Towards assessing the impact of circadian lighting in elderly housing from a holistic perspective

Sumit Sen, Anton Flyvholm, Emmanouil Xylakis, Stine Maria Louring Nielsen, Ellen K. Hansen, Michael Mullins and Georgios Triantafyllidis

Lighting Design, Architecture, Design & Media Technology Department, Aalborg University Copenhagen

Abstract

Circadian lighting has the potential to be used as a welfare technology, and improve the health and well-being of the general public. A research-based dynamic circadian lighting scheme can be developed using LED lighting. Testing and evaluating circadian lighting however requires a holistic approach, bringing together several different disciplines, in particular technological, medical and anthropological fields. The analysis of the of tests must combine qualitative and quantitative data, and implies the use of a mixed methods approach. This paper presents the framework for such analysis for the evaluation of circadian adjusted lighting.

Introduction

With the discovery of the intrinsically photosensitive retinal ganglion cells (ipRGC) in 2002 (Berson et al. 2002), a biochemical link was made between the circadian rhythm and light. This has enabled a shift in focus from lighting as a purely visual and functional aid, to one that can equally enhance and help regulate aspects of the diurnal rhythm, and as such our health and well-being. This has made lighting a recent addition to welfare technology, which relies to a great extent on solid state lighting technologies, in particular LED lighting.

The development of lighting adjusted to support the circadian rhythm, indicated as CALED (Circadian Adjusted LED), is based on cognitive and medical studies. Yet, although tailor made light therapies have shown to remedy circadian disruptions in especially Alzheimer sufferers and night shift workers by improving sleep quality and sleeping patterns (Hanford, Figueiro, 2013, Yoon et al. 2002), and as such quality of life and activity, they have a narrow target group, invariably resulting in highly focused therapeutic sessions. In addition, these therapies can involve many hours of session with specialized lighting platforms, making them cumbersome and intrusive. Research into the application and effects of circadian adjusted lighting on the general, and ageing, population remain in their infancy (Shikder, 2012).

The concept of lighting to assist and adjust the circadian system may increase the general health and well-being of the population, and lead to a reduced dependency on the social services. As such, research into its general applicability is the next logical step. Due to the various angles of this topic, the overall study of circadian lighting requires a holistic approach. In this context, this paper presents the framework for the evaluation of circadian adjusted LED lighting. The use case of elderly housing will be considered for this framework.

Circadian lighting curve

The theoretical basis for the development of the circadian lighting scheme comes from previous chronobiological and cognitive research relating to flicker, illuminance levels and correlated colour temperature (CCT). Firstly, a number of studies have shown the correlation of CCT and illuminance on the circadian rhythm. Research by Figueiro et al. indicates that high circadian stimulation should have an illumination of at least 400 lux at the cornea and a CCT of 6500 K (blue rich light), and suggests this for daytime use. Evening hours are recommended to have an illuminance of 100 lux at the cornea and a colour temperature of 2700K (Figueiro, 2008). In a study on old and demented people, Sust et al. similarly propose a scheme for elderly with a 1200 lux and 6500 K exposure during the daytime, and an 800 lux and 3000 K exposure after three o'clock in the afternoon (Sust et al. 2012). Finally, within a working environment, Van den Beld has proposed a curve which starts at 800 lx and 6000 K at 8.00 in the morning, which gradually decreases to 500 lux and 3000 K by 12.00. This is repeated starting with around 750 lux at 12.30 which again gradually decreases to 500 lux and 3000 K at 16.00 (Van den Beld, 2002). An important aspect of research on the circadian rhythm is the study of the sleep-wake cycle. As an effect of the combination of the circadian rhythm and sleep homeostasis, sleep cycles for humans have been argued to be biphasic, although current society is interrupting this with technology (Ekirch, 2001).

Besides research on the circadian rhythm, there are equally a number of cognitive studies related to emotional response, task performance and alertness with respects to CCT and illuminance levels. Goven et al. have shown that an increase from 3000 K to 4000 K increases alertness (Goven et al. 2007). Similarly, Choi and Suk showed that 6500 K produced the greatest alertness (Choi & Suk, 2016). The same studies indicated that 100 lux produced the best emotional responses (Goven et al, 2007), and that 3500 K was associated with increased relaxation (Choi and Suk, 2016). This is equally reflected by Park et al. who found that a lower CCT of 2766 K increased relaxation (Park et al. 2013).

