and usefulness of the lighting.

The research question is as follows: Can hospital staff members' satisfaction with the lit environment and their visual comfort be improved by implementing a CLS?

H0. There is no improvement in staff satisfaction after two months of exposure to circadian lighting.

H1. After two months of being exposed to circadian lighting, staff satisfaction with the lit environment increased.

In the paper, we define visual comfort as a subjective judgement of a room's brightness and color temperature related to appraisal and visual capabilities. Visual comfort is connected to perception of adequate light e.g., illuminance levels, and having enough options to adjust the lighting [40–42]. In this paper, visual comfort refers to whether the nurses perceive the light as adequate to perform a task at hand. In this respect, visual comfort can affect perceived usefulness because poor visual comfort can affect the staff's capability to perform tasks with varying degrees of accuracy [13].

The study contributes to a holistic understanding of nurses' experience of a CLS and indoor environmental quality. The novelty of this study lies in its focus on circadian lighting in relation to health care staff's visual comfort and satisfaction. To our knowledge, other researchers have taken similar approaches to studying satisfaction with lighting in health care settings (see, for example 6,20,27,28), but very few with an automated 24-h lighting profile as the primary light setting [19,43,44,56].

2. Site and lighting conditions

The study was conducted at a newly built hospital facility housing a neuro-ICU and PACU; the department is a part of the Neuroscience Centre, University Hospital Rigshospitalet, located in Copenhagen, Denmark. This study was an investigation of two lighting conditions: the PeL solution that the department was equipped with when it was built in 2020 and a CLS commissioned by the Neuroscience Centre commissioned and installed in the summer of 2021. The CLS, designed by Chromaviso, has an evidence-based lighting profile that entrains occupants' circadian rhythm. The non-visual effects of the lighting profile have been tested in a clinical quasi-randomized control trial, which showed improvement in anxiety and depression scores and fatigue measures of stroke patients [45]. The CLS was installed on three floors of the Neuroscience Centre that treat brain- and nerve-related diseases. This study focused on the floor belonging to the neuro-ICU and the PACU. During the implementation process, key stakeholders from the respective units at the Neuroscience Centre were involved. The design proposal was discussed and adjusted to accommodate their needs. Prior to the installation of the circadian lighting, data was collected about the existing lighting. At this stage of the project, the aim was to map out the current lighting installation and to identify the lighting system's advantages and disadvantages. The main identified advantages included having a light source that was flexible and adjustable in height and angle [13]. The nurses valued this light source specifically for its lower correlated color temperatures (CCT) compared to the other light sources in the room. This was also useful for shielding the patients from the overhead lighting while still providing a bit of light with which to work. The ability to adjust the illuminance manually using the lighting controls was also appreciated; however, the nurses often found themselves in a dilemma when having to choose a light setting because they went to great lengths to shield the patient from unwanted light exposure, and they had difficulty finding the right setting [13]. This might be due to the settings' lack of change in CCT; only the intensity of the lighting changed. In the PACU, the nurses expressed the need to individualize the lighting by each patient's bed. As a result, when treating a patient, they switched on a 3000 K floss desk lamp or a 3000 K medical penlight. A general critique identified for the two units was the absence of light at the medical cart. Based on this feedback, a spotlight (CV3 spot) mounted in the ceiling was added to the floor plan, providing lighting specifically for the purpose of using the medical cart (see Fig. 4).

2.1. Pre-existing lighting system (PeL)

The PeL consisted of a 4000 K dimmable lighting system with the option to adjust the illuminance level [13] (Fig. 1), including six linear ceiling luminaires by Zumtobel (Tecton C LED4000-840 L2000 WB, Dali controlled, 4000 K, CRI 80) with five light settings (Table 4): The ceiling luminaires could be set to 25% intensity or 50% intensity and had a manual dimming option where the illuminance increased in steps. In addition, a small square-shaped luminaire (Berker B.7) fitted in the wall behind the patients' bed, close to the floor, provided a night-light. This was intended as orientation light but was not dimmable. Finally, the lighting could be switched off completely. Exclusively for the neuro-ICU patients' rooms, an examination lamp (Maquet Lucea, 4500 K, CRI 95) was attached on one of two ceiling mounted articulating arms. Besides the examination lamp and ceiling luminaires, the ceiling mounted articulating arm had three light sources (Maquet Moduevo, Getinge): uplights, downlights and vertical illumination at the height of the bed's headboard. In addition, the nurses carried an Abena medical pencil light, "medical penlight" (3000 K, CRI 99.5).

In the department, there are three open workstations in the hallways, with spotlights (Pleiad G3 CMP by Fagerhult) fitted in the ceiling and a 4000 K lighting strip fitted in the front of the desks, facing the hallway. An adjustable table lamp (Kelvin Edge by Flos, 2700/3200 K, CRI 90) with three settings was mounted on the desks in the open workstation in the patient rooms. The linear ceiling luminaires were also installed in the medicine dispensary, cleaning and storage spaces. The hallway lighting consisted of a continuous LED by Zumtobel (Tecton C LED2000-840 L1000 WB, 4000 K, CRI >80) located on the left side of the ceiling.

2.2. Circadian lighting system (CLS)

The CLS provides a dynamic lighting profile that changes during the day, ranging from 1800 K to 5500 K (CRI 90 at 2500–5500 K) (Figs. 1 and 2A and 2B). It operates automatically, with a reset at 05:55 each day. In addition to the pre-existing ceiling luminaires (PeL), Chromaviso Halo luminaires with a prismatic surface were installed. This integration of PeL and Halo luminaires will be referred to as CLS. When the CLS was implemented, a new lighting profile was applied to the PeL which we refer to as "Adopted PeL". The Halo luminaires provide the main illuminance whereas the existing ceiling luminaires supplement with light (Table 2). In each room, a spotlight (CV3 Spot, 1800 K–5500 K, CRI 90 at 2500–5500 K) was installed in the ceiling above a medical cart, which was stationed against a wall. In the neuro-ICU, only one CV3 Spot was needed whereas in the PACU, there are two medical carts in each of the rooms, hence two spotlights. In the medicine dispensary, cleaning and storage spaces the luminaires were not changed, but the lighting profile at night was dimmed to minimize the contrast from the hallway. During the daytime, the existing ceiling luminaires in the patient rooms, hallways and common workstations increase and decrease in illuminance, but the CCT stays at 4000 K. The Berker luminaire on the wall was unplugged due to limited control options for CCT and the dimming profile. Similarly, the 4000 K light strips in front of the desk in the open workstations were unplugged.

Common between the neuro-ICU and the PACU are four light settings (Tables 3 and 4): circadian lighting (Fig. 2A and 2B), night task light, night lighting and night spotlight (Fig. 3). The lighting can be controlled by a light switch with a capacity of six settings. For each workstation, the light can be controlled by a similar switch on the wall and a wall-mounted touchscreen. The staff can still use the desk lamps and lighting on the ceiling mounted articulating arm; however, they have been advised to use them with care during the evening and night. The new lighting scheme was placed into service on October 1, 2021.

Table 1
Light measurements.

Placement	Standing facing medical cart, mid-room position, and by the bedside	Seated at desk, facing computer screen	Medical cart
Vertical measurements	170 cm above floor	130 cm above floor	
Horizontal measurements		80 cm above floor	95 cm above floor

Note: Measurements heights are based on work surfaces and positions observed in the staff's behavior.

Light measurements were collected before and after the installation of the CLS with a spectrometer (Konika Minolta CL500A). The measurements for the pre-existing lighting were taken in September 2021 and are described in greater depth in Ref. [13]. Measurements of the Halo luminaires were collected in December 2022 (height of measurements are decribed in Table 1). Table 4 shows illuminance conditions for the medical cart that was frequently used by staff during a shift to store and prepare medical equipment and medicine. To achieve stable measurements with little interference, they were taken after dusk. The lighting scheme was simulated in an available patient room in the PACU. An off-state measurement was subtracted all CLS measurements to disregard the ambient illuminance from e.g., monitors and stray-light from the hallway. The data of the measurement simulated at midnight were so low that they may lead to increased uncertainty; the measurements were all below 0.5 lux M-EDI.

