LED virtual windows are valuable in windowless consultation rooms

Sumit Sen[1], Tove Nielsen[2], Erik Nielsen[3], Pryds Ole[2, 4] & Dina Cortes [2, 5]

ABSTRACT

INTRODUCTION: Due to the design of Hvidovre Hospital, the outpatient clinic of the Department of Paediatrics has windowless consultation rooms. Work environment surveys revealed that nurses and doctors working in these windowless rooms considered the lack of natural light a considerable health problem. This study evaluated the effects of installing light-emitting diode (LED) virtual windows in these rooms.

METHODS: Four similar windowless consultations rooms located next to each other were used in the study. All had older T-5 fluorescent luminaires installed. In two of these rooms, Servodan LED virtual windows depicting various natural scenes were installed. The illuminance and correlated colour temperature (CCT) of each room's lighting was measured, and a work environment questionnaire was filled out by nurses and doctors working in each room.

RESULTS: A total of 113 questionnaires were collected and evaluated. LED virtual windows produced an improved perception of lighting conditions, both at the desk ($p < 0.001$) and in the rooms in general ($p < 0.001$) and improved the overall positive experience of the rooms ($p = 0.02$). A tendency towards concentration difficulties was reported less often in the rooms with LED virtual windows, ($p = 0.11$). Retinal illuminance ($p = 0.02$) as well as CCT at the desk ($p < 0.005$) and at the retina ($p < 0.01$) alike were increased in rooms with LED virtual windows.

CONCLUSIONS: LED virtual windows improved the lighting experience, the impression of the space, the retinal illuminance and the CCT at the desk and at the retina in the windowless rooms.

FUNDING: none.

TRIAL REGISTRATION: not relevant.

In 2008, the outpatient clinic at the Department of Paediatrics, Hvidovre Hospital, was relocated to an internal space within the hospital. Previously, all consultations rooms had windows, but in the new location only half of the consultation rooms have windows.

Surveys of the work environment in the relocated outpatient clinic were carried out in 2009 and 2010. These revealed that 85% of the nurses and doctors (the medical staff) working and staying in the windowless rooms considered the lack of natural light a considerable health problem. A pilot study was therefore set up to evaluate the effects of installing light-emitting diode (LED) virtual windows in these windowless rooms.

Natural light in the workplace is an important factor for overall employee perceptions of positive working environments. Natural light is also the preferred type of lighting at the workplace in relation to view and depth of vision. Windowless rooms and the resulting lack of sufficient natural light may affect the circadian rhythm and overall psychological well-being [1]. Melatonin production in the suprachiasmatic nucleus controls the sleep-wake cycle and is affected when the photosensitive retinal ganglion cells are excited with 447 nm to 484 nm wavelength (blue light) and with as little as one lux (lx) illuminance [1, 2]. Key to melatonin regulation is a combination of correlated colour temperature (CCT) and illuminance. CCT is expressed in Kelvin (K) and depends on the concentration of blue light. A candle flame emits 2,700 K and is referred to as warm light. A clear blue sky emits 27,000 K and is referred to as cold light. Most commercially available luminaires range between 2,700 K and 6,500 K [3].

The overall perception of health in the workplace is optimum when there is exposure to natural light [4], which emits a CCT of roughly 5,800 K [5]. In general, CCT levels higher than 4,000 K and illuminance levels higher than 500 lx increase alertness and task performance, whereas lower CCT and illuminance levels induce calm and relaxation [6-10]. LED luminaires have a distinctive peak in the 450 nm bandwidth. Older lighting systems, such as fluorescent tubes, generally lack this blue peak and instead show two peaks with a lower bandwidth in the yellow and red range [11].

Although there are studies which indicate the benefits of bright light therapy or blue-enriched polychromatic light on health, e.g. in Alzheimer patients [12] and nightshift workers [13], there is an absence of studies about LED virtual windows in windowless working environments during daytime shifts.