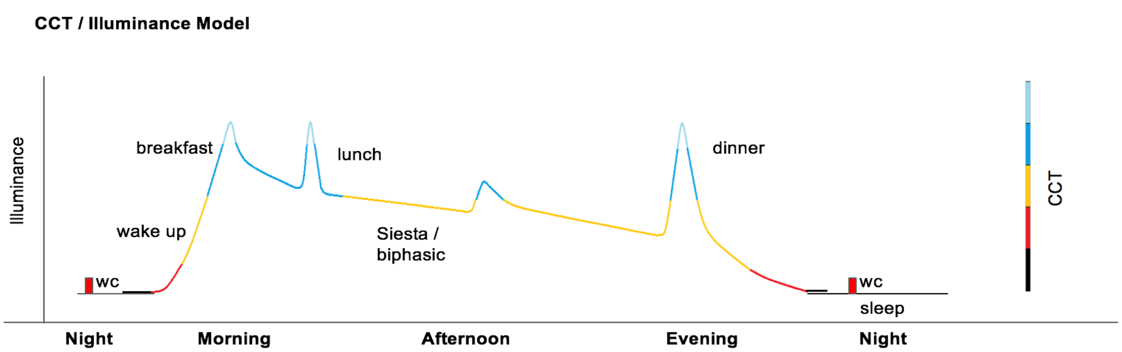
By using research a dynamic circadian lighting scheme (Figure 1) can be produced with a circadian lighting curve (Figure 2). This scheme would be punctuated by task performance requirements such as dinner, and toilet visits. The light needs to be dynamic, and change illuminance levels and colour temperature in a prescribed sequence depending on the time of day, biological needs and task requirements.

		Morning			Afternoon				Evening
		Wake up	Breakfast	Morning activity	Lunch	Afternoon dip	Recovery, afternoon activity	Dinner	Evening activity
Chronobiology	lx	1000 / 600[1]	400[2]			Biphasic[8]			60[1] / 100[2]
	K	6500[2]	6500[2]						2700[2]
Cognitive studies	lx			1000[3]		1000 →500[4]	1000[3]		1000 →500[4]
	K		5000[5]	3000/5000 [3]/ 4000[4]	5000[5]	2700[4]	3000/5000[3]	5000[5]	2700[4]
Standards and recommendations	lx	200[6]	300-500[6]	750-1000[6]	300-500[6]	100 / 5[7]	750-1000[6]	300-500[6]	750-1000[6]
	K								

References in figure:

1 Figueiro, M.G. (2008), A 24 Hour Lighting Scheme for Older adults**.** http://www.lrc.rpi.edu/programs/lightHealth/LightOlderAdults.asp
2 Figueiro, M.G., Saldo, E., Rea, M., Kubarek, K., Cunningham, J., Rea, M.S. (2008). Developing Architectural Lighting to Improve Sleep in Older Adults, The Open Sleep Journal 1(1):40-51
3 Weitbrecht, W.U., Bäwolff, H., Lischke, A., Jünger, S. (2015), Fortschritte der Neurologie
4 Manav, B. (2007) An experimental study on the appraisal of the visual environment at offices, Building and Environment 42 (2007) 979–983
5 Yamagishi, M., Yamaba, K., Kubo, C., Nokura, K., Nagata, M., (2008), Effects of LED lighting Characteristics on Visual Performance of Elderly People, International Society for Gerontology
6 Terkildsen, M. (2004), Indretning af Plejecentre– for svage ældre og mennesker med demens, Styrelsen for Social Service
7 DS ES 12464-1 2011
8 Kryger et al. (2011), Principles and Practice of Sleep Medicine, Elsevier Saunders

Figure 1. Circadian lighting scheme



Medical requirements and recommendations:

Examination room general: 500 lx, 4000-5000 K, Ra 90 (DS EN 12464-1 2011: 5.40.1)
Examination, simple: 300lx (DS EN 12464-1 2011: 5.39.3)
Examination and treatment: 1000lx, Ra 90 (DS EN 12464-1 2011: 5.39.4 / 5.40.2)
Cleaning and examination: 100 - 200 lx (Styrelsen for Social Service, 2004)
Examination and Observation: 500 lx, 5000 K, Ra 90 (Styrelsen for Social Service, 2004)
Emergency lighting: 1500 lx / 5000 K: manual override button.