3. Materials and methods

3.1. Participants

Staff members' working in the neuro-ICU and the PACU participated in this study. The data was collected from two surveys in various stages as a within-group study. Survey 1 (n = 63) was used to collect data about the pre-existing lighting (distributed June 2021). Survey 2 (n = 48) was used to collect data about the implemented CLS (distributed December 2021–February 2022). The variables included in the surveys were gender, age, chronotype, years of work experience and job title. Table 5 outlines the participants' characteristics. As shown in the table, nurses and female respondents were overrepresented. In Survey 1, the staff worked mainly day shifts (n = 36) whereas in Survey 2, the staff mainly stated that they work all shift types (n = 27). In comparison, 16 respondents reported working all shift types in Survey 1. In Survey 1, 21 respondents reported working evening shifts and 13 worked night shifts whereas in Survey 2, only seven participants reported working evening shifts and four reported working night shifts. The majority of the participants in both surveys were 30–39 years old and most of the staff had

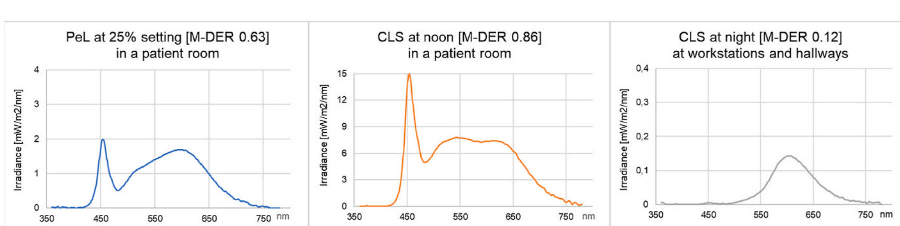
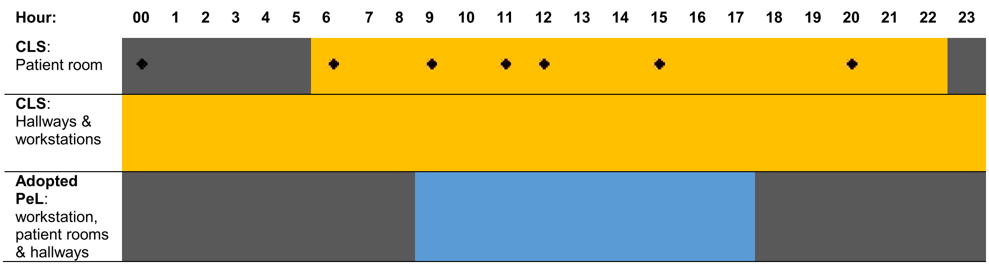


Fig. 1. Spectral power distribution and M-DER of PeL and CLS.

Table 2
Lighting profiles for CLS and Adopted PeL.



● = indicates when the light measurements were taken

worked in the department between 1 and 5 years. In Survey 1, most staff considered themselves early chronotypes. This was more balanced for Survey 2. All participants reported that they had no visual impairments other than myopia or hyperopia, which they corrected by wearing contact lenses or glasses (46% of the participants). At the neuro-ICU and PACU, the day is divided in three shifts: 07 a.m. - 3 p.m. (dayshift), 3 p.m.–11 p.m. (evening shift) and 11 p.m.–07 a.m. (nightshift).

The ethics committee at Aalborg University ethically approved the study (ID2021- 020-00540), and the head of the Neuroscience Centre delivered and accepted a protocol. The staff who participated in the study were anonymized with assigned ID numbers. Prior to participation, the staff completed an informed consent form informing them about their right to withdraw from the study at any time, the right to not answer questions and their anonymity. Special ethical conditions for data handling for the health care sector were applied.

3.2. Procedure

The study employed elements of the Technology Acceptance Model - TAM2 [46], e.g., perceived ease of use, to address technology implementation of a lighting system. Survey 1 addressed the staff experience with the existing lighting and their expectations for the new lighting system, and survey 2 addressed the staff's experience with the new CLS. Surveys 1 and 2 were distributed in paper format to avoid password logins and to increase the response rate. The participants were kept anonymous and were instructed to return the questionnaires to a locked physical mailbox located in the unit. The participants recorded the date and time of completion of the surveys on the questionnaire. Survey 1 consisted of 23 questions, and Survey 2 consisted of 24 questions, both using a five-point Likert scale. Only one item included a 0–10-point scale. Because the study was conducted during the COVID-19 pandemic in a real-life setting, the number of responses from Survey 1 ($n = 63$) to Survey 2 ($n = 48$) varied. Chromaviso and the researcher gave the staff members a 15-min presentation about the CLS in the end of September 2022. The presentation introduced the concept of circadian lighting, e.g., the visual appearance of the lighting, how to control the lighting, an explanation of the settings, use of lighting at night and a very brief introduction to the evidence of light's effects on health. The latter included results found in a quasi-randomized control trial on stroke patients, collected within the Neuroscience Centre but at another hospital [45]. The staff was not given any training or information on how to use the PeL.

3.3. Data analysis

The survey data was prepared in Excel before the data analysis was conducted in Stata12. A skewness and kurtosis test for normality was conducted, indicating that the data is non-parametric. A Wilcoxon rank-sum test was applied to test the null hypothesis that two independent samples derive from the same population. The null-hypothesis was rejected at $p < 0.05$, demonstrating a statistically significance difference between the PeL and the CLS. To verify the results found in Stata12, a Wilcoxon rank-sum test was conducted on the same dataset in SAS, which produced the same results. The first Wilcoxon rank-sum test was conducted to compare responses between the PeL and CLS (Table 6). The second Wilcoxon test was conducted to observe the differences between chronotype night owls and morning larks. The third Wilcoxon test was conducted to identify staff's visual comfort (Table 7). As the circadian lighting changed throughout the day, the participants were asked to consider how they experienced various visual comfort attributes, such as glare, at three times of day. These results were compared with the responses regarding the PeL, which excluded the factor of time. Because several statistical tests with multiple comparisons were conducted, a Benjamini and Hochberg correction [47] was executed for p-value adjustments to control for type-1 errors.

3.4. Interviews

Ten nurses were recruited as participants for interviews, by quota sampling. In this paper, examples from three participants are used to elaborate on the accumulated opinions from the interviewed nurses. To be eligible for the interviews, the participants had to be able to communicate about their work routines and work environments in Danish or English and had to have worked at the hospital for a minimum of two months at the point of inclusion, with a minimum of 25 h per week at the unit. All interviews were conducted after the CLS had been installed. The interviews were used to supplement the survey results to interpret and elaborate on the responses. Meaning condensation of conversations was used as method for analysis.

4. Results

4.1. Perceived satisfaction and visual comfort

The results in Table 6 show a statistically significant difference between the PeL and CLS groups in six out of fourteen tests. The test (Q1.1) revealed an increase in satisfaction with the CLS compared to the PeL (Mean diff. 0.73, $p = 0.0003$). For the CLS, the reported mean satisfaction at three times of day is 3.86 for day shifts ($p = 0.0003$), 3.61 for evening shifts ($p = 0.0412$) and 3.5 for night shifts ($p = 0.1121$). Their satisfaction was noticeable by their perception of the light's appearance (Table 7). For example, the staff found the CLS more naturalistic than the PeL, and particularly at night (Mean diff. 1.22, $p = 0.0000$). The staff found the CLS to be warmer in CCT compared to the PeL with a main difference between PeL and nighttime CLS (Mean diff. 1.369, $p = 0.0000$). In addition, perception of coziness also increased between the PeL and CLS at nighttime (Mean diff. 1.671, $p = 0.0000$). ID1, a nurse working in PACU, appraised the lighting in their workstation from the hallway in the evening (Fig. 4, second picture from the left) and noted that the CLS is less harsh than the PeL and that there was no need to use other light settings or light sources. The nurse's perception of glare decreased with the CLS with the main difference at night (Mean diff.