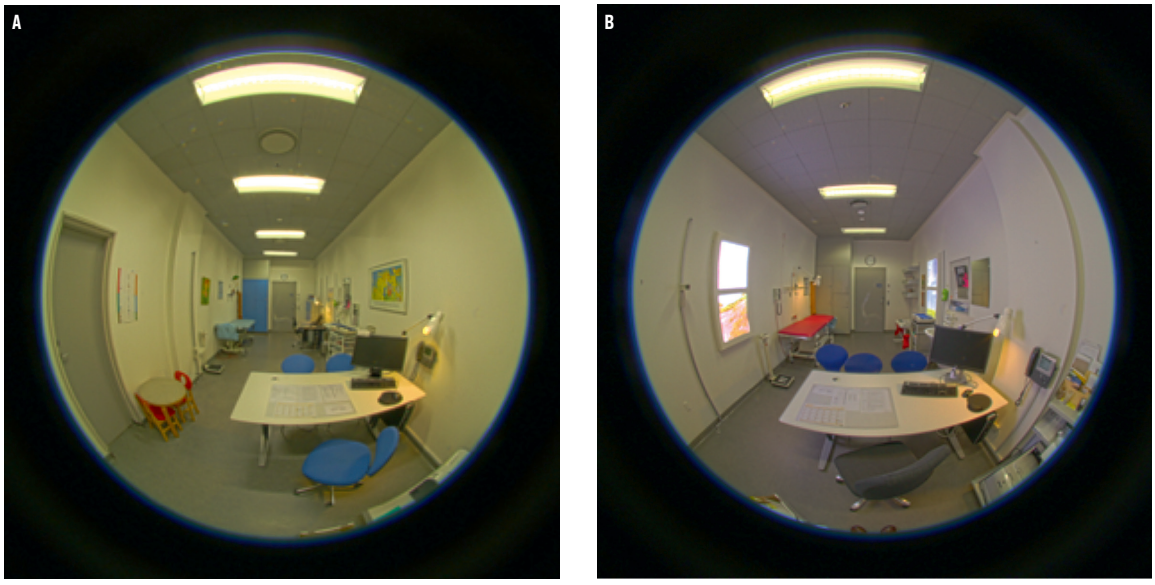
The aim of this pilot study was to evaluate the effects of LED virtual windows in windowless consultation rooms with respect to CCT, illuminance and medical staff perceptions of lighting conditions and wellbeing.

ORIGINAL ARTICLE

1) Department of Architecture, Design and Media Technology, Aalborg University
2) Department of Paediatrics, Hvidovre Hospital
3) Department of Road Construction, Danish Road Directorate
4) Department of Paediatrics, Aarhus University Hospital, Randers
5) Faculty of Health and Medical Sciences, University of Copenhagen, Denmark

Dan Med J 2018;65(9)A5499

FIGURE 1



A. Room fitted with T-5 fluorescent tube lighting only. The room had a uniform distribution of light (high-dynamic-range (HDR) image). **B.** Room fitted with two light-emitting diode (LED) virtual windows and T-5 fluorescent tube lighting. The LED virtual windows increased CCT both at the desk and at the retina and also increased the illuminance at the retina. The room had a non-uniform distribution of light (HDR image). Photos: *Sumit Sen.*

METHODS

The windowless rooms

Four similar consultations rooms, located next to each other, were used in the study. Each room measured 3 × 5.8 m, with a ceiling height of 3 m. The primary lighting in all rooms consisted of older T-5 fluorescent luminaires (T = tubular shape, 5 = 15.9 mm), which provided an equal distribution of light.

The LED virtual windows

Two Servodan LED-based lights, commonly referred to as luminous virtual windows by the industry at large, were installed in two windowless rooms. The remaining two windowless rooms acted as controls and had no virtual windows installed, **Figure 1**A. Each LED virtual window measured 71 × 132 cm (width × height) and had 4,000 × 4,000 pixels at 300 dots per inch. The lighting of the four luminous virtual windows consisted of tuneable white LEDs, and each illuminated one of four natural scenes, all including a horizon as their defining focal point, e.g. a picture of a beach and a blue sky, Figure 1B. A horizon is of primary importance for view and depth vision [14].