Toilet:

Daytime: 200 lx (DS EN 12464-1 2011: 5.39.6 / 5.2.4)
Night time: 5 lx, 2700 K, or amber light (Figueiro, A 24 Hour Lighting Scheme for Older Adults, 2008)

Figure 2. Circadian lighting curve

A holistic approach: mixed methods model

Due to the complex nature of care of the elderly i.e. psychological well-being, personalized space, adaptations to functional decline, and therapeutic focus, the evaluation of a circadian lighting system for geriatric use must incorporate data from widely dispersed fields. This trial relies on both qualitative and quantitative data from three fields: anthropological, sensor-based and medical (see Figure 3)

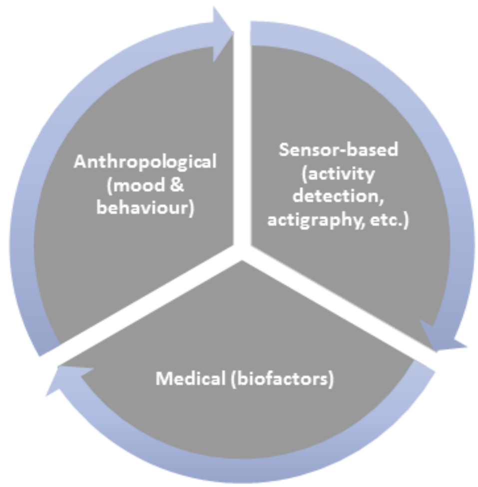


Figure 3. Holistic approach scheme

There are a number of epistemological issues in combining sets of qualitative and quantitative data (Creswell & Clark, 2011), each of which relate to the seeming incompatibility of a post-positivist approach to science and an interpretive approach. Although each paradigm in and of itself have a fairly robust system of inquiry, the comparison of results between the two i.e. a mixed method approach, warrant careful reasoning.

In this context, the framework for collecting the data will consist of a cross-over non-blinded randomized trial involving three target groups (Table 1). Groups A and B will be divided in subgroups A1, A2, B1 and B2. Group C will remain undivided. For each group the trial will take place over a 16-week period within which each subgroup will alternate between intervention and control.

Table 1.

Participants	No	Week 0	Randomization	No	Week 1-8 Period 1	Week 9-16 Period 2
Group A, frail elderly receiving CALED	15	Baseline	Subgroup A1	8	Intervention	Control
			Subgroup A2	7	Control	Intervention
Group B, residents with dementia receiving CALED	9	Baseline	Subgroup B1	4	Intervention	Control
			Subgroup B2	5	Control	Intervention
Group C, frail elderly not receiving CALED	15	Baseline	Non	15	Control	Control

The type of mixed method design depends on the research question. In this study, the aim is to enhance the knowledge of the impact of circadian adjustable lighting on the health and well-being of the elderly, and to identify what possible consistencies and inconsistencies might emerge from cross comparison of the results.

This implies the use of a convergent parallel design mixed method approach in which both of the data strands i.e. the qualitative and the quantitative strand, are obtained and analyzed separately (Creswell & Clark, 2011).

Following this model, each research field (anthropological, sensor-based and medical) will start out by obtaining and analyzing data from either a qualitative or a quantitative angle, depending on the field in question. To structure the analysis in a more precise way a two-phase model is introduced (Table 2), which is based on expanding the data analysis from the level of subgroups and methods to that of the groups and fields. Within this, *method* refers to the specific tool used for data collection, and *field* refers to the research discipline, i.e. anthropological, sensor-based and medical.

The first phase, or phase A, consists of three steps, and involves data collection and data analysis for each field and method individually. As such it does not mix qualitative and quantitative sets of data. The second phase, or phase B, consists of two steps and involves cross comparisons between methods and fields. This phase will mix qualitative and quantitative data. The following is a description of each phase and its steps:

Phase A (individual qualitative and quantitative analysis):

Step 1 (1st order analysis), each subgroup, i.e. A1, A2 and B1, B2 is analyzed individually based on their respective methods of observation. This is indicated as the 1st order of analysis and described as the **Intra Subgroup Sequential Comparison**.