Table 3
Light settings for CLS.

Light Settings	What luminaires are on	Description of setting
Circadian Light	Halo + CV3 + Adopted PeL	The lighting follows a 24-hr scheme, which simulate natural daylight, ranging from 1800 K to 5500 K. From 22:30–05:55, the lighting is switched off in the patient rooms to induce sleep, but in the hallways and open workstations, an 1800 K light is on.
Emergency Light	Halo + CV3 + Adopted PeL (100%)	4000 K, high illuminance for emergency situations. If this setting is left on, it will return to circadian lighting at dawn.
Night Task Light	Halo + CV3	2100 K task lighting for the night. The setting is designed to be non-disruptive to the circadian rhythm and melatonin production. After being switched on for 60 min, it returns to circadian lighting, which at night is off.
Night Spotlight or Medical Cart Spotlight	CV3	2300 K task light at the medical cart. The lighting is designed not to disrupt the patient. Illuminates the area at the medical cart. It follows the circadian lighting scheme during the day (1800 K–5500 K) and provides task lighting during the night when needed. The lighting can be switched on with the lighting control closest to the medical cart.
Night Light	Halo	Switches on one halo lamp located at the opposite side of the patient's head. Provides a dim 1800 K illuminance for a sense of security or for patients who want some light while they sleep. Returns to circadian light at sunrise. This setting also provides light for quick inspection of the patients at night.
Conversation [PACU Exclusively]	Halo + Adopted PeL (20% intensity)	2700 K lighting which provides a warm white light for conversations with doctors or visitors or for patients. Returns after 60 min to circadian lighting.
Nightly Sink Light [Neuro-ICU Exclusively]	Halo (only the fixture that is closest to the sink)	2300 K lighting that illuminates the area near the sink in the patient room. A soft, warm white illumination.
Night Reading Light [Workstations only]	Halo	2300 K task light for reading at night.
Hallway [The hallway lighting can be controlled from a touch screen at each of the workstations]	Halo + linear luminaires. (After 17:00, the linear luminaires switch off)	Like the circadian light setting, it follows a 24-hr scheme. During the late evening, it transitions to a 1800 K night mode, which is non-disruptive to the circadian rhythm and melatonin production. After being switched on for 60 min, it returns to circadian lighting, which at night is off.

−0.973, $p = 0.0002$). According to the interviewed nurses, when the lighting becomes gradually warmer in the evening, a sense of calm settles over the department. One major change from the PeL was an added feature that enables the staff to control the luminaire above each bed (Fig. 4, picture to the fare left). In the PACU, a lighting control was installed by each bed. This was especially important in the rooms with up to five patients during the layover from operation to the patient ward. When treating a patient at night or providing medicine doses, the nurses expressed content with the ability to turn on only the luminaire above one patient to avoid disturbing the other patients in the room. For these types of inspections at night, this setting was appraised as having warmer light that they could switch on (Fig. 4). For instance, ID1 explains, *"Sometimes in the evening, if the light is too bright for a patient who needs to fall asleep, I have changed the light to night task light [light setting], as it gives a light that allows you to see what you are doing but without being too much."* In addition, ID2 expressed that some patients want some light in the room to create a feeling of safety. In these cases, the nurses sometimes turn on a luminaire on the far side of the room to the night light setting to create ambient lighting in the room.

These zone-divided controls and warmer settings were considered an improvement from the previous lighting, with which nurses mainly relied on medical penlights when visiting the patient rooms for short periods. In ICU units, the light during the night shift was considered useful for reading monitors and screens. The staff explained that they prefer to work in dark environments during the night. This was apparent when PACU faculty switched off all lighting in the workstations and hallways at night and only left the computer screens on and when nurses in the neuro-ICU patient rooms switched on the light above the medical cart in the corner for some ambient and soft illuminance in the room as opposed to the night-light, which lit the entire room. The nurses positively appraised the new spotlight setting because it provides light on the cart surface for specific tasks without them having to turn on all ceiling luminaires (Fig. 4, picture to the fare right). The spotlight and additional settings were also valued because they, among other things, minimize the amount of work the staff must do to obtain proper lighting.

Although the staff was satisfied with the CLS overall (Fig. 5), the interviews uncovered some criticisms relating to the brightness (perceived illuminance) around midday and the lack of manually controlling the illuminance. ID1 explains, *"Later in the day, when the patients get sleepy, sometimes I think there can be a bit too much light. Then I do dim it down slightly"*. The staff said that if it is too bright for them, then it must also be too bright for the patients. Their criticism of the perceived brightness around midday was also indicated by the mean difference for perceived glare during the day with the CLS compared to the PeL (Mean diff. −0,517, $p = 0.0205$). Other nurses criticized the lighting during the night, such as ID3, who explained that during the night, they lack a light setting that is *in between* the "night task light" setting and the "emergency lighting" setting and that there are tasks for which the "night task light" setting is not sufficiently bright, but where the "emergency lighting" setting is too bright. Moreover, the night task light was criticized for being too dim for detailed-oriented tasks such as taking blood samples.

4.2. Perceived ease of use and usefulness

In Q2.1, the CLS was rated as easier to control than the PeL (Mean diff. 0.639 $p = 0.0011$). The perceived ease of use was measured based on the staff's understanding of the icons (Q2.2), which increased for the

Table 4
Illuminance conditions at medical cart for PeL and CLS.

	Light Settings	Lighting Fixtures	M-EDI	Illuminance
			Medical cart Horizontally 95 (+9) cm, 32 cm from table edge	Medical cart Horizontally 95 (+9) cm height, 32 cm from table edge
PeL	**Minimum Intensity** *[lowest state for manual dimmer]* Observed used during night by staff.	PeL Ceiling Fixtures	1,6 lux	3 lux
	25% Intensity Observed used during night by staff.	PeL Ceiling Fixtures	49 lux	77 lux
	50% Intensity Observed used during the day	PeL Ceiling Fixtures	103 lux	163 lux
	Maximum Intensity *[highest state on manual dimmer]* Never observed used, unless for demonstration of the capacity of the lighting.	PeL Ceiling Fixtures	206 lux	324 lux
	Desk Lamp Between evening and early morning, some of the nurses would point the desk lamp mounted on the computer desk towards the medical cart to avoid turning on the ceiling lighting. This behavior was observed particularly for PACU.	Desk Lamp	1,3 lux	3 lux
CLS	**Night Spotlight** Provides lighting on the medical cart. Observed used during night for tasks or for ambient lighting in the room.	CV3 Spot	5,1 lux	24 lux
	Night Light Used mostly during night or when a patients want a bit of light in the room while sleeping or for comfort.	Only one Halo	0,4 lux	1,5 lux
	Night Task Light Used during night for inspection and tasks, but occasionally observed used during the day as well.	Halo and CV3	12 lux	52 lux
	Conversation Observed used when patients wanted a milder light during the day.	*Halo and Adopted PeL*	128 lux	257 lux
	Lighting profile at noon Daylight has been shielded with external and internal curtains.	*Halo and Adopted PeL*	925 lux	1310 lux
	Emergency Lighting Intended only for emergency situations – rarely observed used. Occasionally used by cleaning staff and one nurse used it as general lighting, during the day, as they particularly preferred very bright light.	*Halo and Adopted PeL*	1200 lux	1680 lux

Note: Measured with Konika Minolta CL500A which is 9 cm in height. The measurements for PeL and CLS was conducted in two different rooms due to capacity at the hospital and room availability, however, the rooms are in the same department. T he medical carts are identical and located in the same place. More photometric data about the PeL can be read in Ref. [13].