The questionnaire

A questionnaire specifically designed for this pilot study was created in cooperation with environmental consultant Kim Mikiki Paris from the Department of Human Resources and Working Environment, Hvidovre Hospital. The content of the questionnaire was based on questions used in Danish surveys on working conditions, **Figure 2**. The key points included in the questionnaire were the perception of lighting conditions at the desk and when looking at patients in the room, as well as the overall experience of being in the room. These questions could be answered along a Likert scale with the following options: Very good, Good, Acceptable, Not that good and Bad. In the statistical analysis, these answers were transformed to scores ranging 5-1. In addition, the questionnaire included questions regarding the presence of headaches, concentration ability and fatigue during the working day. The questionnaire concluded with a comment box where open comments could be included.

The survey was conducted in the summer and autumn period. Doctors and nurses working one to four days per week in the outpatient clinic were asked to fill out the questionnaire at the end of their working day. All responses were anonymous and voluntary. A questionnaire was placed on the desk in each of the four rooms in the morning and collected in the evening by one of the authors (TN). The medical staff was randomly allocated to one of the four rooms by one of the authors (TN). Participants rotated between rooms on a daily basis and did not have the possibility of influencing the choice of room allocated.

Light measurements

Light measurements were made with a Metrue SIM spectral irradiance meter. CCT and illuminance levels at the desk and at the retina were measured.

Light conditions at the desk were measured across the room at a height equal to that of the desk in order to evaluate the light conditions on the surface of the desk. Light conditions at the retina were measured by holding the spectrometer vertically at the level of the

eyes of the occupants of the room in order to evaluate the light conditions at the retina when talking to patients face to face while sitting at the desk. Light conditions at the retina were also measured when occupants looked in a downward gaze at the desk.

In the rooms with LED virtual windows, the signature and distribution of light was non-uniform due to the existence of two different lighting technologies, each of which was placed perpendicularly to each other. The ceiling fluorescent lighting produced an even distribution of light downwards throughout the room, whereas the two LED virtual windows - one on each wall - provided more directed light coming off the walls in a horisontal direction, causing a non-uniform distribution with a different light signature. Thus, depending on the direction of gaze in the room, the lighting could have a different CCT and illuminance.

Lighting results from the rooms fitted with LED virtual windows were compared to lighting results from the rooms without LED virtual windows.

Statistics

Data collected from the questionnaires were analysed statistically using Fisher's exact test in the programme StatGraphics (Manugistics, Inc., USA). Light measurement data were analysed using an online Mann-Whitney U test calculator [15] and Microsoft Excel 2016. Two-sided tests were used for which a significance level < 0.05 was considered statistically significant.

Trial registration: not relevant.

RESULTS

The participants

The participation rate among the medical staff was 76% (113 of 148 questionnaires). Of these, 71 (63%) respondents were women and 28 (25%) were men. A total of 14 (12%) did not fill in their gender. All questionnaires were answered fully; 69 (61%) of respondents spent six to eight hours per day in the rooms (38 (61%) of these responders had worked in the rooms with LED virtual windows), 31 (27%) spent a maximum of six hours per day in the rooms and 13 (12%) did not inform of the length of time spent per day in the rooms. Due to the anonymity of the survey, age, employment position and other private information was not included.

The questionnaire

The LED virtual windows improved the general experience of the lighting conditions in the room ($p < 0.001$), the lighting conditions at the desk ($p < 0.001$) and the overall experience of the room ($p = 0.02$), **Table 1**. In the rooms without virtual windows, 42% (24/57) experienced difficulties concentrating as opposed to 27% (15/56) in the rooms with LED virtual windows ($p = 0.11$), **Table 1**.

From the Comments section of the questionnaire, it appeared that the medical staff were unhappy with the windowless rooms, but quite often wrote that the LED virtual windows were part of the reason why they expe-

FIGURE 2

The questionnaire, in Danish.
Spørgeskemaundersøgelse i Børneambulatoriet, Hvidovre Hospital, vedrørende ændringer i arbejdsmiljømæssige forhold ved installation af kunstige dagslysvinduer.

Spørgeskema undersøgelse i Børneambulatoriet Hvidovre Hospital vedrørende ændringer i arbejdsmiljømæssige forhold ved installation af kunstige dagslysvinduer.