Step 2 (2nd order analysis), comparing the results between each subgroup, i.e. A1 with A2 and B1 with B2, within their method of observation. This is indicated as the 2nd order of analysis and described as **Inter Subgroup Cross Comparison**.

Step 3 (3rd order analysis), a comparison of the results between groups, i.e. A, B and C for each of the respective methods of observation. This is indicated as the 3rd order of analysis and is described as **Inter Group Cross Comparison**.

Phase B (mixed qualitative and quantitative analysis):

Step 4 (4th order analysis), comparison of the results between methods of observation within the respective three fields: anthropological, sensor based and medical. Each method of observation at this step can be weighted when compared. This level is indicated as the 4th order of analysis and described as **Inter Method Cross Comparison Weighted**.

Step 5 (5th order analysis), comparison of the results across the methods and fields. This is done along well defined lines and queries, and forms an important aspect of the data-transformation merged analysis variant of the parallel convergent mixed method design. This level of analysis is indicated as the 5th order of analysis and described as **Inter Field Cross Comparison**

Table 2.

	Research question	Whether circadian adjusted lighting has an impact on the health and well-being of elderly people													
		Quantitative											Qualitative		
	Outcomes (Dependent variables)	Light exposure		Sleep assessment	24-hour Mobility	Delirium	Daytime sleepiness	**Sleep Quality**	Depression	Health related quality of life	Independence	Cognition	Experience and practice (rhythm, routes and routines)		
	Methods of data collection	Sensors	Lighting On/Off	ActiWatch	ActivPal	Blood test	Structured Questionnaire						Interviews	Social -Mapping	Observations
Phase A	**Intervention and 1st order analysis** Intra subgroup sequential comparison (for each test)	A1I - A1C → A1*													
		A2I - A2C → A2*													
		B1I - B1C → B1*													
		B2I - B2C →B2*													
	2nd order analysis Inter subgroup cross comparison	A1-A2→A*													
		B1-B2→B*													
	3rd order analysis Inter group cross comparison	A – B													
		A - C													
		B - C													
Phase B	**4th order analysis** Inter method cross comparison weighted	Comparison of results between methods within each field													
	5th order analysis Inter field cross comparison	Comparison of results from 4th order analyses between fields													

Quantitative survey

The aim of the quantitative survey is to investigate the circadian rhythm by looking at changes in associated outcomes for sleep quality, delirium, and well-being defined as physical and mental functioning (Okawa et al. 1991, Slatore et al. 2012).

Quantitative data collection

The trial participants will be assessed at baseline, and after 4, 8, 12 and 16 weeks, respectively. The test panel will consist of questionnaires, functional and cognitive tests, and a blood sample for detecting underlying causes of delirium and illness during the trial. A full test panel will be used at baseline, after 8 weeks and after 16 weeks; with a smaller test panel being used after 4 weeks and 12 weeks. The tests are supplemented by sensory data from wrist and leg worn monitors in weeks 1, 4, 8, 9, 12 and 16. An overview of the outcomes to be assessed is presented in Table 3.

Table 3.

Variables	Baseline	4-week	8-week	12-week	16-week
Primary outcome; quality of sleep					
PSQI; total sleep time	x	x	x	x	x
Secondary outcomes: sleep efficiency, mobility and immunological status					
1. Actigraphy, Actiwatch; sleep and wake activity	x	x	x	x	x
2. ESS; daytime sleepiness	x	x	x	x	x
3. Biomarkers; immunological status	x	x	x	x	x
4. CAM; delirium and confusion	x	x	x	x	x
5. MoCA, MMSE; cognition	x	x	x	x	x
6. MDI; depression	x		x		x
7. ActivePal; mobility	x	x	x	x	x
8. EQ-5D; well-being	x		x		x
9. ADL; self-efficacy;	x		x		x
Additional variables					
10. Registration; medication	x		x		x
11. IVI-test; vision	x				x
12. MNA; nutritional status	x		x		x
13. Personal light exposure; Actiwatch	x	x	x	x	x

PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleepiness Scale; CAM: Confusion Assessment Method; MoCA: Montreal Cognitive Assessment; MMSE Mini Mental State Examination; MDI: Major Depression Inventory; EQ-5D: EuroQol; ADL: Activities of Daily Living; MNA: Mini Nutritional Assessment

Quantitative data analysis

Data will be presented as means with standard deviations, medians with inter-quartile ranges or frequencies with percentages depending on the distribution of the variable. The primary analysis for the primary outcome will be performed using the SAS procedure PROC MIXED (dif(intervention-control)). The difference in the PSQI scores between the intervention period and the control period will be analysed using mixed models, with treatment (intervention and control) and period (period 1 and period 2) as fixed effects and the participant identification as random effect. Secondly, the models will be adjusted for baseline PSQI scores.