CLS than the PeL (Mean diff. 0.47, $p = 0.0147$) (Fig. 6). However, there is no significance in whether the staff found the lighting intuitive (Q2.4, p = 0.8950) or found it easy to instruct a colleague (Q2.5, p = 0.4873). Likewise, no statistical significance was found regarding whether the staff finds the lighting useful (Q2.8, p = 0.6082). No significant difference was found in whether the staff saw potential in the circadian lighting (Q2.9, p = 0.7947) or wished for the lighting to be installed at the unit (Q2.10, p = 0.1789).

When staff were asked to indicate whether the light settings support tasks of instrumental care, a significant difference were found between the two questionnaires: the staff rated the circadian light settings as more satisfactory for this kind of tasks (Q1.5, mean diff. 0.733 $p = 0.005$). In addition, the staff had the necessary light settings to provide patient care (Q1.6, mean diff. 0.488, $p = 0.0183$).

The results showed a significant difference in whether they found the lighting easy to adjust, when necessary (Q2.3, mean diff. 0.571, p = 0.0023), suggesting that the CLS is considered easier to change than the PeL. During the interviews, some nurses mentioned that they had to get use to operating the lighting. ID1 explains,

> *"I think it is easy to use, but you have to work out how much light the functions and lamps actually provide when you try the light settings. [...] I don't find it difficult to use, but you must think about and remind yourself what lighting suits best for the situation, for instance if I need lighting to work but at the same time do not wish to* disturb *the sleeping patient"*. In addition, the nurses stated that they go to look at the control panel to remember the name of a light setting or to remind themselves which setting to use at night.

A statistical significance showed in the participants' reported familiarity (Q2.6) with the CLS. The participants reported they were more familiar with CLS when asked in survey 2 compared to survey 1 (Mean diff. 0.926, $p = 0.0036$, possibly due to training given prior to survey 2 about how to use the new lighting. A descriptive comparison of familiarity across years of work experience in the department shows that staff working 0–1 years were more familiar with circadian lighting than staff working 1–3 years and 5–10 years.

5. Discussion and limitations

A significant advantage of this study is that CLS is implemented on-site and evaluated with actual occupants in a hospital building. The implemented CLS was adjusted throughout the evaluation period,

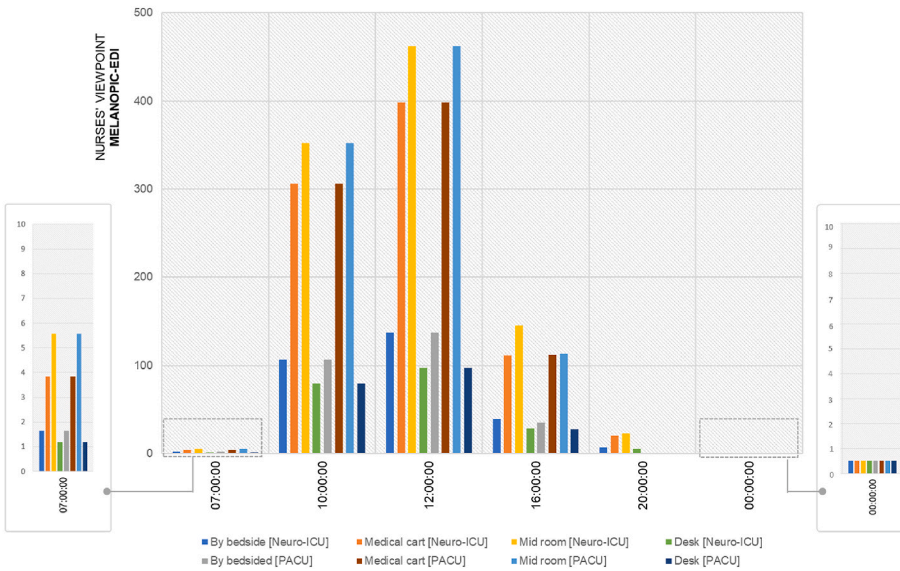


Fig. 2A. Vertical M-EDI of Halo luminaires displayed for six times per day in a patient room.

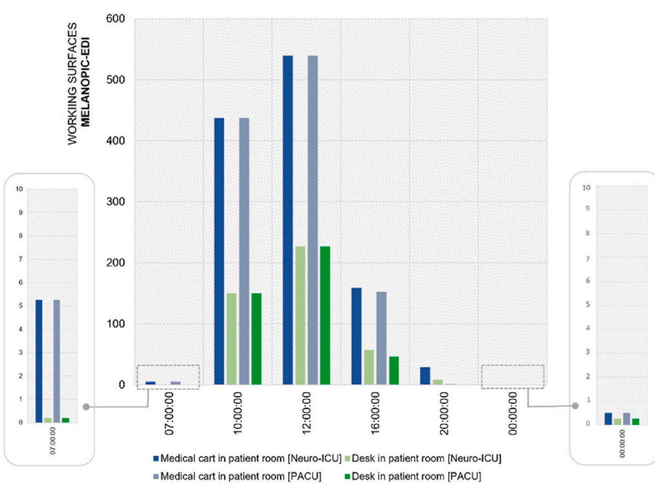


Fig. 2B. Horizontal M-EDI of Halo luminaires displayed for six times per day in a patient room.

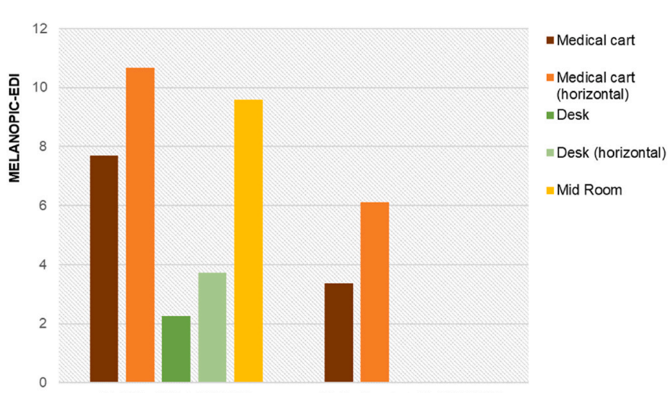


Fig. 3. M-EDI of Halo luminaires for two frequently used light settings.

leading to less control of the variables but improved feedback for improved circadian lighting. This study is therefore not a before and after study but a before and during study. One of the modifications made based on feedback was a faster "sundown" in the evening, meaning that the lighting gradually becomes warmer and lower in illuminance earlier in the afternoon and evening. This was implemented to accommodate light-sensitive patients who had come directly from neurological surgery, who often needed more rest in the afternoon and evening. Another adjustment was to have the circadian lighting dim 1 h later in the evening than programmed to accommodate routine tasks, including hygienic tasks taking place at around 9pm. Additionally, the CCT of the night task light was increased to improve visibility at night.

Table 5
Characteristics of participants.

	Survey 1: PeL		Survey 2: CLS	
	Freq	%	Freq	%
Gender				
Female	54	13	36	21
Male	8	86	10	77
Other	1	1	1	2
n	63	100	47	100
Age				
18–24	3	5	1	2
25–29	12	19	8	17
30–49	41	65	32	68
50–59	7	11	6	13
n	63	100	47	100
Chronotype				
Early Chronotype	34	56	21	46
Late Chronotype	23	38	24	52
Uncertain	4	6	1	2
n	61	100	46	100
Years of Work Experience in The Unit				
0–1	21	33	13	27
1–3	12	19	11	23
3–5	10	16	7	14.5
5–10	9	14	7	14.5
10+	11	18	10	21
n	63	100	48	100
Job Title				
Nurse	45	71	36	75
Doctor	9	14	5	11
Physio- and occupational therapist	3	5	3	6
Other	6	10	4	8
n	63	100	48	100

Many researchers across disciplines have used TAM in many contexts [48,49]. In this study, the TAM was used to provide self-reported measures on how the nurses are to accept and use the circadian lighting and

Table 6
Perceived satisfaction, ease of use and usefulness.