Stue nr ☐ Dato ☐

Er du: Kvinde ☐ Mand ☐

Hvor mange timer har du opholdt dig i lokalet ? 0-2 ☐ 2-4 ☐ 4-6 ☐ 6-8 ☐

Hovedpine

Har du fået hovedpine i løbet af dagen ? Ja ☐ Nej ☐

Ved **Ja** bedes du besvare nedenstående spørgsmål

Mener du denne kan være opstået pga dette lokales belysning? Ja ☐ Nej ☐ Ved ikke ☐

Koncentration

Har du fået sværere ved at koncentrere dig i løbet af dagen? Ja ☐ Nej ☐

Ved **Ja** bedes du besvare nedenstående spørgsmål

Mener du dette kan være opstået pga dette lokales belysning? Ja ☐ Nej ☐ Ved ikke ☐

Træthed

Er du generet af øget træthed i dag? Ja ☐ Nej ☐

Ved **Ja** bedes du besvare nedenstående spørgsmål

Mener du dette kan være opstået pga dette lokales belysning? Ja ☐ Nej ☐ Ved ikke ☐

Belysningens kvalitet

	Meget godt	Godt	Acceptabelt	Mindre godt	Dårligt
Hvad synes du om belysningen i lokalet generelt?	☐	☐	☐	☐	☐
Hvad synes du om den specifikke arbejdsbelysning?	☐	☐	☐	☐	☐

Lokalet generelt

	Meget godt	Godt	Acceptabelt	Mindre godt	Dårligt
Hvad synes du om at arbejde i lokalet alt i alt?	☐	☐	☐	☐	☐

Bemærkninger

TABLE 1

Questionnaire results.

	Rooms with LED virtual windows	Rooms without virtual windows	p-value
Experience of light in the room, median (range)[a]	3 (1-5)	2 (1-4)	0.0003
Experience of light at the desk, median (range)[a]	3 (1-5)	2 (1-4)	0.0002
Overall impression of the room, median (range)[a]	3 (1-5)	2 (1-4)	0.0220
Occurrence of headache, n/N	10/56	11/55	1.0000
Occurrence of fatigue, n/N	20/56	27/57	0.2535
Occurrence of lack of concentration, n/N	15/56	24/57	0.1137

LED = light-emitting diode.
a) 5 = very good, 4 = good, 3 = acceptable, 2 = not that good, 1 = bad.

TABLE 2

Comments from questionnaires from the nurses and doctors about the rooms with and without light-emitting diode (LED) virtual windows.

Theme	Comments	Mentioned in the questionnaire, n
Light	I miss the natural daylight	20
	If it is not possible to work in a room with natural daylight, then I want a room with virtual windows	7
	I appreciate the light and nature scenes from the virtual windows, but the ceiling lighting is too weak	-
	The ceiling lighting is too weak	-
	I like the virtual windows, but would prefer it if the pictures on them could change during the year	-
	The light in the LED virtual windows is too bright so I turn them off	-
Air	I lack fresh air, the air in the room is stale	6
Other factors	It is too hot in the room	-
	I got a headache because my day is too busy	-
	It is unpleasant to have a printer in the room	-
	I got tired, but it may also depend on the many interruptions	-

TABLE 3

Light measurements in rooms with and without LED virtual windows. The values are median (range).

	Rooms with LED virtual windows	Rooms without virtual windows	p-value
CCT, K			
At the desk	3,989 (3,666-4,414)	3,834 (3,649-3,859)	0.0031
At the retina	4,197 (3,913-4,575)	3,742 (3,656-3,806)	0.0051
Illuminance, lx			
At the desk	303 (223-366)	275 (209-347)	0.1971
At the retina	229 (200-282)	200 (180-205)	0.0164

CCT = correlated colour temperature; K = kelvin; LED = light-emitting diode; lx = lux.

rienced the room in a positive way. Some, however, wanted the natural scene to change in accordance with the time of year. It was also noted that some participants lacked fresh air and that the temperature of the room and emissions from the printer had a negative impact on the overall experience of the rooms, **Table 2**.