The primary analysis will follow the intention-to-treat principle using multiple imputations in case of missing outcome measures. For the secondary outcomes, similar analyses will be performed. Moreover, all analyses will be repeated using adjustments for baseline vision. All models will be investigated for goodness-of-fit (linearity, variance homogeneity and normal distribution of residuals) by visual inspection of plots and remodelling will be performed accordingly. All statistical tests will be performed using SAS (SAS Institute Inc, Cary, NC, US) and p values ≤ 0.05 will be considered statistically significant.

Qualitative survey

The aim of the anthropological study is to reveal changes in experiences and practices of everyday life with an emphasis on how elderly experience and practice their home, as a consequence of the intervention, from a phenomenological perspective (Curry, Nembhard, & Bradley, 2009). In instrumental terms we will look into changes in rhythms, routes and routines which will give an indication of the essence of what it means to practice home. The assumptions are that a house or apartment is not automatically a home but is something which is created through practice (Vacher, 2006), and that experience and practices are related to well-being of the participants.

The major outcome of the anthropological survey is well-being from a holistic point of view taking into account the context and culture of the participants. Where the medical survey looks at well-being defined as physical and mental functioning from a medical perspective, the anthropological survey will look at well-being with the assumption that well-being is not a universal parameter which is easily comparable between subjects but is individual where the context and the lived experience of the individual plays a big role. Quantitative measures of well-being have been criticized due to not being able to cover cultural bias (Ryan & Deci, 2001) and the use of mixed methods overcomes this issue.

Qualitative data collection

The participants of groups A, B and C will be surveyed at baseline (see Table 4), which for the anthropological study is before the new fixtures is going to be installed in the participant's' apartments and will show the impact of change from using their own fixtures to using the intervention fixtures. Group A and B will then be surveyed every 3rd week within each period (week 1-2, week 4-5 and week 7-8). Group C will be surveyed twice for each period. The major purpose of group C is to control the confounding variable, seasonal change, and less emphasis is therefore put on developing rapport for this group.

The early surveying of a period will show immediate effects and implications of the intervention, before participants have had time to adapt to their new context and surveying late in the period will show effects when rhythms, routes, and routines have become more stable. The early and plentiful contact points between the interviewer and participants will also serve to develop rapport with the participants which will increase the quality of the data gained from the survey (Spradley, 1979).

Table 4.

		Period 1 (Intervention/control)								Period 2 (Intervention/control)							
Week	Baseline	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Group A, frail elderly receiving CALED																	
Interview	x		x			x			x		x			x			x
Social mapping	x		x						x		x						x
Group B, elderly with dementia receiving CALED																	
Observation	x	x			x			x		x			x			x	
Staff interview	x	x			x			x		x			x			x	
Group B, frail elderly not receiving CALED																	
Interview	x			x			x					x			x		x
Social mapping	x			x								x					x

Semi-structured interviews and social mapping (Group A & C)

Group A and C will be surveyed by interviews and a social mapping exercise which will look into how the participants practice their homes through rhythms, routes and routines and their relation to light.
The interview guide will be built on Spradley's (1979) ethnographic interview, for the method's ability to gain in-depth information about perceived reality from the participant's point of view. The semi structured interview format will allow comparing between participants and allow hypothesis testing (Leech, 2002), and at the same time be flexible to what the participants tells us.

The interview will be supplemented by a social mapping method which is inspired by cartography (Roessler, 2015). The method is also used within environmental psychology to show relationships between actors and their environment and provides insights about the subjective experience of the built environment describing patterns of behaviour (Roessler, 2015). Mapping how the participants use light in their homes will provide useful data for tracking use of the environment before and after the intervention while at the same time serve as a nonthreatening way of starting the relationship between interviewee and interviewer. Therefore this method will be used in the beginning of the interview.