1.0 Perceived Satisfaction	Lighting	Obs	Mean	Rank-sum	SD	P-value
1.1 I am overall satisfied with the lighting at my workplace	PeL CLS	63 48	3.158 3.895	2970.5 3245.5	0.805 1.08	0.0003*
1.2 The lighting is satisfactory during the day	PeL CLS	63 45	3.158 3.866	2909 2977	1.080 1.013	0.0003*
1.3 The lighting is satisfactory during the evening	PeL CLS	63 36	3.158 3.611	2059 2891	1.080 1.021	0.0412*
1.4The lighting is satisfactory during the night	PeL CLS	63 32	3.15 3.5	2837 1723	1.080 1.218	0.1121
1.5 I have the light settings I need to perform instrumental care (e.g., taking blood samples, monitoring blood pressure, catheter placement)	PeL CLS	63 48	2.809 3.542	2.809 3252	1.075 1.009	0.0005*
1.6I have the lighting settings I need to care for the patients (non-instrumental care)	PeL CLS	63 48	3.095 3.583	3150.5 3065.5	1.102 1.007	0.0183*
2.0 Perceived Ease of Use and Usefulness						
2.1 I find it easy to control the lighting	PeL CLS	63 47	3.126 3.765	2986.5 3118.5	1.054 0.865	0.0011*
2.2 The icons on the lighting panel are easy to understand	PeL CLS	63 47	3.317 3.787	3121.5 2983.5	1.044 0.858	0.0147*
2.3 It is easy to change the lighting when necessary	PeL CLS	63 46	3.015 3.586	2992.5 3002.5	0.958 0.979	0.0023*
2.4 The circadian lighting seems intuitive	PeL CLS	42 45	3.738 3.777	1833.5 1994.5	0.857 0.849	0.8950
2.5 I can easily explain how to use the lighting control to a colleague	PeL CLS	63 46	3.349 3.5	3358.5 2636.5	1.152 1.027	0.4873
2.6 How familiar are you with circadian lighting?	PeL CLS	63 47	3.031 3.957	3025 3080	1.626 1.398	0.0036*
2.7 How often do you use the lighting?	PeL CLS	63 48	3.968 4.083	3410 2806	1.331 1.411	0.4418
2.8 I believe the circadian lighting is useful	PeL CLS	42 46	4.190 4.130	1925 1991	0.740 0.748	0.6082
2.9 I can see potential in getting/having circadian lighting at the department	PeL CLS	42 48	4.285 4.170	1918.5 2086.5	0.596 0.867	0.7947
2.10 I am interested in the circadian lighting	PeL CLS	35 46	4.228 3.978	1563.5 1757.5	0.645 0.802	0.1789

Questions translated from Danish. Day is 07am - 3pm, evening is 3pm–11pm and night is 11pm - 07am. Q1.1–2.5, 2.7–2.10: 1 = strongly disagree, 5 = strongly agree. Q2.6: 0 = no familiarity, 6 = profound familiarity.
*P < 0.00.05. The tests are significance when controlling for false-discovery rate of 7%.

Table 7
Subjective assessment of various lighting attributes as an indicator of visual comfort.

Question: "The light is …"	Lighting	Obs	Mean	SD	P-value
Glary	PeL	62	3.161	1.204	
Glary during the day	CLS	45	2.644	1.171	0.0205*
Glary during the evening	CLS	35	2.229	0.731	0.0001*
Glary during the night	CLS	32	2.188	0.859	0.0002*
Naturalistic	PeL	61	2.623	0.897	
Naturalistic during the day	CLS	45	3.444	0.943	0.0000*
Naturalistic during the evening	CLS	37	3.622	0.758	0.0000*
Naturalistic during the night	CLS	32	3.844	0.808	0.0000*
Refreshing	PeL	62	3.161	1.027	
Refreshing during the day	CLS	44	3.386	0.895	0.1596
Refreshing during the evening	CLS	36	3.667	0.793	0.4441
Refreshing during the night	CLS	32	3.313	0.896	0.0322*
Warm	PeL	63	2.381	0.812	
Warm during the day	CLS	45	2.911	1.083	0.0014*
Warm during the evening	CLS	36	3.611	0.645	0.0000*
Warm during the night	CLS	32	3.75	0.762	0.0000*
Cool	PeL	63	3.492	0.931	
Cool during the day	CLS	45	3.222	1.064	0.2213
Cool during the evening	CLS	35	2.571	0.85	0.0000*
Cool during the night	CLS	31	2.419	0.848	0.0000*
Cozy	PeL	63	2.238	0.875	
Cozy during the day	CLS	44	2.864	1.025	0.0014*
Cozy during the evening	CLS	37	3.568	0.728	0.0000*
Cozy during the night	CLS	33	3.909	0.678	0.0000*
Uniform	PeL	62	3.5	0.919	
Uniform during the day	CLS	44	2.932	0.998	0.0018*
Uniform during the evening	CLS	35	2.743	0.657	0.0000*
Uniform during the night	CLS	31	2.935	0.892	0.0022*

Questions translated from Danish. Day is 07am - 3pm, evening is 3pm–11pm and night is 11pm - 07am. Rating scale: 1 = strongly disagree, 5 = strongly agree. *P < 0.00.05. The tests are significance when controlling for false-discovery rate of 7%.

its perceived usefulness, perceived ease of use and behavioral intention to use the system. Although the TAM model [50,51] was useful in this study, it has some limitations, which should be considered. One limitation of the TAM is the variable of user behavior, which is evaluated through subjective means, such as behavioral intention and interpersonal influence [52]. We mitigated this limitation by including not only TAM questions in the questionnaire, especially in the interviews. The interviews provided many beneficial insights and extensive complexity in contrast with the TAM model's simplicity. The insights from the interviews also included (as the quotes show) subjective reflections on the indoor hospital lighting, norms and personality traits. Another of the TAM's limitations is the missing external variables [53], such as age, tasks/role and years of job experience at the unit/place, which was mitigated by asking for exactly those variables. Other approaches and extensions of the TAM involve introducing additional or alternative belief factors into the model [54], which provides the advantage of a more holistic view of the technology acceptance. However, a common challenge is still how to transform the theoretical founded items within the TAM to be applied and useful in a very specific practice and context.

One limitation of the questionnaire was the variable of time, which was included in survey 2 to account for the dynamic aspect of the CLS. While the question provides some data about the staff's satisfaction with the lighting at various times, it also produced an uneven response rate. This could have been because a lower proportion of the staff worked nightshifts compared to dayshifts. Furthermore, recall bias was also a potential risk of adding the variable of time. We attempted to mitigate this by asking the staff to note the time at the beginning of the questionnaire. In addition, the staff was also encouraged to complete the questionnaire on-site and not at home.

We were aware of the potential bias that the staff's training about CLS and light's effect on health could have for the results, however, because the units treat critical care patients, it is important that the staff can respond quickly to the situation at hand, and therefore they need to know how to operate the lighting.

6. Conclusion and future works

This study investigated the research question "Can hospital staffs' satisfaction with the lit environment at their workplace and their visual comfort be improved by implementing a circadian lighting system?"