Light measurements

Light measurements showed that the rooms fitted with LED virtual windows had a significantly increased CCT at both the desk ($p < 0.005$) and the retina ($p < 0.01$). The LED virtual windows also increased the illuminance at the retina ($p = 0.02$), **Table 3**.

DISCUSSION

This study found that LED virtual windows have a significant impact on lighting levels and help create a positive work environment. The LED virtual windows improved the experience of the lighting in the room and at the desk as well as the general experience with the room. Similarly, they increased the CCT at the desk and the retina and the illuminance on the retina. Although earlier studies have reported a correlation between psycho-physiological responses and CCT and illuminance levels, results were based on differences of at least 1,000 K and 300 lx [6-10]. The present study found an impact based on median differences of 155 K, 455 K and 29 lx between the rooms with and without LED virtual windows. As a result, it may be argued that the increase in illuminance and CCT created by the LED virtual windows was too small to result in changes in human response implying that other factors may play a role. The comments written in the survey's questionnaire may provide some indications as to these other factors. Although most comments consisted of criticism of the existing lighting conditions and the air quality of the rooms, some of the positive comments related to the scenic natural imagery which the LED virtual windows illuminated. The impact of natural scenes has been demonstrated in previous studies and is recommended in geriatric care centres by the Danish Ministry of Social Affairs [16-18]. Although the question of imagery was not the focus of this study, it may be argued that the imagery may have been a relevant factor, and further research on this issue is recommended.

Although not correlated, there was a clear trend towards improved concentration in the rooms with LED virtual windows. The number of participating medical staff was only 113, and it may be argued that if the participant number had been higher, the results would have been significant. Moreover, we do not know if there would have been an effect if the number of LED virtual windows in each room had been three or four.

The current requirement for general lighting in hospital staff offices and consultation rooms at the office

desk is 500 lx, with no CCT requirements [19]. In addition, daylight, i.e. windows, are a design requirement for workspaces [20]. This was not part of the requirements when Hvidovre Hospital was planned, and that is why regulatory dispensation has been obtained. The staff would, however, benefit from modernising and increasing the illuminance levels to 500 lx in line with current regulations. In addition, it would be beneficial to increase the CCT of the rooms to between 4,500 K and 5,000 K, which has been shown to increase concentration and work performance [6-10]. These improvements could be achieved by replacing the current fluorescent tube lighting with ones capable of higher CCT levels, or by installing other lighting systems, such as LED lighting in the ceilings, or by adding more LED virtual windows. Based on the possibility that natural scenic depictions may have had an impact on the positive experience of the space, LED virtual windows on the walls with illuminated natural scenic depictions may be a relevant addition to the overall lighting in consultation rooms without windows.

The study was set up as a pilot study to evaluate the impact of LED-based luminous virtual windows in the daily clinical setting, and, as such, has limitations which beset any surveys from real world situations. Firstly, the survey was - by necessity - voluntary, and the questionnaire was as short and to the point as possible in order to encourage participation. Secondly, due to the lack of validated standard questionnaires for the impact of light in windowless workplaces in a daytime setting, a new questionnaire was constructed with help from an environmental consultant at the Department of Human Resources and Working Environment, Hvidovre Hospital. Consequently, the questionnaire drew upon questions used in Danish surveys on general working conditions and was adjusted to address the aspect of light. This possibly resulted in bias as participants were potentially primed to think of light when answering. On the other hand, the questionnaire offered a comment box in which other factors could be mentioned and the box was used by several participants.

Future studies are needed to evaluate the impact of illuminated natural scenes on the well-being of employees working in windowless environments. Furthermore, it could be beneficial to include a short cognitive task to test whether LED virtual windows have any effect on vigilance.

CONCLUSIONS

LED-based virtual windows with illuminated natural scenic depictions in rooms without windows positively affected the experience of the light, the amount of light at the desk and at the retina as well as the general experience of the room.