Observation and staff interviews (Group B)

Interviewing as a method is limited by the discrepancy between what informants say and what they actually do, among other issues due to recall bias (Bernard & Gravlee, 2014). The issue of recall bias is especially prominent for people with dementia and interviewing this group requires careful attention because informants are likely to also have reduced capacity to articulate meaning, consequently making interviewing difficult. Because several participants from group B suffer from moderate to severe dementia, we will instead use observation in the common living room of the dementia ward, combined with semi-structured staff interviews (Hubbard, Downs, & Tester, 2003).

The observation will be semi-structured with a moderate degree of participation which will allow informal talks with the participants. The observation will look into the behaviour of the participants, and look at changes in their rhythms, routes and routines, with a special emphasis on daytime drowsiness, and how they interact with the light in the space.

From initial interviews with staff from the dementia ward it was learned that the residents' mental state varied a lot throughout the day. To account for this issue, staff interviews will be used to account for non-representative observation sampling, and also as a proxy interview to elucidate the view of the dementia patients based on the idea that the staff are experts in interpreting their behavior (Hubbard, Downs, & Tester, 2003). The staff interview will be a semi-structured interview which will touch upon the same themes as the interview for group A and C but will go into less detail.

Qualitative data analysis

The qualitative data will be analyzed from a phenomenological perspective by thematic coding and looking into routes, routines and rhythms. Thematic coding (Aronson, 1994) is chosen over lifeworld analysis (Dahlberg, 2006) in order to make comparison between qualitative and quantitative data easier, while maintaining the complexity of the context in the themes.

The analysis will be deductive in the way that we already know what aspects to look for: well-being, sleep, activity, exposure to light, but the analysis will also have an inductive and iterative character (O'Reilly, 2008) in the way that it will be open for new emerging themes and theories which will help to describe the complexity of the processes and impacts of the intervention which are not anticipated. The data will then be analyzed according to Table 2, phase A, and the emerging themes will be presented along with quotes and contextual descriptive information.

Mixed data analysis

Although it is possible within the mixed method approach to keep the resulting data separate in the analysis stage, this survey will quantify the qualitative data to make a more direct comparison possible. As such it will employ the data-transformation variant of the convergent mixed method design (Creswell & Clark, 2011). This variant results in a scheme indicating statistical relevance between sets of data, while at the same time preserving the richness of the qualitative data. In this study the majority of quantitative data will stem from the medical tests and the results from the tracking devices for mobility. Qualitative data will be obtained from the semi-structured interviews and a social mapping exercise.

The data-transformation variant refers to the comparison of qualitative and quantitative data of the overall study, and occurs in phase B of the structural model of analysis (Table 2). As such it involves the **Inter Method Cross Comparison Weighted** and the **Inter Field Cross Comparison** steps of the analysis, implying that at this step certain data can be weighted, and certain results can be compared across the various methods and across the three fields of inquiry.

Conclusions

With the rapid population ageing in Europe, there is an increasing interest in technologies and designs that can support the elderly citizens in sustaining well-being and health along with preventing functional decline. To date, the designs of lighting systems in elderly housing are simple and primarily made to support only visual acuity without taking into account other parameters. But elderly people have higher demands on quality of light as their body has to cope with immobility, pathologies and age-related functional decline.

To this regard, there is a strong research effort in adjusting lighting design in order to improve well-being and comfort levels, as well as to meet the needs of elderly people at home. To this goal, circadian adjusted LED-based lighting is used, which can reflect the rhythm of out-door daylight. Based on the latest research a circadian lighting curve is proposed. But strong and holistic evidence for the use of such circadian lighting is still missing

In this context, this paper presents a fully developed framework for performing a holistic evaluation of circadian lighting. More specifically three different types of data are considered and cross-checked: a) medical (biofactors), b) sensor-based (activity detection, actigraphy, etc.) and c) anthropological (mood and behaviour). A convergent parallel design mixed method approach is then used following a 2-phase plan. By using this framework, a holistic evidence can be defined and support the use of circadian lighting.

Acknowledgements

This work was held in the context of the research project Lightel funded by ElForsk. Lightel is a collaboration project between Albertslund Municipality, Amager-Hvidovre Hospital and Aalborg University Copenhagen, and is coordinated and managed by Gate 21. The authors would like to especially thank Linda Andresen and Mette Merete Pedersen from Amager-Hvidovre Hospital for their valuable contribution to the medical part of the framework.