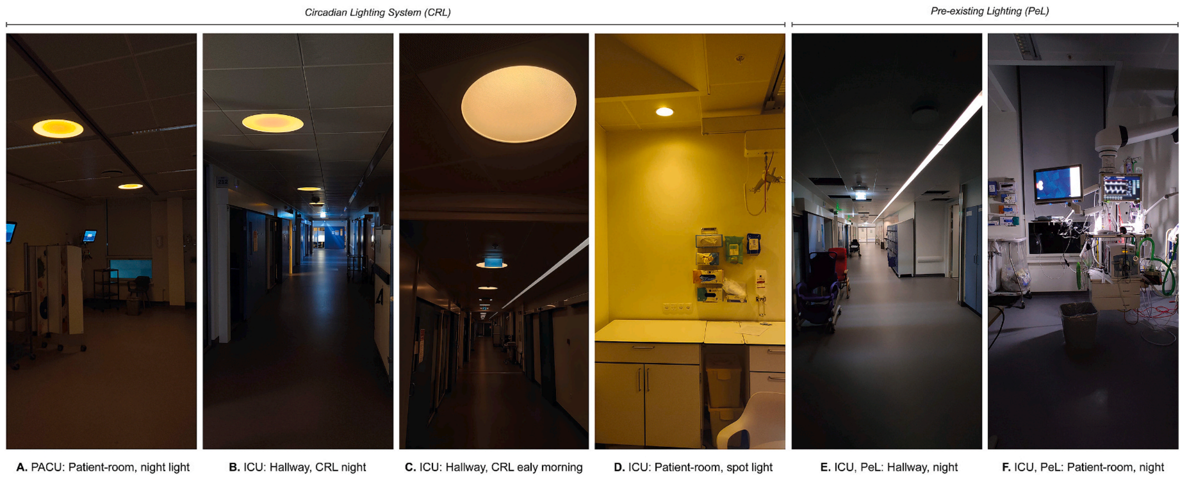


Fig. 4. Nighttime in the unit.

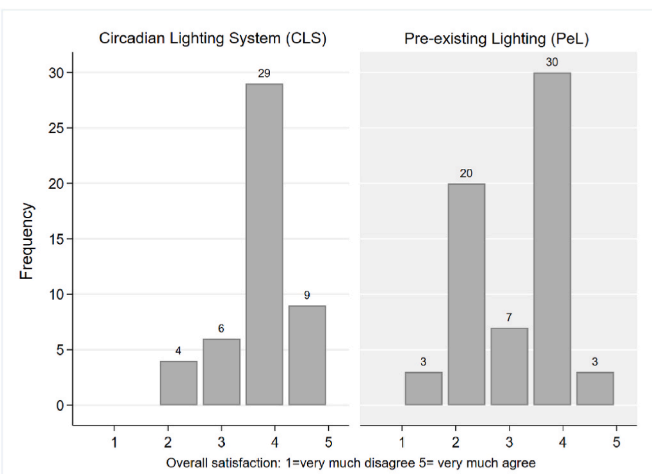


Fig. 5. Frequency of responses to thestatement: "I am overall satisfied with the lighting". P = 0.0003*.

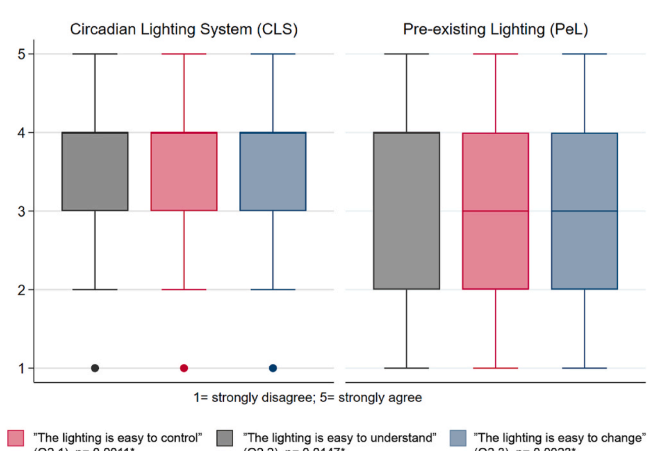


Fig. 6. Box plots for questions regarding ease of use, understand and change.

Based on the results, we can reject the null hypothesis because the analysis showed that the staff expressed greater satisfaction with the CLS than with the PeL after two months of use. The staff's appraisal of the CLS was also indicated by their perceived visual comfort. They found the CLS less glary than the PeL. They found the CLS more natural than the PeL, particularly at night. Likewise, the staff found the CLS warmer at night, and this was significantly different from the PeL and they found the PeL colder in appearance at nighttime. They found the CLS easy to use and adjust, but there was no statistically significant difference in perceived usefulness or the intuitiveness of the lighting.

The circadian lighting systems are designed with the aim to improve occupants' health through entrainment of our circadian rhythm [34,55], and such benefits from the lighting should be prioritized; however, it is important to produce further knowledge on how we design systems for complex health care environments that meet both visual and non-visual effects. When implementing a circadian lighting in a health care environment, it is important to focus on the users' experience and interaction with an automated lighting systems in practice, as this may affect their use of the lighting which can have an influence the non-visual effects of the lighting. For example, as seen by the interviews when a patient or the staff found the lighting too bright during the day, they would switch to a setting with a lower CCT.

We acknowledge that circadian lighting has capabilities to affect almost all physiological and biochemical processes in the human body, including sleep physiology, homeostatic processes, cognitive, and mental behavior of both the patients and staff. However, this study focused an evaluation of staffs' satisfaction and visual comfort, which are not directly related to rhythms.

This paper demonstrates a successful implementation of CLS, a result of a close collaboration with the staff and key stakeholders throughout the implementation phase, which may have contributed to their increased satisfaction. The increased satisfaction found in this study could be explained by the variability in the lighting during the day which the staff had expressed they were missing while having the PeL. The increase in satisfaction could also be explained by the lower CCT at night and the diversity in the light settings, for example being able to switch on a single or multiple luminaires. Thus, having more autonomy to adjust the lighting to the individual work situation and patient needs. Their satisfaction and reported familiarity with the CLS may be explained by the fact that training was offered to the staff on the CLS and no training in the use of PeL, the increased focus on improving their work environment and attention to the staff's' well-being and/or the nature of research, in which a close collaboration among the staff and researchers was established. In this study, evaluations of the lighting and after-installation adjustments were carried out which may have affected the staff's satisfaction.

Some future works are suggested:

1. Provide data on light sensitivity: In this study, it was not possible to control for whether the older staff members felt more sensitive to the lighting than younger staff members.
2. Further research is needed to provide stronger data regarding correlations of satisfaction and of melanopic-EDI value in specific hospital settings e.g., considering glare, contrast and limits of visual comfort in relation to brightness.
3. The study mainly applied subjective scales for evaluation. Future studies should consider supplementing with objective measurements such as monitoring individual light exposures, changes in workflow and work procedures, medicine errors, logging use of light settings and sick days.
4. Future research should consider whether time is an appropriate measure to include in questionnaires about CLS.
5. Light measurements were collected in real life patient rooms; however, this were not always optimum as the occupation of the rooms changed e.g., due to new patients, next of kin staying, other research projects or for storage of equipment and furniture. It was not possible to predict which rooms would be occupied. Future field studies collected in a hospital setting should consider supplementing with light measurements in a laboratory or mock-up setting of a patient room and/or computer simulations.

This study concludes that CLS can improve the work environment of hospital staff working in a neuro-ICU or PACU. The results presented might be case-specific; thus, more research to establish its transferability to other hospitals is needed.

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CRediT authorship contribution statement

K.M. Schledermann: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **T. Bjørner:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization. **A.S. West:** Validation, Formal analysis. **T.S. Hansen:** Writing – review & editing, Supervision, Resources.

Declaration of competing interest

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Data availability

Data will be made available on request.

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References

[1] X. Shen, H. Zhang, Y. Li, K. Qu, L. Zhao, G. Kong, W. Jia, Building a satisfactory indoor environment for healthcare facility occupants: a literature review, Build. Environ. 228 (2023), https://doi.org/10.1016/j.buildenv.2022.109861.

[2] G. Newsham, J. Brand, C. Donnelly, J. Veitch, M. Aries, K. Charles, Linking indoor environment conditions to job satisfaction: a field study, Build. Res. Inf. 37 (2009) 129–147, https://doi.org/10.1080/09613210802710298.