CORRESPONDENCE: *Dina Cortes.* E-mail: Dina.Cortes@regionh.dk

ACCEPTED: 2 July 2018

CONFLICTS OF INTEREST: none. Disclosure forms provided by the authors are available with the full text of this article at www.danmedj.dk

ACKNOWLEDGEMENTS: We thank the head of the Department of Paediatrics, Hvidovre Hospital, Chief *Nurse Stine Fjelstervang* and Chief Consultant *Klaus Børch*, for their interest in the study and for their support, without which we would have been unable to do the study. We also th ank Working Environmental Consultant *Kim Mikiki Paris,* the Department of Human Resources and Working Environment, Hvidovre Hospital, for help with the design of the questionnaires. Moreover, we thank Chief of Staff and Laboratories, *Linda Camilla Andresen,* Hvidovre Hospital, for her interest in the study and for the contact to *Sumit Sen*.

LITERATURE

1. Duffy JF, Czeisler CA. Effect of light on human circadian physiology. Sleep Med Clin 2009;4:165-77.
2. Lucas RJ, Peirson S, Berson DM et al. Measuring and using light in the melanopsin age. Trends Neurosis 2014;37:1-9.
3. What is correlated colour temperature? www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightsources/whatisCCT.asp (6 May 2018).
4. Boubekri M, Cheung IN, Reid KJ et al. Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case control pilot study. J Clin Sleep Med 2014;10:603-11.
5. Williams DR. Sun Fact Sheet. Nasa. Archives. https://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html (6 May 2018).
6. Lee JH, Moon JW, Kim S. Analysis of occupants´ visual perception to refine indoor lighting environment for office tasks. Energies 2014;7:4116-39.
7. Chellappa SL, Steiner R, Blattner P et al. Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert? Public Libr Sci One 2011;6:e16429.
8. Manav B. An experimental study on the appraisal of the visual environment at offices in relation to colour temperature and illuminance. Build Environ 2007;42:979-83.
9. Choi K, Suk HJ. Dynamic lighting system for the learning environment: performance of elementary students. Optics Express 2016;24:907-16.
10. Mills PR, Tomkins CT, Schlangen JM. The effect of high correlated colour temperature office lighting on employee wellbeing and work performance. Circad Rhythms 2007;5:2-5.
11. Aubé M, Roby J, Kocifaj M. Evaluating potential spectral impacts of various artificial lights on melatonin suppression, photosynthesis and start visibility. PLOS ONE 2013;8:e67798.
12. Sekiguchi H, Iritani S, Fujita K. Bright light therapy for sleep disturbance in dementia is most effective for mild to moderate Alzheimer's type dementia: a case series. Psychogeriatrics 2017;17:275-81.
13. Motamedzadeh M, Goimohammadi R, Kazemi R et al. The effect of blue-enriched white light on cognitive performances and sleepiness of night-shift workers: A field study. Physiol Behav 2017;177:208-14.
14. Hunter MC, Askarinejad A. Designer´s approach for scene selection in tests of preference and restoration along a continuum of natural to manmade environments. Front Psychol 2015;6:1228,1-21.
15. www.socscistatistics.com/tests/mannwhitney/Default2.aspx (6 May 2018).
16. Terkildsen M. Indretning af plejecentre – for svage ældre og mennesker med demens. Styrelsen for Social Service, 2004. https://socialstyrelsen.dk/udgivelser/indretning-af-plejecentre-for-svage-aeldre-og-mennesker-med-demens (6 May 2018).
17. Ulrich, RS. Natural versus urban scenes, some psychophysiological effects. Environ Behavior 1981;13:523-56.
18. Valtchanov D, Ellard CG. Cognitive and affective responses to natural scenes: effects of low level visual properties on preference, cognitive load and eye-movements. J Environ Psych 2015;43:184-95.
19. Danish Standards, lighting regulations DS/EN 12464-1:201. Dansk Standard/Dansk Norm. https://webshop.ds.dk/da-dk/standard/ds-en-12464-12011 (6 May 2018).
20. Danish Working Environment Authority. Danish Working Environment Act, Executive Order No 96, 2001. Arbejdstilsynet. http://engelsk.arbejdstilsynet.dk/en/regulations/executive-orders/96-conditions-permanent-places-work (6 May 2018