References

Aronson, J. (1994). A pragmatic view of thematic analysis. *The Qualitative Report*, *2*(1), 3. https://doi.org/10.4135/9781446214565.n17

Berson DM, Dunn FA, Takao M. (2002). "Phototransduction by retinal ganglion cells that set the circadian clock". *Science*, Feb. 295 (5557): 1070–3

Bonmati-Carrion, Arguelles-Prieto, Martinez-Madrid, Reiter, Hardeland, Rol, Madrid (2014). Protecting the Melatonin Rhythm through Circadian Healthy Light Exposure. *Int. J. Mol. Sci*, 15

Hróbjartsson, A., Thomsen, A.S.S., Emanuelsson, F., Tendal, B., Hilden, J., Boutron, I., Ravaud, P., & Brorson, S. (2013). Observer bias in randomized clinical trials with measurement scale outcomes: a systematic review of trials with both blinded and nonblinded assessors. *CMAJ,* January 28. https://doi.org/10.1503/cmaj.120744

Bernard, H. R., & Gravlee, C. C. (2014). *Handbook of Methods in Cultural Anthropology*. *Sociological Research Online* (Second Ed), Rowman & Littlefield. https://doi.org/10.1525/aa.2000.102.1.183

Buysse, D.J., Reynolds, C.F., Monk, T.H., Berman, S.R., Kupfer, D.J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res*, May;28(2):193–213.

Choi K, Suk J. (2016). Dynamic lighting system for the learning environment: performance of elementary students. *Optics Express,* 24(10): A907-A916
circadian personal exposure devices. *Lighting Res. Technol*, 44: 17–26

Curry, L. A., Nembhard, I. M., & Bradley, E. H. (2009). Qualitative and mixed methods provide unique contributions to outcomes research. *Circulation*, *119*(10), 1442–1452. https://doi.org/10.1161/CIRCULATIONAHA.107.742775

Creswell, J., & Clark, V. (2011). Designing and conducting mixed-methods research. The Sage handbook of qualitative research.

Dahlberg, K. (2006). The essence of essences - The search for meaning structures in phenomenological analysis of lifeworld phenomena. *International Journal of Qualitative Studies on Health and Well-Being*, *1*(1), 11–19. https://doi.org/10.1080/17482620500478405

Ekirch, A. Roger. (2001). "Sleep We Have Lost: Pre-industrial Slumber in the British Isles". *American Historical Review*, Oxford University Press on behalf of the American Historical Association. 106 (2): 343–386.

Figueiro, M.G., Hamne, R., Bierman, A., Rea, M.S. (2013). Comparisons of three practical field devices used to measure personal light exposures and activity levels. *Light Res Technol*. 2013; 45: 421–434

Figueiro, M.G. (2008). A proposed 24 h lighting scheme for older adults. *Lighting Res Technol*; 40:153–16

Govén, T., Laike, T., Pendse, B., Sjöberg, K. (2007). The background luminance and colour temperatures influence on alertness and mental health. *Proceedings Volume 2. CIE 26th session of the CIE* 4-11 July, D6-8 – D611

Hanford, N., Figueiro, F. (2013). Light Therapy and Alzheimer´s Disease and Related Dementia: Past, Present and Future. *J Alzheimers Dis*, Jan 1; 33(4): 913-922
http://grouper.ieee.org/groups/1789/FlickerTR1_2_26_10.pdf (accessed 18/12/2016)

Hubbard, G., Downs, M. G., & Tester, S. (2003). Including older people with dementia in research: challenges and strategies. *Aging & Mental Health*, *7*(5), 351–362. https://doi.org/10.1080/1360786031000150685

IEEE Power Electronics Society. (2015). IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers. IEEE Std 1789-2015. https://doi.org/10.1109/IEEESTD.2015.7118618

IEEE Standard P1789. (2010). A Review of the Literature on Light Flicker: 2 Ergonomics, Biological Attributes, Potential 3 Health Effects, and Methods in Which Some LED 4 Lighting May Introduce Flicker.