[3] T. Verulava, R. Jorbenadze, B. Dangadze, L. Karimi, H. Çalışma, O. Özellikleri, İ. Tatmini, Gürcistan'dan Bulgular, Nurses' Work Environment Characteristics and Job Satisfaction: Evidence from Georgia, 2018, https://doi.org/10.12996/gmj.2018.04.

[4] D. Applebaum, S. Fowler, N. Fiedler, O. Osinubi, M. Robson, The impact of environmental factors on nursing stress, job satisfaction, and turnover intention, J. Nurs. Adm. 40 (2010) 323–328, https://doi.org/10.1097/NNA.0b013e3181e9393b.

[5] M. Suliman, A. Rn Maen, A. Al, Nurses' work environment: indicators of satisfaction, J. Nurs. Manag. 26 (2018) 525–530, https://doi.org/10.1111/JONM.12577.

[6] K. Hadi, J.R. DuBose, E. Ryherd, Lighting and nurses at medical–surgical units: impact of lighting conditions on nurses' performance and satisfaction, Health Environ. Res. Des. J. 9 (2016) 17–30, https://doi.org/10.1177/1937586715603194.

[7] E.M. de Araujo Vieira, J.M.N. da Silva, L.B. da Silva, J.A. do Nascimento, W.K. dos Santos Leite, L.G.M. Bispo, How do thermal conditions in intensive care units affect the health and well-being of intensivists? Hum. Factors Ergon. Manuf. Serv. Ind. 33 (2023) 27–39, https://doi.org/10.1002/HFM.20968.

[8] K. Freihoefer, D. Guerin, C. Martin, H.Y. Kim, J.K. Brigham, Occupants' satisfaction with, and physical readings of, thermal, acoustic, and lighting conditions of sustainable office workspaces, Indoor Built Environ. 24 (2015) 457–472, https://doi.org/10.1177/1420326X13514595.

[9] X. Shen, H. Zhang, Y. Li, K. Qu, L. Zhao, G. Kong, W. Jia, Building a satisfactory indoor environment for healthcare facility occupants: a literature review, Build. Environ. 228 (2023), https://doi.org/10.1016/j.buildenv.2022.109861.

[10] H. Hemphälä, M. Heiden, P. Lindberg, P. Nylén, Visual symptoms and risk assessment using visual ergonomics risk assessment method (VERAM), in: Lecture Notes in Networks and Systems, Springer Science and Business Media Deutschland GmbH, 2021, pp. 729–735, https://doi.org/10.1007/978-3-030-74605-6_92.

[11] I. Dianat, A. Sedghi, J. Bagherzade, M.A. Jafarabadi, A.W. Stedmon, Objective and subjective assessments of lighting in a hospital setting: implications for health, safety and performance, Ergonomics 56 (2013) 1535–1545, https://doi.org/10.1080/00140139.2013.820845.

[12] M.G. Figueiro, C.M. Hunter, P.A. Higgins, T.R. Hornick, G.E. Jones, B. Plitnick, J. Brons, M.S. Rea, Tailored lighting intervention for persons with dementia and caregivers living at home, Sleep Health 1 (2015) 322–330, https://doi.org/10.1016/j.sleh.2015.09.003.

[13] K. Schledermann, T. Bjørner, M. Mullins, T. Hansen, Identifying nurses' perception of a lighting installation in a newly built hospital, in: IOP Conf Ser Earth Environ Sci, Institute of Physics, 2022, https://doi.org/10.1088/1755-1315/1099/1/012027.

[14] M.G. Figueiro, D. Pedler, Red light: a novel, non-pharmacological intervention to promote alertness in shift workers, J. Saf. Res. 74 (2020) 169, https://doi.org/10.1016/J.JSR.2020.06.003.

[15] A. Lowden, G. Kecklund, Considerations on how to light the night-shift, Light. Res. Technol. 53 (2021) 437–452, https://doi.org/10.1177/14771535211012251.

[16] M.G. Figueiro, Disruption of circadian rhythms by light during day and night, Curr. Sleep Med. Rep. 3 (2017) 76–84, https://doi.org/10.1007/s40675-017-0069-0.

[17] L. Sahin, M.G. Figueiro, A 24-hour lighting scheme to promote alertness and circadian entrainment in railroad dispatchers on rotating shifts: a field study, Light. Res. Technol. 54 (2022) 441–457, https://doi.org/10.1177/14771535211040985.

[18] L. Sahin, M.G. Figueiro, A 24-hour lighting scheme to promote alertness and circadian entrainment in railroad dispatchers on rotating shifts: a field study, Light. Res. Technol. 54 (2022) 441–457, https://doi.org/10.1177/14771535211040985/FORMAT/EPUB.

[19] C. Cajochen, M. Freyburger, T. Basishvili, C. Garbazza, F. Rudzik, C. Renz, K. Kobayashi, Y. Shirakawa, O. Stefani, J. Weibel, Effect of daylight LED on visual comfort, melatonin, mood, waking performance and sleep, Light. Res. Technol. 51 (2019) 1044–1062, https://doi.org/10.1177/1477153519828419.

[20] H. Hemphälä, M. Heiden, P. Lindberg, P. Nylén, Visual symptoms and risk assessment using visual ergonomics risk assessment method (VERAM), in: Lecture Notes in Networks and Systems, Springer Science and Business Media Deutschland GmbH, 2021, pp. 729–735, https://doi.org/10.1007/978-3-030-74605-6_92.

[21] J.R. Anshel, Visual ergonomics in the workplace, AAOHN J. 55 (2007) 414–420, https://doi.org/10.1177/216507990705501004.

[22] R. Jafarifiroozabadi, M. Woo, A. Joseph, P. MacNaughton, S. Mihandoust, The effects of window blind positions and control on patients' hospital and care quality perception: a mediation and moderation analysis, Build. Environ. 226 (2022), 109672, https://doi.org/10.1016/J.BUILDENV.2022.109672.

[23] L.J. McCunn, S. Safranek, A. Wilkerson, R.G. Davis, Lighting control in patient rooms: understanding nurses' perceptions of hospital lighting using qualitative

methods, Health Environ. Res. Des. J. 14 (2020) 204–218, https://doi.org/10.1177/1937586720946669.
[24] A. Gharaveis, H. Yekita, G. Shamloo, The perceptions of nurses about the behavioral needs for daylighting and view to the outside in inpatient facilities, HERD 13 (2020) 191–205, https://doi.org/10.1177/1937586719851271.
[25] M.K. Alimoglu, L. Donmez, Daylight exposure and the other predictors of burnout among nurses in a University Hospital, Int. J. Nurs. Stud. 42 (2005) 549–555, https://doi.org/10.1016/j.ijnurstu.2004.09.001.
[26] J.H. Choi, L.O. Beltran, H.S. Kim, Impacts of indoor daylight environments on patient average length of stay (ALOS) in a healthcare facility, Build. Environ. 50 (2012) 65–75, https://doi.org/10.1016/J.BUILDENV.2011.10.010.
[27] R.S. Zadeh, M.M. Shepley, G. Williams, S.S.E. Chung, The impact of windows and daylight on acute-care nurses' physiological, psychological, and behavioral health, HERD 7 (2014) 35–61, https://doi.org/10.1177/193758671400700405.
[28] J. Golvani, L. Roos, M. Henricson, Operating room nurses' experiences of limited access to daylight in the workplace – a qualitative interview study, BMC Nurs. 20 (2021) 1–8, https://doi.org/10.1186/S12912-021-00751-8/TABLES/2.
[29] K. Gbyl, H. Østergaard Madsen, S. Dunker Svendsen, P.M. Petersen, I. Hageman, C. Volf, K. Martiny, Depressed patients hospitalized in southeast-facing rooms are discharged earlier than patients in northwest-facing rooms, Neuropsychobiology 74 (2016) 193–201, https://doi.org/10.1159/000477249.
[30] L. Fay, J.E. Santiago, K. Real, K. Isaacs, Patient room design: a qualitative evaluation of attributes impacting health care professionals, Crit. Care Nurs. Q. 44 (2021) 334–356, https://doi.org/10.1097/CNQ.0000000000000369.
[31] R.G. Davis, L.J. McCunn, A. Wilkerson, S. Safranek, Nurses' satisfaction with patient room lighting conditions: a study of nurses in four hospitals with differences in the environment of care, Health Environ. Res. Des. J. 13 (2020) 110–124, https://doi.org/10.1177/1937586719890940.
[32] A. Keyvanfar, A. Shafaghat, M.Z. Abd Majid, H. Bin Lamit, M. Warid Hussin, K. N. Binti Ali, A. Dhafer Saad, User satisfaction adaptive behaviors for assessing energy efficient building indoor cooling and lighting environment, Renew. Sustain. Energy Rev. 39 (2014) 277–295, https://doi.org/10.1016/j.rser.2014.07.094.
[33] K.M. Schledermann, T. Bjørner, T.S. Hansen, Danish nursing home staff's perceived visual comfort and perceived usefulness of a circadian lighting system, in: Proceedings of ACM International Conference on Information Technology for Social Good (GoodIT '21), September 9–11, 2021, Roma, Italy, ACM, New York, NY, USA, ACM, New York, 2021, p. 6, https://doi.org/10.1145/3462203.3475881.
[34] K.W. Houser, P.R. Boyce, J.M. Zeitzer, M. Herf, Human-centric lighting: myth, magic or metaphor? Light. Res. Technol. 53 (2021) 97–118, https://doi.org/10.1177/1477153520958448.
[35] K.W. Houser, T. Esposito, Human-centric lighting: foundational considerations and a five-step design process, Front. Neurol. 12 (2021) 1–13, https://doi.org/10.3389/fneur.2021.630553.
[36] C. Vetter, P.M. Pattison, K. Houser, M. Herf, A.J.K. Phillips, K.P. Wright, D. J. Skene, G.C. Brainard, D.B. Boivin, G. Glickman, A review of human physiological responses to light: implications for the development of integrative lighting solutions, LEUKOS - J. Illuminating Eng. Soc. North Am. 18 (2022) 387–414, https://doi.org/10.1080/15502724.2021.1872383.
[37] J.A. Olson, D.Z. Artenie, M. Cyr, A. Raz, V. Lee, Developing a light-based intervention to reduce fatigue and improve sleep in rapidly rotating shift workers, Chronobiol. Int. 37 (2020) 573–591, https://doi.org/10.1080/07420528.2019.1698591.
[38] T.M. Brown, G.C. Brainard, C. Cajochen, C.A. Czeisler, J.P. Hanifin, S.W. Lockley, R.J. Lucas, M. Münch, J.B. Ohagan, S.N. Peirson, L.L.A. Price, T. Roenneberg, L.J. M. Schlangen, D.J. Skene, M. Spitschan, C. Vetter, P.C. Zee, K.P. Wright, Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults, PLoS Biol. 20 (2022), e3001571, https://doi.org/10.1371/JOURNAL.PBIO.3001571.
[39] L.J. McCunn, J. Wright, Hospital employees' perceptions of circadian lighting: a pharmacy department case study, J. Facil. Manag. 17 (2019) 422–437, https://doi.org/10.1108/JFM-04-2019-0016.
[40] P.R. Boyce, Human Factors in Lighting, third ed., CRC Press. Taylor & Francis Group, 2014 https://doi.org/10.1201/9780203426340.
[41] V.R.M. Lo Verso, F. Caffaro, C. Aghemo, Luminous environment in healthcare buildings for user satisfaction and comfort: an objective and subjective field study, Indoor Built Environ. 25 (2016), https://doi.org/10.1177/1420326X15588337.
[42] J.A. Veitch, G.R. Newsham, P.R. Boyce, C.C. Jones, Lighting appraisal, well-being and performance in open-plan offices: a linked mechanisms approach, Light. Res. Technol. 40 (2008), https://doi.org/10.1177/1477153507086279.
[43] L.J. McCunn, J. Wright, Hospital employees' perceptions of circadian lighting: a pharmacy department case study, J. Facil. Manag. 17 (2019) 422–437, https://doi.org/10.1108/JFM-04-2019-0016.
[44] M.C. Giménez, L.M. Geerdinck, M. Versteylen, P. Leffers, G.J.B.M. Meekes, H. Herremans, B. de Ruyter, J.W. Bikker, P.M.J.C. Kuijpers, L.J.M. Schlangen, Patient room lighting influences on sleep, appraisal and mood in hospitalized people, J. Sleep Res. 26 (2017) 236–246, https://doi.org/10.1111/jsr.12470.
[45] A. West, S.A. Simonsen, A. Zielinski, N. Cyril, M. Schønsted, P. Jennum, B. Sander, H.K. Iversen, An exploratory investigation of the effect of naturalistic light on depression, anxiety, and cognitive outcomes in stroke patients during admission for rehabilitation: a randomized controlled trial, NeuroRehabilitation 44 (2019) 341–351, https://doi.org/10.3233/NRE-182565.
[46] R.J. Holden, B.-T. Karsh, The Technology Acceptance Model: its past and its future in health care, J. Biomed. Inf. 43 (2010) 159–172, https://doi.org/10.1016/J.JBI.2009.07.002.
[47] Y. Benjamini, Y. Hochberg, Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing, 1995.
[48] T. Bjørner, The advantages of and barriers to being smart in a smart city: the perceptions of project managers within a smart city cluster project in Greater Copenhagen, Cities 114 (2021), 103187, https://doi.org/10.1016/J.CITIES.2021.103187.
[49] N. Marangunić, A. Granić, Technology acceptance model: a literature review from 1986 to 2013, Univers. Access Inf. Soc. 14 (2015) 81–95, https://doi.org/10.1007/S10209-014-0348-1/TABLES/3.
[50] V. Venkatesh, C. Speier, M.G. Morris, User acceptance enablers in individual decision making about technology: toward an integrated model, Decis. Sci. J. 33 (2002) 297–316, https://doi.org/10.1111/J.1540-5915.2002.TB01646.X.
[51] F.D. Davis, User acceptance of information technology: system characteristics, user perceptions and behavioral impacts, Int. J. Man Mach. Stud. 38 (1993) 475–487, https://doi.org/10.1006/IMMS.1993.1022.
[52] P. Ajibade, Technology Acceptance Model Limitations and Criticisms: Exploring the Practical Applications and Use in Technology-Related Studies, Mixed-Method, and Qualitative Researches, Library Philosophy & Practice, 2018, 1941, https://www.researchgate.net/publication/329308172_Technology_Acceptance_Model_Limitations_and_Criticisms_Exploring_the_Practical_Applications_and_Use_in_Technology-related_Studies_Mixed-method_and_Qualitative_Researches. (Accessed 27 February 2023).
[53] M.J.A. Zahid, M.M. Ashraf, B.T. Malik, M.R. Hoque, Information communication technology (ICT) for disabled persons in Bangladesh: preliminary study of impact/outcome, IFIP Adv. Inf. Commun. Technol. 402 (2013) 652–657, https://doi.org/10.1007/978-3-642-38862-0_48/COVER.
[54] B.H. Wixom, P.A. Todd, A theoretical integration of user satisfaction and technology acceptance, Research 16 (2005) 85–102, https://doi.org/10.1287/isre.1050.0042.
[55] K.W. Houser, T. Esposito, Human-centric lighting: foundational considerations and a five-step design process, Front. Neurol. 12 (2021) 1–13, https://doi.org/10.3389/fneur.2021.630553.
[56] M. Engwall, I. Fridh, L . Johansson, I. Bergbom, B. Lindahl, Lighting, sleep and circadian rhythm: An intervention study in the intensive care unit, Intensive and Critical Care Nursing. 31 (2015) 325-335, https://doi.org/10.1016/j.iccn.2015.07.001.