Yoon, In-Young Yoon, Do-Un Jeong, Ki-Bum Kwon, Sang-Bum Kang & Byoung-Gun Song (2002). Bright Light Exposure at Night and Light Attenuation in the Morning Improve Adaptation of Night Shift Workers. *Sleep*, May 1;25(3):351-6

Karanicolas, P. J. (2010). Practical tips for surgical research: blinding: who, what, when, why, how?. *Canadian Journal of Surgery*, *53*(5), 345.

Leech, B. L. (2002). Asking Questions: Techniques for Semistructured Interviews. *PS: Political Science & Politics*, *35*(I), 665–668. https://doi.org/doi:10.1017.S1049096502001129

Lucas, R.J., Peirson, S., Berson, D.M., Brown, T.M., Cooper, H.M., Czeisler, C.A., Figueiro, M.G., Gamlin, P.D., Lockley, S.W., O'Hagan, J.B., Price, L.L.A., Provencio, I., Skene, D.J., & Brainard, G.C. (2013). Measuring and using light in the melanopsin age. *Trends in Neurosciences,* January 2014, Vol. 37, No. 1

Markvart, J., Hansen, Å.M., Christoffersen, J. (2015). Comparison and Correction of the Light Sensor Output from 48 Wearable Light Exposure Devices by Using a Side-by-Side Field Calibration Method. *LEUKOS*, 00:1–17, 2015

Okawa M, Mishima K, Hishikawa Y, Hozumi S, Hori H, Takahashi K. (1991). Circadian rhythm disorders in sleep-waking and body temperature in elderly patients with dementia and their treatment. *Sleep*, Dec;14(6):478–85.

O'Reilly, K. (2008). *Key concepts in ethnography*. Sage.

Park, J. Y., Ha, R.Y., Ryu, V., Kim, E., & Jung, Y. C. (2013). Effects of color temperature and brightness on electroencephalogram alpha activity in a polychromatic light-emitting diode. *Clinical Psychopharmacology and Neuroscience*, *11*(3), 126.

Pedersen et al. (2013). Twenty-Four-Hour Mobility During Acute Hospitalization in Older Medical Patients. Journals of Gerontology - Series A Biological Sciences and Medical Sciences, 68(3), 331–337. https://doi.org/10.1093/gerona/gls165

Roessler, K. K. (2015). Arkitektur og Psykologi: Casestudier i sygehuse, arbejdspladser og byrum. *ARKITEKTUR OG PSYKOLOGI*, *nr. 2*(Movements, 2015;2)

Ryan, R. M., & Deci, E. L. (2001). ON HAPPINESS AND HUMAN POTENTIALS: A Review of Research on Hedonic and Eudaimonic Well-Being. Annu. Rev. Pschol., 52, 141–66.

Shikder, S., Mourshed, M., & Price, a. (2012). Therapeutic lighting design for the elderly: a review. Perspectives in Public Health, 132(6), 282–291. https://doi.org/10.1177/1757913911422288

Slatore, C.G., Goy, E.R., O'Hearn, D.J., Boudreau, E.A., O'Malley, J.P., Peters, D., & Ganzini, L (2012). Sleep quality and its association with delirium among veterans enrolled in hospice. *The American Journal of Geriatric Psychiatry*, *20*(4), 317-326.

Spradley, J. (1979). Step 4: Asking Descriptive Questions. *The Ethnographic Interview*, 44–61. https://doi.org/10.1017/CBO9781107415324.004.

Sust, C.A., Dehoff, P., Hallwirth-Spörk, C., Lang, D., & Lorenz, D. (2015). More Light! Improving Well-being for Peoples suffering from Dementia. In Lecture Notes in Computer Science (including Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (Vol 9194, pp 193-200).

Terkildsen, M. (2004). Indretning af plejecentre – for svage ældre og mennesker med demens. Styrelsen for Social Service, ISBN 87-91247-35-7.

Vacher, M. (2006). Hjemmet-kulmination af en tilegnende praksis. Center for Boligforskning.

Van den Beld, G.J., (2002). Healthy lighting, recommendations for workers. In: *Symposium healthy lighting at work and at home*, SOLG, University of Technology, Eindhoven, The Netherlands.

Wade, D.T., Collin, C. (1988). The Barthel ADL Index: a standard measure of physical disability? *Int Disabil Stud*, 10(2):64–7.